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Predicting the volatility of information technology stocks: Does Beta-*t*-EGARCH(1,1) beat a GARCH(1,1)?

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Abstract. This study uses stock return data from the Information Technology (IT) industry. We focus on those firms which created the 50 best IT products of all time, according to the ranking of the PC World journal. For each firm, the full data period is divided to two subsamples according to the release date of the IT product. We call these subperiods Before Release Date (BRD) and After Release Date (ARD) periods. The release dates of IT products may indicate the start of a new regime in the market valuation for each firm. We take the point of view of financial investors and investigate whether ARD period volatility of stock returns can be predicted by return data from the BRD period. The paper compares the forecast performance of the traditional GARCH(1,1) model with the more recent Beta-t-EGARCH(1,1) model. The Beta-t-EGARCH specification considered includes leverage effects, capturing different impacts of rising and falling prices on volatility. We compare different measures of predictive accuracy. In particular, in-sample point forecasts of volatility, out-of-sample point forecasts of volatility and out-of-sample density forecasts of returns are analyzed. For in-sample and out-of-sample point volatility forecast performance of GARCH and Beta-t-EGARCH we find mixed results. For the more complete density forecasts, we find that Beta-t-EGARCH dominates the GARCH model.

Keywords: information technology firms; volatility forecasts; density forecasts; Beta-t-EGARCH with leverage effects

JEL classification: C52; C53; G17

1. Introduction

In the last decades, several companies changed the path Information Technology (IT) was taking in the world. Many of them, for example Apple, Microsoft and IBM, contributed to this by releasing products that were pioneers in their segments. Also, there were a number of companies that joined this privileged group of innovative IT firms, but in time, their success faded away. Nowadays, the release of a new IT product, for example the iPhone 6 released in September 2014, creates great expectations of potential customers. Information on the capabilities of such IT products is quickly streamed online all around the world. For investors, the release of a new IT product is important since the stock market volatility of the enterprise launching the product may change significantly after each of these events. No matter if the product is a success or a failure, the volatility in daily returns may jump and econometric models may be poor predictors of volatility after a big IT release is made.

In this study, we use stock return data of 50 companies that in a certain date have released a product that gained large popularity among IT consumers. The PC World journal has published a ranking of 50 products which are considered to be the best IT products of all time. This work uses data from two subperiods for each firm, defined according to the date of release of the information technology product. These periods are called Before Release Date (BRD) and After Release Date (ARD) periods.

Due to the importance of the products released, the date of the product may define a new regime in the stock market valuation of information technology firms. This work investigates if ARD period volatility of stock returns can be predicted by using stock price data from the BRD period. The focus was modelling the volatility of the idiosyncratic stock return since the effect of the new IT product on volatility can be analyzed better after controlling for systematic risk. Stock market return is approximated by return on the Standard & Poor's 500 (S&P500) index.

This study compares the predictive performance of GARCH(1,1) (Generalized Autoregressive Conditional Heteroskedasticity) (Bollerslev, 1986 and Taylor, 1986) and Beta-t-EGARCH(1,1) (Beta-t-Exponential GARCH) (Harvey and Chakravarthy, 2008; Harvey and Sucarrat, 2012; Harvey, 2013) models. The GARCH(1,1) model is considered as the benchmark volatility model in this study. This is motivated by Hansen and Lunde (2005), who demonstrate that the forecast performance of GARCH(1,1) is difficult to beat by more sophisticated volatility models. These authors compare the out-of-sample forecast performance of 330 ARCH-type models. They use data on two assets: a) German mark (DM, henceforth) and United States Dollar (USD) exchange rate; b) IBM stock. For the DM/USD exchange rate, Hansen and Lunde (2005) find that there is no evidence that GARCH(1,1) is outperformed by more sophisticated models. However, for the IBM stock, they find that GARCH(1,1) is inferior to several models that accommodate leverage effects. Motivated by their findings on the IBM stock, the competitor of GARCH(1,1) in this study is a Beta-t-EGARCH(1,1) specification with leverage effects (Harvey, 2013).

Performance of the competing models is evaluated based on different forecasts. In particular, the following predictions are analyzed: a) in-sample point forecast of volatility; b) out-of-sample point forecast of volatility; c) out-of-sample stock return density forecast. The main findings are as follows: Firstly, in-sample point forecasts of volatility show that Beta-t-EGARCH is significantly better predictor than GARCH for some firms and in-sample point forecasts of GARCH never dominate significantly. Secondly, out-of-sample point forecasts of volatility demonstrate mixed results. For some firms GARCH produces significantly better volatility forecasts, while for other firms Beta-t-EGARCH is more accurate significantly. Finally, the findings on out-of-sample density forecasts of stock returns are much clearer. For all stocks we find superior density forecasts by Beta-t-EGARCH. In addition, for several companies, the predictive accuracy of Beta-t-EGARCH is significantly superior to GARCH. This final result is useful for investors since the density forecast is a more complete forecast of the probability distribution of stock return that point forecast of volatility. Therefore, investors can use the superior density forecasting model to perform Monte Carlo simulations of future returns in order to test investment performance.

The remainder of this thesis is structured as follows. Section 2 presents the data set. Section 3 describes the GARCH and Beta-t-EGARCH specifications. Section 4 summarizes the empirical findings. Finally, Section 5 concludes.

2. Data

The main objective of this paper is to predict volatility of IT firms after an important IT product has been released. This leads to the following questions. Which IT companies to study? Which IT products were the most relevant in this industry? Trying to leave the subjectivity aside, we use the ranking of the 50 best IT products of all time published by one of the most prestigious magazines in the tech-market: PC World. This journal has more than 300,000 readers only in the US, indicating its importance. The ranking is available at: http://www.pcworld.com/article/130207/article.html.

PC World explains its selection as follows. "In many cases, that means a piece of hardware or software that has truly changed our lives and that we can't live without (or couldn't at the time it debuted). Beyond that, a product should have attained a certain level of popularity, had staying power, and perhaps made some sort of breakthrough, influencing the development of later products of its ilk." (http://www.pcworld.com/article/130207/article.html)

The summary of products, release date and data availability are presented in the Table 1; following the ranking of PC World. Table 1 shows that stock price data are available for 20 companies. For these firms, we have obtained daily stock return, r_t, data from Bloomberg for both the BRD and ARD periods. Descriptive statistics of stock returns are presented in Table 2. The table shows that for the products Voodoo 3 and RIM BlackBerry 857 the BRD period is relatively short due to the relatively small number of observations between the first date the stock is traded in the stock exchange and the date the IT product is released. In addition, data on the S&P500 index have also been collected to approximate the common market factor representing the US economy. We use data on daily S&P500 returns, $r_{m,t}$.

Table 1: Products, their release dates and availability of their stock returns

Product	Company	Release date	Description	Data availability
Netscape Navigator	Netscape Corporation	15 December 1994	Netscape was the reason the people got into the Internet all the time. It was the most popular browser during the 90's.	No. NSCP went public almost a year after the release of the navigator.
Apple II	Apple	10 June 1977	Apple was the first company to finally beat IBM in the personal computers market with its Apple II computer.	No. Apple had not had its IPO then.
TiVo HDR110	TiVo, Inc.	31 March 1999	TiVo replaced the VHS tape with a monster hard drive, being capable of recording shows to disk.	No. TiVo had its IPO until September 1999.
Napster	Napster	1 June 1999	Napster was the pioneer inventing peer-to-peer technology.	No. Napster was forced out of business due to copyright-infringement lawsuits by 2001.
Lotus 1-2-3	Lotus Software	26 January 1983	This spreadsheet program was one of the critical applications for the PC's; a must-have software.	No, data could not be found.
Ipod	Apple	23 October 2001	Portable music players were big, heavy, and unpractical before this product.	Yes.
Hayes Smartmodem	Hayes Microcomputer Products	1 July 1981	Although some of the initial modems required acoustic couples, it was the introduction of these devices into many homes.	No. The company went public until 1997.
StarTAC	Motorola	3 January 1996	The StarTAC model by Motorola was the first cell phone that did not look like a heavy brick.	Yes.
WordPerfect 5.1	Corel	6 November 1989	WordPerfect is a word processing application, which in the late 80's introduced pulldown menus, support for tables, and other features.	No. Date could not be found. Corel went public until 2006.
Tetris	Alexey Pajitnov	6 June 1984	The game, consisting of falling bricks trying to fill empty spaces was a total hit even for young people nowadays.	No. It was originally released independently and later bought by IBM-PC.
Photoshop 3.0	Adobe Systems	14 September 1994	It was the 3.0 version of this product the one that introduced the layers (images and effects on multiple levels). This feature made possible image manipulation on an unprecedented scale.	Yes.
ThinkPad 700C	IBM	5 October 1992	IBM continued to grow in the laptop market and the ThinkPad 700C amazed everyone with its weight, power, and screen.	Yes.
Atari 2600	Atari	11 September 1977	All the consoles now own some heritage from this machine. Its importance in home gaming is never underestimated.	No. Atari was sold to Warner Communications. Data could not be found.
Macintosh Plus	Apple	16 January 1986	This is where the Macs started. Beautiful design. One of the most-loved products in the brand even today.	Yes.

RIM BlackBerry 857	BlackBerry	18 October 2000	This was the first phone that could send/receive emails and had a QWERTY keyboard installed.	Yes. But not all data was present since BlackBerry went public in 1999.
Voodoo 3	3Dfx	7 April 1999	These were series of computer gaming video cards. It's considered the best video card of all time.	Yes. But not all data was available since the company went public in 1997.
Digital Elph S100	Canon	17 May 2000	Early digital cameras were the opposite: clunky, heavy, and unpractical. This model could mix sophistication and a widely variety of features.	Yes.
Pilot 1000	Palm, Inc.	15 March 1996	The Pilot 1000 was a Personal Digital Assistant that had as its primary feature pocketability.	No. The company went public several years later.
Doom	id Software	10 December 1993	Doom was the first first-person-shooter game. It had also the first 3D-alike graphics and the chainsaw (one of the most iconic weapons in video games of all time).	No. The company was always private.
Windows 95	Microsoft	24 August 1995	Windows 95 was the first operating system that really implemented multitasking; also it had such a great GUI that made the Mac start fading away.	Yes.
Itunes 4	Apple	28 April 2003	The first 3 versions of iTunes were a great way to manage music for your iPod, but the iTunes 4 changed the music industry by introducing iTunes Store and the possibility of purchasing any track for 99 cents.	Yes.
Game Boy	Nintendo	28 September 1990	Although it was equipped only with a four-way control pad, a monochrome screen, and two action buttons, it is considered widely as the most influential portable gaming device ever.	No. Nintendo was not public by that date.
Zip Drive	Iomega	11 November 1994	Zip Drive was a medium-capacity removable floppy disk. They are still in use due to its popularity.	Yes.
Spybot - Search & Destroy	Safer-Networking Ltd.	2000 (no exact date was found)	This was the number one application in antimalware.	No. The company never went public.
Deskpro 386	Compaq	9 September 1986	The first x86 computer came from Compaq rather than IBM. This machine brought the cutthroat PC market into the modern era.	Yes.
CompuServe	CompuServe Information Service	1969 (no exact date was found)	This was the first major commercial online service in the US. It pioneered the use of the e-mail and chat rooms.	No. CompuServe went public until 1975.
World of Warcraft	Blizzard	11 February 2005	This game now has more than 8 million players worldwide. This massively multiplayer online RPG has changed the "strategy game market".	Yes.
PageMaker	Aldus	15 July 1985	When computing really hit the mainstream, one of the premises was desktop publishing; PageMaker was the obvious choice for printing brochures, magazines, and reports.	No. Aldus was bought by Adobe in 1994.
LaserJet 4L	HP	4 May 1993	This product introduced the era of personal laser printing.	Yes.
Mac OS X	Apple	24 March 2001	This OS marked for Apple the return to the big leagues in the personal computer market.	Yes.

Nintendo Entertainment System	Nintendo	1 September 1986	NES came to save the gaming world introducing the classics Super Mario Bros. and Donkey Kong.	No. Nintendo was not public by that date.
Eudora	Eudora	1988 (no exact date was found)	Eudora was the first nonmainframe e-mail client that went mainstream.	No. Eudora started independently being bought by Qualcomm later.
Handycam DCR-VX1000	Sony	18 October 1995	This was the product that finally brought the camcorder into the digital era.	Yes.
Airport Base Station	Apple	21 July 1999	Even though Apple is not the leader in networking hardware anymore, its Airport Base Station helped the migration to the wireless world as it is known today.	Yes.
The Print Shop	Brøderbund	1984 (no exact date was found)	Although it was designed to create extremely attractive prints, it is considered the first useless killer app.	No. Brøderbund went public until 1991.
VirusScan	McAfee	1990 (no exact date was found)	VirusScan was the top choice in virus protection.	No. McAfee had its IPO until 1999.
Amiga 1000	Commodore	23 July 1985	Although this operative system bankrupted the company, it was years ahead of any other computer. Probably that generation was not ready for such a great device.	No. Commodore went public until 2002.
TurboTax	Chipsoft	9 March 1985	TurboTax may not be revolutionary, but as far as essential PC software goes, many users can't easily live without their tax assistant.	No. Chipsoft never went public.
ICQ	Mirabilis	15 November 1996	From phone calls to emails to instant messages. ICQ introduced the IM to the mainstream.	No. The company never went public.
Sound Blaster	Creative Technology	15 June 1992	Some beeps and other simple sounds were all you could get from the computer speakers before Sound Blaster.	No. This stock will not be used since it is traded only in the Singapur stock exchange.
Hypercard	Apple	11 August 1987	HyperCard was a programming environment that provided you with a stack of blank "cards," upon which you could add text, graphics, and little videos.	Yes.
MX-80	Epson	15 October 1980	With the MX-80, Epson gained 60% of the dot-matrix printers all around the world.	No. Epson listed in the stock exchange until 2012.
PC Tools	Central Point Software	1985 (no exact date was found)	PC Tools was a series of products that saved every person who does not know a thing about software all the time.	No. The company never went public.
EOS Digital Rebel	Canon	20 August 2003	Canon could finally introduce the professional camera into the personal market for an affordable price also.	Yes.
Red Hat Enterprise Linux	Red Hat, Inc.	29 July 1994	Red Hat was finally the Linux version beginner-friendly and also easy to install. Successors like Ubuntu had copied this.	No. Red Hat had its IPO until 1999.
Easy CD Creator	Adaptec, Inc.	26 June 1996	The product that made writing in a CD easy and a standard.	No. Data could not be found.
PC-Talk	Andrew Fluegelman	1982 (no exact date was found)	Originally an online service, it is better known to be the pioneer in creating a new business model: Shareware.	No. The company never went public.

Mavica MVC-FD5	Sony	15 September 1997	Before this, moving the photos from the camera to the computer was a real challenge; with its evolution, the Mavica even included a DVD-Writer.	Yes.
Excel	Microsoft	30 September 1985	The success of Excel is not totally based in burying Lotus 1-2-3, also all the Office Suite was redesigned to look more like Excel in the earlier versions.	No. Microsoft went public until 1986.
OmniKey Ultra	Northgate	1987 (no exact date was found)	Any computer in the 90's had this durable keyboard. Practically a beast.	No. The company never went public.

Table 2. Descriptive statistics

Panel A. Before period

Product	Start date	End date	*T*	Average	Standard deviation	Skewness	Excess kurtosis
Voodoo 3	6/25/1997	4/6/1999	448	0.0001	0.0556	-0.1344	5.4536
Airport Base Station	1/12/1996	7/20/1999	888	0.0005	0.0368	0.9755	7.4997
RIM BlackBerry 857	2/4/1999	10/17/2000	431	0.0053	0.0710	-1.0894	11.1580
Deskpro 386	3/5/1993	9/6/1996	888	0.0015	0.0265	-0.3894	4.0902
EOS Digital Rebel	2/4/2000	8/19/2003	888	0.0001	0.0247	0.1869	1.3487
Handycam DCR-VX1000	4/14/1992	10/17/1995	888	0.0006	0.0148	0.4378	2.9705
Hypercard	2/6/1984	8/10/1987	888	0.0015	0.0293	0.2673	0.6049
iPod	4/13/1998	10/22/2001	888	0.0004	0.0468	-4.2942	66.1104
iTunes 4	10/12/1999	4/25/2003	888	-0.0010	0.0447	-4.9099	79.2923
LaserJet 4L	10/27/1989	5/3/1993	888	0.0005	0.0237	-0.0797	7.5288
MacintoshPlus	7/14/1982	1/15/1986	888	0.0008	0.0350	-0.3652	3.6544
Mavica MVC-FD5	3/10/1994	9/12/1997	888	0.0005	0.0133	0.1857	2.7918
Mac OS X	9/16/1997	3/23/2001	888	0.0009	0.0468	-4.1559	66.4753
Photoshop 3.0	3/12/1991	9/13/1994	888	0.0004	0.0335	0.5137	2.4459
Digital Elph S100	11/7/1996	5/16/2000	888	-0.0009	0.0608	-21.5057	574.8423
StarTAC	6/29/1992	1/2/1996	888	0.0013	0.0194	0.0339	3.1190
ThinkPad 700C	4/3/1989	10/2/1992	888	-0.0002	0.0130	-0.5920	5.8164
Windows 95	2/20/1992	8/23/1995	888	0.0011	0.0197	0.0812	1.5285
World Of Warcraft	7/30/2001	2/10/2005	888	0.0008	0.0329	-0.2789	4.6331
Zip Drive	5/10/1991	11/10/1994	888	-0.0004	0.0465	0.1547	3.1907

Panel B. After period

Product	Start date	End date	*T*	Average	Standard deviation	Skewness	Excess kurtosis
Voodoo 3	4/7/1999	10/17/2002	888	-0.0096	0.1315	-5.4703	110.6124
Airport Base Station	7/21/1999	1/31/2003	888	-0.0007	0.0454	-4.7223	74.4617
RIM BlackBerry 857	10/18/2000	5/4/2004	888	-0.0002	0.0558	0.3920	6.4844
Deskpro 386	9/9/1996	3/15/2000	888	0.0011	0.0330	-0.2976	4.8321
EOS Digital Rebel	8/20/2003	3/1/2007	888	0.0006	0.0147	-0.1406	0.2689
Handycam DCR-VX1000	10/18/1995	4/26/1999	888	0.0007	0.0189	0.2601	3.7383
Hypercard	8/11/1987	2/12/1991	888	0.0003	0.0291	-1.3651	17.3221
iPod	10/24/2001	5/4/2005	888	0.0016	0.0270	-0.0220	3.4639
iTunes 4	4/28/2003	11/1/2006	888	0.0028	0.0248	0.5863	2.3512
LaserJet 4L	5/4/1993	11/4/1996	888	0.0010	0.0211	0.0659	3.4744
MacintoshPlus	1/16/1986	7/20/1989	888	0.0014	0.0301	-1.0291	14.7812
Mavica MVC-FD5	9/15/1997	3/22/2001	888	0.0005	0.0263	0.0000	2.4025
Mac OS X	3/26/2001	10/7/2004	888	0.0016	0.0405	9.8455	206.2209
Photoshop 3.0	9/14/1994	3/19/1998	888	0.0003	0.0344	-0.4496	12.8224
Digital Elph S100	5/17/2000	11/28/2003	888	0.0001	0.0234	0.1520	1.1727
StarTAC	1/3/1996	7/9/1999	888	0.0006	0.0398	-0.7467	147.2851
ThinkPad 700C	10/5/1992	4/9/1996	888	0.0005	0.0191	0.3232	4.9256
Windows 95	8/24/1995	3/2/1999	888	0.0020	0.0218	0.0967	0.7678
World Of Warcraft	2/11/2005	8/21/2008	888	0.0012	0.0233	0.6932	3.8011
Zip Drive	11/11/1994	5/19/1998	888	0.0036	0.0535	-0.3460	7.2751

3. Volatility models

3.1 *GARCH(1,1)*

The Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model, introduced independently by Bollerslev (1986) and Taylor (1986), is probably the most widely used model for capturing changing variance. GARCH(1,1) is formulated as follows:

$$r_t = c + \gamma r_{m,t} + \epsilon_t \quad (1)$$

$$\epsilon_t = \sigma_t u_t \text{ where } u_t \sim N\ (0,1) \text{ i.i.d.} \quad (2)$$

$$\sigma_t^2 = \alpha_0 + \alpha_1 \epsilon_{t-1}^2 + \beta_1 \sigma_{t-1}^2 \quad (3)$$

σ_t represents the conditional standard deviation (volatility) of stock return at day t. The model is covariance stationarity when $\alpha_1 + \beta_1 < 1$. α_0, α_1 and β_1 are positive parameters; c and γ are unrestricted. γ represents the systematic risk of the firm, i.e. the sensitivity of firm value on general market conditions in the US. ϵ_t is the firm-specific or idiosyncratic stock return. The error term, u_t in Equation (2) is assumed to be independent and identically distributed (i.i.d) with standard normal distribution, N(0,1). The choice of this distribution is motivated by Hansen and Lunde (2005), who demonstrate that volatility models under this error distribution tend to be the best predictors for IBM stock return volatility. The model is estimated by the Quasi Maximum Likelihood (QML) method. Table 3 presents the parameter estimates of the GARCH(1,1) model. For some firms, some numerical problems in the QML estimation procedure were found. These are indicated by Not Available (NA) in Table 3.

Table 3: Parameter estimates of the GARCH(1,1) model

	Voodoo 3	Airport Base Station	RIM BlackBerry 857	Deskpro 386	EOS Digital Rebel
c	0.0003(0.0030)	-0.0009(0.0012)	0.0067**(0.0027)	0.0015(0.0009)	0.0007(0.0006)
γ	1.0326***(0.2483)	1.0705***(0.1179)	1.8267***(0.2191)	1.3707***(0.1858)	0.7470***(0.0512)
α_0	0.0009***(0.0003)	0.0003***(0.0001)	0.0003(0.0002)	0.0004***(0.0001)	0.0000(0.0000)
α_1	0.1264(0.0849)	0.0865**(0.0411)	0.1543***(0.0564)	0.2647*(0.1598)	0.0527***(0.0198)
β_1	0.5789***(0.1088)	0.6344***(0.0647)	0.7941***(0.0599)	0.1310(0.1446)	0.9355***(0.0234)
Stationarity	0.7054	0.7209	0.9484	0.3957	0.9882
	Handycam DCR-VX1000	Hypercard	iPod	iTunes 4	LaserJet 4L
c	0.0003(0.0005)	0.0008(0.0009)	-0.0009(0.0013)	-0.0003(0.0012)	0.0002(0.0007)
γ	0.4162***(0.0890)	1.4000***(0.1024)	1.1980***(0.1105)	1.1009***(0.1048)	1.4457***(0.0986)
α_0	0.0000(0.0000)	0.0002***(0.0001)	0.0009***(0.0001)	0.0004(0.0004)	0.0003**(0.0001)
α_1	0.0609**(0.0288)	0.0758***(0.0272)	0.7270*(0.3994)	0.8699(0.5330)	0.0927(0.0780)
β_1	0.8583***(0.0775)	0.6667***(0.0934)	0.0048(0.0111)	0.1735(0.3490)	0.2089(0.2874)
Stationarity	0.9192	0.7425	0.7318	1.0435	0.3016
	MacintoshPlus	Mavica MVC-FD5	Mac OS X	Photoshop 3.0	Digital Elph S100
c	0.0005(0.0010)	0.0003(0.0004)	-0.0007(0.0029)	NA	-0.0050***(0.0015)
γ	0.9591***(0.1419)	0.2982***(0.0653)	1.1115***(0.3664)		0.7998***(0.1232)
α_0	0.0000(0.0000)	0.0000(0.0000)	0.0008***(0.0002)		0.0004***(0.0001)
α_1	0.0631***(0.0203)	0.0792(0.0911)	0.6871*(0.4007)		5.1212(3.7505)
β_1	0.9038***(0.0321)	0.8747***(0.1771)	0.1173(0.1299)		0.0000(0.0000)
Stationarity	0.9670	0.9540	0.8045		5.1212
	StarTAC	ThinkPad 700C	Windows 95	World Of Warcraft	ZipDrive
c	0.0008(0.0006)	-0.0008*(0.0004)	NA	0.0017*(0.0009)	NA
γ	1.5013***(0.1037)	0.8841***(0.0450)		1.2101***(0.1018)	
α_0	0.0000(0.0000)	0.0001***(0.0000)		0.0001(0.0000)	
α_1	0.0373(0.0581)	0.3823**(0.1906)		0.1566**(0.0708)	
β_1	0.8764***(0.1852)	0.0314(0.0537)		0.7720***(0.1064)	
Stationarity	0.9137	0.4137		0.9287	

Notes: Parameters are estimated by the QML method. Not Available (NA) shows numerical problems with the QML estimation procedure. Standard errors, reported in parentheses, are estimated by the robust sandwich estimator. The stationarity row presents $\alpha_1 + \beta_1$, which should be less than one to have covariance stationarity (Bollerslev, 1986). Bold numbers indicate problems with covariance stationarity. *, ** and *** denote parameter significance at the 10%, 5% and 1% levels, respectively.

3.2 *Beta-t-EGARCH(1,1) with leverage effects*

The Beta-t-EGARCH model was first introduced by Harvey and Chakravarty (2008). The motivation for this model is to overcome an important problem with the GARCH model: it does not capture the higher order moments of the return distribution. Unlike these models, the Beta-t-EGARCH lets the conditional variance depend on past values of the score of a likelihood function. This means the conditional variance is able to resist more extreme observations in the data sets used. Another advantage of using this model is that it does not overestimate the impact of past returns on the change of volatility as it happens with the benchmark model of this paper, GARCH(1,1). A detailed description of this model can be found in Harvey and Chakravarty (2008), Harvey and Sucarrat (2012) and Harvey (2013). The Beta-t-EGARCH model with leverage effects is specified as follows:

$$r_t = c + \gamma r_{m,t} + \epsilon_t \quad (4)$$

$$\epsilon_t = \exp(\lambda_t) u_t \text{ where } u_t \sim t(\nu) \text{ i.i.d.} \quad (5)$$

$$\lambda_t = \alpha_0 + \alpha_1 e_{t-1} + \beta_1 \lambda_{t-1} + \tilde{\alpha}_1 \tilde{e}_{t-1} \quad (6)$$

$$e_t = (\nu + 1) b_t - 1 \quad (7)$$

$$\tilde{e}_t = (\nu + 1) b_t D(\epsilon_t < 0) - 1 \quad (8)$$

$$b_t = \frac{\epsilon_t^2 / \nu \exp(2\lambda_t)}{1 + \epsilon_t^2 / \nu \exp(2\lambda_t)} \quad (9)$$

The model is covariance stationarity if

$$(\beta_1)^2 - \alpha_1 \beta_1 \frac{4\nu}{\nu+3} + [(\alpha_1)^2 + (\tilde{\alpha}_1)^2] \frac{12\nu(\nu+1)(\nu+2)}{(\nu+7)(\nu+5)(\nu+3)} < 1 \quad (10)$$

The degrees of freedom parameter, ν is positive; Harvey (2013, p. 105) suggests to assume that $\alpha_1 \geq \tilde{\alpha}_1 \geq 0$; all other parameters are unrestricted. The conditional volatility of stock returns is given by

$$\sigma_t = \exp(\lambda_t) \sqrt{\nu / (\nu - 2)} \quad (11)$$

The Beta-t-EGARCH model used includes leverage effects since Hansen and Lunde (2005) found that volatility models with leverage effects are the only ones that predict significantly better than the GARCH(1,1). Leverage effects are first noted in Black (1976), who proposes that stock returns are negatively correlated with changes in return volatility. This implies that the volatility tends to rise in response to bad news and tends to fall after good news. For further details on the leverage effect; see for example Engle and Patton (2000). These effects are modelled by the Equation (8) in the Beta-t-EGARCH model, where the dummy variable $D(\epsilon_t < 0)$ indicates negative idiosyncratic return at day t.

The Beta-t-EGARCH model is estimated by the QML method. Table 4 presents the parameter estimates. The QML method provides robust standard errors for parameter estimates, although some numerical problems were found; see Table 4.

Table 4: Parameter estimates of the Beta-t-EGARCH(1,1) model

	Voodoo 3	Airport Base Station	RIM BlackBerry 857	Deskpro 386	EOS Digital Rebel
c	0.0014(0.0027)	-0.0028***(0.0010)	0.0025(0.0028)	0.0011(0.0007)	0.0004(0.0007)
γ	1.7358***(0.1954)	1.0685***(0.1026)	1.7367***(0.2078)	1.4482***(0.1470)	0.7365***(0.0533)
α_0	-0.4892**(0.2357)	-2.1044***(0.6728)	-0.4862*(0.2500)	-0.1867(0.1324)	-0.1026(0.0700)
α_1	0.0968**(0.0387)	0.1854***(0.0428)	0.0954**(0.0392)	0.0363**(0.0170)	0.0419*(0.0245)
β_1	0.9100***(0.0406)	0.7163***(0.0912)	0.9101***(0.0437)	0.9741***(0.0176)	0.9856***(0.0085)
ν	5.5072***(1.3015)	4.2989***(0.7262)	5.5314***(1.3314)	5.9825***(1.2884)	28.7595(22.5349)
$\tilde{\alpha}_1$	0.0968	0.0000	0.0954	0.0363	0.0222
Stationarity	0.6542	0.2774	0.6559	0.8629	0.8404

	Handycam DCR-VX1000	Hypercard	iPod	iTunes 4	LaserJet 4L
c	-0.0003(0.0004)	-0.0001(0.0009)	0.0008(0.0012)	NA	0.0001(0.0006)
γ	0.3066***(0.0855)	1.4004***(0.0996)	1.3494***(0.0859)		1.3602***(0.0771)
α_0	-0.6791(0.7675)	-1.3554**(0.5275)	-1.2853(0.8431)		-0.3357(0.2411)
α_1	0.0761(0.0498)	0.0615***(0.0165)	0.1295*(0.0691)		0.0358**(0.0158)
β_1	0.9210***(0.0849)	0.8149***(0.0706)	0.8187***(0.1191)		0.9582***(0.0287)
ν	4.1386***(0.5787)	9.9932***(3.1452)	5.6595***(1.3915)		4.6058***(0.7686)
$\tilde{\alpha}_1$	0.0761	0.0616	0.0000		0.0358
Stationarity	0.7107	0.5460	0.4427		0.8412

	MacintoshPlus	Mavica MVC-FD5	Mac OS X	Photoshop 3.0	Digital Elph S100
c	-0.0002(0.0010)	-0.0002(0.0004)	0.0002(0.0011)	NA	0.0005(0.0007)
γ	1.0064***(0.1492)	0.2595***(0.0488)	1.3595***(0.0770)		0.4792***(0.0675)
α_0	-0.3496(0.2955)	-0.5215(0.4488)	-2.0807**(1.0057)		-0.2359(0.1436)
α_1	0.0552(0.0343)	0.1141**(0.0577)	0.1752***(0.0589)		0.0917***(0.0283)
β_1	0.9473***(0.0417)	0.9390***(0.0490)	0.7052***(0.1427)		0.9695***(0.0390)
ν	7.4480***(1.8473)	4.8241***(0.8131)	5.8009***(0.6071)		4.7203***(1.3464)
$\tilde{\alpha}_1$	0.0552	0.0824	-0.0002		0.0000
Stationarity	0.7715	0.6676	0.2647		0.7434

	StarTAC	ThinkPad 700C	Windows 95	World Of Warcraft	ZipDrive
c	0.0007(0.0005)	-0.0005*(0.0003)	0.0005(0.0005)	0.0010(0.0007)	NA
γ	1.4515***(0.0902)	0.8402***(0.0339)	1.4534***(0.0927)	1.2644***(0.0807)	
α_0	-0.2198**(0.0880)	-5.9119(5.4252)	-0.8943*(0.5145)	-0.4743(0.3473)	
α_1	0.0287**(0.0138)	0.2107**(0.0876)	0.0626***(0.0223)	0.1138**(0.0542)	
β_1	0.9724***(0.0107)	0.3825(0.5633)	0.8896***(0.0622)	0.9332***(0.0461)	
ν	6.4412***(1.4585)	5.9088***(1.1922)	8.2741***(2.0567)	3.5938***(0.4599)	
$\tilde{\alpha}_1$	0.0287	0.0353	0.0626	0.1138	
Stationarity	0.8748	0.0734	0.6604	0.6872	

Notes: Parameters are estimated by the QML method. Not Available (NA) shows numerical problems with the QML estimation procedure. Standard errors, reported in parentheses, are estimated by the robust sandwich estimator. The stationarity row indicates

$$(\beta_1)^2 - \alpha_1\beta_1\frac{4\nu}{\nu+3} + [(\alpha_1)^2 + (\tilde{\alpha}_1)^2]\frac{12\nu(\nu+1)(\nu+2)}{(\nu+7)(\nu+5)(\nu+3)}$$

which should be less than one to have covariance stationarity (Harvey, 2013). *, ** and *** denote parameter significance at the 10%, 5% and 1% levels, respectively.

4. Empirical results

4.1 *In-sample statistical performance*

In-sample statistical performance of GARCH and Beta-t-EGARCH is compared by two likelihood-based model selection metrics. The first one is Log Likelihood (LL), which is based on the probability of the dependent variable series observed. Higher values of the LL indicate better model performance. The second one is the Bayesian Information Criterion (BIC), $BIC = K\ln(T) - 2LL$, where K is the number of parameters included in the specification and T is the number of time periods observed. Lower BIC values imply a better model performance. The BIC penalizes for the number of parameters included in the model. Table 5 shows the LL and BIC metrics for both models. The table shows that according to the LL and BIC, for 94% and 88% of the cases, respectively, the Beta-t-EGARCH model is superior.

Table 5: Likelihood-based model diagnostics

	LL GARCH	LL Beta-t-EGARCH	BIC GARCH	BIC Beta-t-EGARCH
Voodoo 3	**684.88**	638.07	**-1333.13**	-1227.30
Airport Base Station	1738.38	**1818.68**	-3436.02	**-3583.05**
RIM BlackBerry 857	585.92	**607.22**	-1135.44	**-1165.92**
Deskpro 386	2032.90	**2073.43**	-4025.06	**-4092.54**
EOS Digital Rebel	2166.27	**2167.56**	**-4291.80**	-4280.81
Handycam DCR-VX1000	2507.12	**2555.44**	-4973.51	**-5056.57**
Hypercard	1968.67	**1978.88**	-3896.61	**-3903.46**
iPod	1638.65	**1723.24**	-3236.57	**-3392.17**
iTunes 4	1726.45	NA	-3412.16	NA
LaserJet 4L	2193.11	**2283.68**	-4345.48	**-4513.05**
MacintoshPlus	1772.17	**1789.99**	-3503.61	**-3525.68**
Mavica MVC-FD5	2623.26	**2671.45**	-5205.78	**-5288.59**
Mac OS X	1616.48	**1719.11**	-3192.23	**-3383.92**
Photoshop 3.0	NA	NA	NA	NA
Digital Elph S100	1501.08	**2023.96**	-2961.42	**-3993.60**
StarTAC	2348.18	**2392.17**	-4655.63	**-4730.04**
ThinkPad 700C	2805.64	**2847.89**	-5570.55	**-5641.47**
Windows 95	NA	2358.01	NA	-4661.71
World Of Warcraft	1931.82	**2006.48**	-3822.90	**-3958.64**
Zip Drive	NA	NA	NA	NA
Winner (%)	6%	94%	13%	88%

Notes: Log Likelihood (LL); Bayesian Information Criterion (BIC); Not Available (NA). $BIC = K\ln(T) - 2LL$, K denotes the number of parameters estimated and T indicates the sample size.

4.2 *In-sample and out-of-sample point forecast performance*

Point volatility forecast performance of GARCH and Beta-t-EGARCH is compared by the Root Mean Squared Error (RMSE):

$$\text{RMSE} = \sqrt{(1/T)\sum_{i=1}^{T}(\sigma_t - \tilde{\sigma}_t)^2} \quad (12)$$

The RMSE is used in this study to compare forecast performance as Hansen and Lunde (2006) and Patton (2011) demonstrate that the MSE is a robust volatility forecast comparison metric (see Patton, 2011). The RMSE compares the distance between the estimated volatility, σ_t and a benchmark of the true volatility, $\tilde{\sigma}_t$. In this study, we use as benchmark the following proxy of true volatility:

$$\tilde{\sigma}_t = \left| r_t - \frac{1}{T}\sum_{t=1}^{T} r_t \right| \quad (13)$$

This choice for true volatility is motivated by Pagan and Schwert (1990) and Day and Lewis (1992). Lower values for the RMSE imply a more precise volatility forecast performance.

Panel A of Table 6 presents the RMSE values for the BRD period. These represent in-sample forecast evaluation. The table shows mixed results. For 75% of the cases, the Beta-t-EGARCH model produces lower RMSE errors. Nevertheless, for 25% of the cases the GARCH is the winner. To see the statistical significance of forecast performance differences, we also performed the Diebold-Mariano (DM, 1995) test. The null hypothesis of this test is the identical forecast performance of competing models. The DM test results show that the null hypothesis is rejected at least at the 10% level of significance in favor of the Beta-t-EGARCH for 8 out of 16 cases. We can also see from Table 6 that GARCH(1,1) is never significantly better in-sample predictor of volatility.

Panel B of Table 6 presents the RMSE values for the ARD period. Again, the table shows mixed results. For 69% of the cases the GARCH(1,1) produces lower RMSE, while Beta-t-EGARCH(1,1) dominates only for 31% of the cases. The DM test results show that these differences are significant for several firms. The out-of-sample predictive power of GARCH is in line with Hansen and Lunde (2005).

Table 6: In-sample and out-of-sample point forecast performance

	Panel A. In-sample point forecasts					Panel B. Out-of-sample point forecasts				
	GARCH RMSE	Beta-t -EGARCH RMSE	DM		DM p-value	GARCH RMSE	Beta-t-EGARCH RMSE	DM		DM p-value
Voodoo 3	**0.0432**	0.0478	-0.7035		0.4818	0.1130	**0.0466**	1.8845	*	0.0595
Airport Base Station	**0.0270**	0.0271	-0.3888		0.6974	**0.0349**	0.0374	-3.5645	***	0.0004
RIM BlackBerry 857	0.0508	**0.0483**	3.1798	***	0.0015	**0.0417**	0.0471	-8.3252	***	0.0000
Deskpro 386	0.0186	**0.0180**	2.4066	**	0.0161	**0.0229**	0.0238	-1.8963	*	0.0579
EOS Digital Rebel	0.0163	**0.0163**	2.8865	***	0.0039	**0.0098**	0.0100	-7.7908	***	0.0000
Handycam DCR-VX1000	**0.0109**	0.0110	-2.8075	***	0.0050	**0.0129**	0.0156	-10.6009	***	0.0000
Hypercard	0.0201	**0.0200**	1.7345	*	0.0828	**0.0220**	0.0227	-7.5726	***	0.0000
iPod	0.0406	**0.0341**	1.3889		0.1648	**0.0249**	0.0265	-3.3946	***	0.0007
iTunes 4	0.0423	NA	NA		NA	0.0231	NA	NA		NA
LaserJet 4L	0.0167	**0.0164**	2.8772	***	0.0040	**0.0149**	0.0171	-10.1124	***	0.0000
MacintoshPlus	0.0260	**0.0258**	1.6491	*	0.0991	**0.0223**	0.0238	-8.8373	***	0.0000
Mavica MVC-FD5	**0.0096**	0.0097	-1.4288		0.1531	**0.0174**	0.0188	-5.7111	***	0.0000
Mac OS X	0.0409	**0.0344**	1.5244		0.1274	0.0441	**0.0388**	0.9488		0.3427
Photoshop 3.0	NA	NA	NA		NA	NA	NA	NA		NA
Digital Elph S100	0.1431	**0.0569**	1.1350		0.2564	0.0400	**0.0207**	13.1896	***	0.0000
StarTAC	0.0130	**0.0129**	1.5427		0.1229	0.0363	**0.0346**	2.5954	***	0.0094
ThinkPad 700C	0.0090	**0.0087**	1.8822	*	0.0598	0.0139	**0.0132**	2.9494	***	0.0032
Windows 95	NA	0.0126	NA		NA	NA	0.0139	NA		NA
World Of Warcraft	0.0234	**0.0234**	0.0292		0.9767	**0.0181**	0.0274	-21.9193	***	0.0000
Zip Drive	NA	NA	NA		NA	NA	NA	NA		NA
Winner (%)	25%	75%				69%	31%			

Notes: Root Mean Squared Error (RMSE); Diebold-Mariano test statistic (DM); p-value of the DM test statistic (DM p-value); Not Available (NA). The null hypothesis of the DM test is that the predictive accuracy of competing models is identical. The DM test statistic is computed by subtracting the squared forecast errors of Beta-t-EGARCH from those of GARCH. Therefore, negative DM values indicate smaller average forecast errors of GARCH and positive DM values indicate smaller average forecast errors of Beta-t-EGARCH. Bold numbers indicate lower RMSE. *, ** and *** denote significance at the 10%, 5% and 1% levels, respectively.

4.3 *Out-of-sample density forecast performance*

In this section, out-of-sample forecast performance is evaluated by density forecasts instead of the point forecasts. An advantage of the density forecast compared to the volatility forecast is that is involves more complete information about the probability distribution of stock returns. Therefore, it is possible to perform Monte Carlo simulations using the parameter estimates of the superior density forecaster model. This way the investor may have a better notion about the possible future evolution of asset returns.

We use the results of Amisano and Giacomini (2007) who indicate that comparing out-of-sample density forecast performance can be done by loss functions based on the log density function. The loss function is defined as follows. Let $\ln f(y_t|\theta)$ denote the log density of returns evaluated over the ARD period according to the parameter estimates of a

GARCH model obtained for the BRD period. Furthermore, let $\ln g(y_t|\tilde{\theta})$ denote the log density of returns evaluated over the ARD period according to the parameter estimates of the Beta-t-EGARCH model obtained for the BRD period. If

$$\frac{1}{T}\sum_{t=1}^{T} \ln f(\,y_t|\theta_t) < \frac{1}{T}\sum_{t=1}^{T} \ln g(\,y_t\big|\tilde{\theta}_t\big) \qquad (14)$$

then the out-of-sample density forecast performance of the Beta-t-EGARCH model, on average, is superior to that of the GARCH model. Otherwise, the out-of-sample density predictive performance of the GARCH model dominates on average. Table 7 shows the average log densities for both models in each product. Furthermore, we also perform the test suggested by Amisano and Giacomini (2007). The null hypothesis of this test is that both models have identical predictive accuracy. The test results presented in Table 7 show that the mean log density of Beta-t-EGARCH is always higher than that of the GARCH. Moreover, Beta-t-EGARCH predicts significantly better for 12 out of 16 cases, at least, at the 10% level of significance.

Table 7: Out-of-sample density forecast performance

	GARCH mean log density	Beta-t-EGARCH mean log density	AG		AG p-value
3Dfx	-0.0282	**1.7677**	-1.7123	*	0.0868
Airport	1.8250	**2.0298**	-1.2873		0.1980
Blackberry	1.6269	**1.7614**	-2.9431	***	0.0032
DeskPro	2.0481	**2.1489**	-2.3832	**	0.0172
EOS	2.9424	**2.9473**	-2.6796	***	0.0074
HandyCam	2.7095	**2.7495**	-2.5772	***	0.0100
Hypercard	2.4139	**2.4569**	-5.5436	***	0.0000
IPOD	2.2306	**2.3568**	-13.4093	***	0.0000
iTunes	2.2965	NA	NA		NA
LaserJ	2.5428	**2.6198**	-4.6972	***	0.0000
MacintoshPlus	2.3530	**2.3961**	-7.1082	***	0.0000
Mavica	2.2804	**2.3088**	-1.4616		0.1439
OSX	-37.0426	**2.2977**	-1.0031		0.3158
Photoshop	NA	NA	NA		NA
S100	2.1171	**2.4545**	-15.7077	***	0.0000
Startac	-1.3566	**2.3404**	-1.1971		0.2313
ThinkPad	2.2719	**2.5346**	-3.1966	***	0.0014
Win95	NA	2.6720	NA		NA
WoW	2.4090	**2.4784**	-3.3099	***	0.0009
ZipDrive	NA	NA	NA		NA
Winner (%)	0%	100%			

Notes: Amisano-Giacomini test statistic (AG); p-value of the AG test statistic (AG p-value); Not Available (NA). The null hypothesis of the AG test is that the predictive accuracy of competing models is identical. The AG test statistic is computed by subtracting the mean log density of Beta-t-EGARCH from that of GARCH. Positive AG values indicate more precise density forecast of Beta-t-EGARCH. Bold numbers indicate higher mean log density value. *, ** and *** denote significance at the 10%, 5% and 1% levels, respectively.

5. Conclusions

In this study, we use stock return data of 50 companies that in a certain date have released a product that gained large popularity among the IT consumers. We use data from two subperiods for each firm, BRD and ARD periods, defined according to the date of release of the information technology product. We investigate if ARD period volatility of idiosyncratic stock returns can be predicted by using stock price data from the BRD period. This study compares the predictive performance of GARCH(1,1) and Beta-t-EGARCH(1,1) models. Performance of the competing models is evaluated based on a) in-sample point forecast of volatility; b) out-of-sample point forecast of volatility; c) out-of-sample stock return density forecast. We find that, firstly, in-sample point forecasts of volatility show that Beta-t-EGARCH is significantly better predictor than GARCH for some firms and in-sample point forecasts of GARCH never dominate significantly. Secondly, out-of-sample point forecasts of volatility demonstrate mixed results. For some firms GARCH produces significantly better volatility forecasts, while for other firms Beta-t-EGARCH is more accurate significantly. Finally, the findings on out-of-sample density forecasts of stock returns are much clearer. For all stocks we find superior density forecasts by Beta-t-EGARCH. In addition, for several companies, the predictive accuracy of Beta-t-EGARCH is significantly superior to GARCH. This final result is useful for investors since the density forecast is a more complete forecast of the probability distribution of stock return that point forecast of volatility. Therefore, investors can use the superior density forecasting model to perform Monte Carlo simulations of future returns in order to test investment performance.

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