Appendix 1
Model Selection: GARCH Models

Parameter estimates and summary statistics for models of the form:

$$R_t = \mu + \epsilon_t \quad ; \quad \epsilon_t \sim (0, h_t^2) \tag{1}$$

$$h_t^2 = \alpha + \sum_{i=1}^{2} \left(\beta_i h_{t-i}^2\right) + \sum_{i=1}^{2} \left(\gamma_i \epsilon_{t-i}^2\right) + \sum_{i=1}^{2} \left(\delta_i D_{t-i} \epsilon_{t-i}^2\right) \tag{2}$$

$$D_{t-i} = \begin{cases} 1 & if\ \epsilon_{t-i} < 0 \\ 0 & otherwise \end{cases} \tag{3}$$

are found in Panel A for Tables A1.1 to A1.4 below. A model with p lags of h_t, q lags of ϵ_t^2 and r lags of $D_t \epsilon_t^2$ is labeled GJR(p,q,r). Such a model excluding the asymmetric volatility term $D_t \epsilon_t^2$ is labeled GARCH(p,q). These models were estimated on the period from January 4, 1988 to the end of September 1995. Presented in Panel B of the tables are the model Log Likelihood, Schwarz information criteria (BIC), and tests for residual autocorrelation (Wald AR), ARCH and Sign-ARCH. The test for autocorrelation is a χ^2 Wald test on 5 (3) lags of the daily (monthly) data residuals in the mean equation. The test for ARCH is a standard LM test, having us regress the current squared standardized residual on 24 (3) lags of the daily (monthly) data squared standardized residual, collecting the regression R^2 and forming $z = nR^2$, where n is the number of observations, and z is distributed χ^2 with 24 (3) degrees of freedom. The Sign-ARCH tests were proposed by Engle and Ng [1993] and test for stronger (asymmetric) volatility increases from negative shocks to the returns process. Our Sign-ARCH tests on daily data used 5 lags, 3 lags for monthly data.

The R^2 for all the models below are 0 as the mean regression equation in each model contains only a constant, and so this statistic is not included. Of the models that remove significant evidence (at the 5% level) of time series dependence, including residual autocorrelation, ARCH and Sign-ARCH, the GARCH(1,1) specification has the best BIC as well as being the most simple model. The GJR(0,1,2) and GJR(0,1,1) models do very nearly as well on all criteria we investigate failing only one specification test at the 5% level, and slightly better by the BIC, but we will favor the more familiar GARCH(1,1) model.

Table A1.1
Daily Data, In-Sample 1988:1-1995:9
Estimation Results and Diagnostics for
Volatility Models based on Equations (1)-(3)

	Panel A: Parameter Estimates (Robust Standard Error)					
Parameter	MLE GARCH (1,0)	MLE GARCH (2,0)	MLE GARCH (1,1)	MLE GARCH (2,1)	MLE GARCH (1,2)	MLE GARCH (2,2)
μ	0.041**	0.044**	0.047***	0.047***	0.047***	0.047***
	(0.019)	(0.019)	(0.016)	(0.017)	(0.017)	(0.016)
α	0.628***	0.610***	0.002	0.002	0.003	0.004
	(0.047)	(0.054)	(0.001)	(0.001)	(0.003)	(0.003)
β_1			0.980***	0.982***	0.527	0.010
			(0.008)	(0.008)	(1.168)	(0.101)
β_2					0.444	0.949***
					(1.147)	(0.100)
γ_1	0.141***	0.132***	0.016**	0.036	0.023	0.013
	(0.044)	(0.044)	(0.007)	(0.034)	(0.019)	(0.012)
γ_2		0.033		-.021		0.020**
		(0.026)		(0.034)		(0.010)
	Panel B: Diagnostics					
Log Likelihood	-2440.90	-2439.30	-2311.62	-2310.45	-2310.94	-2311.22
BIC	4912.125	4916.499	4661.135	4666.378	4667.369	4675.501
LM ARCH	0.000	0.000	0.980	0.998	0.994	0.959
Wald AR	0.057	0.015	0.124	0.133	0.130	0.096
Sign Test	0.583	0.566	0.521	0.470	0.539	0.610
Negative Sign Test	0.001	0.001	0.445	0.293	0.629	0.451
Positive Sign Test	0.000	0.000	0.058	0.040	0.068	0.223
Joint Sign Test	0.000	0.000	0.223	0.242	0.304	0.446

* Significant at the 10% level, two-sided test.
** Significant at the 5% level, two-sided test.
*** Significant at the 1% level, two-sided test.

Table A1.2
Daily Data, In-Sample 1988:1-1995:9
Estimation Results and Diagnostics for
Volatility Models based on Equations (1)-(3)

	Panel A: Parameter Estimates (Robust Standard Error)					
Parameter	MLE GJR (1,0,1)	MLE GJR (2,0,1)	MLE GJR (1,1,1)	MLE GJR (2,1,1)	MLE GJR (1,2,1)	MLE GJR (2,2,1)
μ	0.039**	0.042**	0.043**	0.044***	0.043**	0.041**
	(0.019)	(0.019)	(0.017)	(0.017)	(0.017)	(0.017)
α	0.631***	0.613***	0.002	0.002	0.002	0.003*
	(0.048)	(0.055)	(0.001)	(0.001)	(0.002)	(0.002)
β_1			0.983***	0.984***	0.511	0.108
			(0.008)	(0.008)	(0.999)	(0.170)
β_2					0.465	0.859***
					(0.985)	(0.171)
γ_1	0.108*	0.096	0.008	0.022	0.010	-.013
	(0.059)	(0.059)	(0.012)	(0.030)	(0.016)	(0.016)
γ_2		0.033		-.014		0.024
		(0.027)		(0.033)		(0.019)
δ_1	0.058	0.063	0.012	0.010	0.018	0.030
	(0.089)	(0.088)	(0.014)	(0.014)	(0.026)	(0.022)
	Panel B: Diagnostics					
Log Likelihood	-2440.45	-2438.75	-2309.62	-2309.14	-2308.83	-2307.49
BIC	4918.802	4922.974	4664.720	4671.332	4670.722	4675.621
LM ARCH	0.000	0.000	0.994	0.998	0.998	0.989
Wald AR	0.055	0.015	0.156	0.152	0.163	0.208
Sign Test	0.605	0.619	0.412	0.386	0.428	0.564
Negative Sign Test	0.001	0.006	0.609	0.380	0.720	0.689
Positive Sign Test	0.000	0.000	0.061	0.044	0.064	0.366
Joint Sign Test	0.000	0.000	0.299	0.283	0.353	0.686

* Significant at the 10% level, two-sided test.
** Significant at the 5% level, two-sided test.
*** Significant at the 1% level, two-sided test.

Table A1.3
Daily Data, In-Sample 1988:1-1995:9
Estimation Results and Diagnostics for
Volatility Models based on Equations (1)-(3)

	Panel A: Parameter Estimates (Robust Standard Error)					
Parameter	MLE GJR (1,0,2)	MLE GJR (2,0,2)	MLE GJR (1,1,2)	MLE GJR (2,1,2)	MLE GJR (1,2,2)	MLE GJR (2,2,2)
μ	0.037**	0.037*	0.043**	0.043**	0.044***	0.041**
	(0.019)	(0.019)	(0.017)	(0.017)	(0.000)	(0.017)
α	0.599***	0.604***	0.001	0.001	0.000	0.003
	(0.051)	(0.055)	(0.001)	(0.001)	(0.000)	(0.002)
β_1			0.985***	0.984***	1.966***	0.212
			(0.007)	(0.007)	(0.000)	(0.145)
β_2					-.965***	0.760***
					(0.000)	(0.143)
γ_1	0.077	0.075	0.008	-.038*	0.000	-.037**
	(0.053)	(0.052)	(0.012)	(0.022)	(0.000)	(0.017)
γ_2		-.011		0.046*		0.049*
		(0.020)		(0.026)		(0.027)
δ_1	0.079	0.081	0.087	0.125**	0.034***	0.063**
	(0.083)	(0.082)	(0.055)	(0.054)	(0.000)	(0.025)
δ_2	0.141***	0.149***	-.080	-.116**	-.034***	-.042
	(0.055)	(0.054)	(0.053)	(0.055)	(0.000)	(0.030)
	Panel B: Diagnostics					
Log Likelihood	-2431.77	-2431.50	-2305.13	-2302.01	-2289.17	-2305.36
BIC	4909.016	4916.068	4663.321	4664.670	4638.985	4678.933
LM ARCH	0.000	0.000	0.999	0.999	0.969	0.995
Wald AR	0.010	0.011	0.145	0.166	0.000	0.133
Sign Test	0.542	0.577	0.423	0.487	0.328	0.620
Negative Sign Test	0.006	0.006	0.658	0.537	0.627	0.823
Positive Sign Test	0.000	0.000	0.042	0.069	0.033	0.633
Joint Sign Test	0.000	0.000	0.309	0.488	0.284	0.869

* Significant at the 10% level, two-sided test.
** Significant at the 5% level, two-sided test.
*** Significant at the 1% level, two-sided test.

Table A1.4
Daily Data, In-Sample 1988:1-1995:9
Estimation Results and Diagnostics for
Volatility Models based on Equations (1)-(3)

	Panel A: Parameter Estimates (Robust Standard Error)					
Parameter	MLE GJR (0,0,1)	MLE GJR (0,1,1)	MLE GJR (0,2,1)	MLE GJR (0,0,2)	MLE GJR (0,1,2)	MLE GJR (0,2,2)
μ	0.042**	0.042**	0.042**	0.039**	0.042**	0.043**
	(0.019)	(0.017)	(0.017)	(0.019)	(0.017)	(0.017)
α	0.673***	0.001	0.002	0.628***	0.001	0.003*
	(0.052)	(0.001)	(0.001)	(0.056)	(0.001)	(0.002)
β_1		0.988***	0.448		0.990***	-.004
		(0.004)	(0.780)		(0.004)	(0.015)
β_2			0.535			0.977***
			(0.772)			(0.012)
δ_1	0.138**	0.018**	0.027	0.134**	0.088*	0.016
	(0.063)	(0.007)	(0.017)	(0.058)	(0.049)	(0.011)
δ_2				0.146***	-.073	0.025***
				(0.056)	(0.050)	(0.009)
	Panel B: Diagnostics					
Log Likelihood	-2445.54	-2311.06	-2310.00	-2434.96	-2306.74	-2308.75
BIC	4921.409	4660.028	4665.489	4907.815	4658.966	4670.569
LM ARCH	0.000	0.991	0.997	0.000	0.998	0.977
Wald AR	0.174	0.283	0.284	0.127	0.250	0.343
Sign Test	0.532	0.355	0.359	0.496	0.345	0.350
Negative Sign Test	0.001	0.731	0.759	0.006	0.710	0.568
Positive Sign Test	0.000	0.037	0.034	0.000	0.017	0.026
Joint Sign Test	0.000	0.243	0.286	0.000	0.214	0.175

Appendix 2
Additional Daily and Monthly Estimation Results

Parameter estimates and summary statistics for models based on the equations below are found in Panel A for Tables A2.1 to A2.3.

$$\sigma_t^2 = \alpha_0 + \alpha_1 V_{t-1} + \phi_{ARCH,0}\hat{h}_{t-1}^2 + \phi_{ARCH,1} V_{t-1}\sigma_{t-1}^2 + \phi_{Option,0}\hat{S}_{t-1}^2 + \phi_{Option,1} V_{t-1}\hat{S}_{t-1}^2$$

$$V_{t-1} = \begin{cases} 1 & if\ Volume_{t-1} \geq \frac{1}{(n-1)}\sum_{i=2}^{n} Volume_{t-i} \\ 0 & otherwise \end{cases}$$

$$R_t = \mu + \epsilon_t \quad ; \quad \epsilon_t \sim (0, \sigma_t^2)$$

$$\sigma_t^2 = \alpha_0 + \alpha_1 V_{t-1} + \beta_0\sigma_{t-1}^2 + \beta_1 V_{t-1}\sigma_{t-1}^2 + \gamma\epsilon_{t-1}^2 + \phi_{Option,0} S_{t-1}^2 + \phi_{Option,1} V_{t-1} S_{t-1}^2$$

Presented in Panel B of the tables are the model Log Likelihood, Schwarz information criteria (BIC), and tests for residual autocorrelation (Wald AR), ARCH and Sign-ARCH. The test for autocorrelation is a χ^2 Wald test on 5 (3) lags of the daily (monthly) data residuals in the mean equation. The test for ARCH is a standard LM test, having us regress the current squared standardized residual on 24 (3) lags of the daily (monthly) data squared standardized residual, collecting the regression R^2 and forming $z = nR^2$, where n is the number of observations, and z is distributed χ^2 with 24 (3) degrees of freedom. The Sign-ARCH tests were proposed by Engle and Ng [1993] and test for stronger (asymmetric) volatility increases from negative shocks to the returns process. Our Sign-ARCH tests on daily data used 5 lags, 3 lags for monthly data.

The R^2 for all the models below are 0 as the mean regression equation in each model contains only a constant, and so this statistic is not included.

These results are qualitatively identical to the results discussed in the paper. An outstanding difference is that residual Sign-ARCH effects for the daily data full sample are not expunged by any of the models, though standard ARCH and autocorrelation effects are not statistically significant for these models and data. Also, the full sample daily results are not as statistically significant and coefficient estimates of interest are not as large in magnitude as for the subsample 1988-1995. In contrast, the monthly results are quite strong both in and out of sample, and change very little as the sample is extended to 2003 from 1995. Given that the option-implied volatility estimate is calibrated to make a one month volatility forecast, not a one day forecast, it is perhaps not surprising that the one-month horizon results are more stable.

TABLE A2.1
Monthly Data, In-Sample 1988:1-1995:9
Estimation Results and Diagnostics for
Volatility Models

	Panel A: Parameter Estimates (Robust Standard Error)				
Parameter Name ↓	Naive	Options Only	ARCH Model	Combining Model	Full MLE
μ	0.992***	0.849***	0.921***	0.918***	1.137***
	(0.364)	(0.316)	(0.328)	(0.312)	(0.290)
α_0	12.35***	-.090	0.137	-1.16	-1.11
	(2.155)	(2.196)	(0.372)	(3.005)	(1.339)
β_0			0.947***		0.408*
			(0.047)		(0.222)
β_1					-1.18***
					(0.381)
γ			0.025		-.111*
			(0.016)		(0.060)
$\phi_{Option,0}$		0.423***		0.123	0.260**
		(0.136)		(0.163)	(0.108)
$\phi_{Option,1}$				0.356	0.635***
				(0.354)	(0.219)
$\phi_{ARCH,0}$				0.630	
				(0.584)	
$\phi_{ARCH,1}$				-.534	
				(0.774)	
	Panel B: Diagnostics				
Log Likelihood	-248.856	-242.903	-244.158	-242.080	-239.223
BIC	511.310	503.936	510.980	515.888	514.707
Wald AR Test	0.066	0.275	0.428	0.039	1.000
LM ARCH Test	0.114	0.129	0.186	0.090	0.185
Sign Test	0.257	0.888	0.796	0.800	0.619
Neg. Sign Test	0.145	0.754	0.951	0.778	0.587
Pos. Sign Test	0.190	0.511	0.478	0.544	0.401
Joint Sign Test	0.167	0.863	0.877	0.913	0.902

* Significant at the 10% level, two-sided test.
** Significant at the 5% level, two-sided test.
*** Significant at the 1% level, two-sided test.

TABLE A2.2
Monthly Data, Full Sample 1988:1-2003:8
Estimation Results and Diagnostics for
Volatility Models

	Panel A: Parameter Estimates (Robust Standard Error)				
Parameter Name ↓	Naive	Options Only	ARCH Model	Combining Model	Full MLE
μ	0.884***	0.842***	1.001***	0.848***	0.936***
	(0.319)	(0.264)	(0.259)	(0.263)	(0.251)
α_0	19.13***	-1.20	0.648	-1.03	-1.17
	(2.018)	(1.561)	(0.528)	(1.736)	(0.877)
β_0			0.831***		0.430**
			(0.075)		(0.189)
β_1					-1.12***
					(0.286)
γ			0.129**		-.084
			(0.056)		(0.053)
$\phi_{Option,0}$		0.525***		0.105	0.273***
		(0.079)		(0.132)	(0.096)
$\phi_{Option,1}$				0.416*	0.655***
				(0.246)	(0.175)
$\phi_{ARCH,0}$				0.700**	
				(0.330)	
$\phi_{ARCH,1}$				-.659	
				(0.465)	
	Panel B: Diagnostics				
Log Likelihood	-544.186	-529.191	-533.230	-528.104	-524.272
BIC	1104.081	1079.328	1092.643	1092.863	1090.435
Wald AR Test	0.692	0.380	0.941	0.429	0.712
LM ARCH Test	0.000	0.972	0.450	0.943	0.734
Sign Test	0.001	0.342	0.259	0.342	0.111
Neg. Sign Test	0.000	0.779	0.798	0.700	0.376
Pos. Sign Test	0.619	0.567	0.907	0.426	0.424
Joint Sign Test	0.000	0.844	0.554	0.805	0.432

* Significant at the 10% level, two-sided test.
** Significant at the 5% level, two-sided test.
*** Significant at the 1% level, two-sided test.

TABLE A2.3
Daily Data, Full Sample 1988:1-2003:8
Estimation Results and Diagnostics for
Volatility Models

	Panel A: Parameter Estimates (Robust Standard Error)				
Parameter Name ↓	Naive	Options Only	ARCH Model	Combining Model	Full MLE
μ	0.042**	0.036***	0.056***	0.038***	0.037***
	(0.018)	(0.014)	(0.014)	(0.014)	(0.014)
α_0	1.232***	-.109***	0.006***	-.102**	-.087**
	(0.048)	(0.040)	(0.002)	(0.042)	(0.038)
β_0			0.951***		0.232
			(0.008)		(0.283)
β_1					-.202
					(0.367)
γ			0.045***		0.010
			(0.009)		(0.024)
$\phi_{Option,0}$		0.704***		0.436***	0.526***
		(0.038)		(0.076)	(0.187)
$\phi_{Option,1}$				0.290**	0.148
				(0.135)	(0.234)
$\phi_{ARCH,0}$				0.375***	
				(0.101)	
$\phi_{ARCH,1}$				-.404**	
				(0.176)	
	Panel B: Diagnostics				
Log Likelihood	-5997.58	-5447.72	-5526.98	-5440.02	-5447.05
BIC	12019.99	10928.56	11095.34	10937.98	10960.32
Wald AR Test	0.143	0.109	0.016	0.072	0.104
LM ARCH Test	0.000	0.495	0.927	0.739	0.551
Sign Test	0.000	0.003	0.013	0.001	0.008
Neg. Sign Test	0.000	0.000	0.000	0.000	0.000
Pos. Sign Test	0.000	0.003	0.003	0.000	0.006
Joint Sign Test	0.000	0.000	0.000	0.000	0.000

* Significant at the 10% level, two-sided test.
** Significant at the 5% level, two-sided test.
*** Significant at the 1% level, two-sided test.