Supplementary Material (ESI) for Chemical Communications

Ruthenium-catalyzed Stereospecific Decarboxylative Allylation of Unstabilized Ketone Enolates.

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Supporting Information

Experimental

Materials. Methylene chloride was dried over activated alumina. All other materials were used as received. β-keto esters **1a-1f** were prepared by the addition of diketene to the corresponding allylic alcohols,[1] which had previously been subjected to enzymatic resolution with Lipase AK "Amano" 20.[2] **1c** degraded slightly on SiO_2 and therefore was used without further purification. **1f** was prepared by alkylation of **1a** using methyl iodide and potassium *tert*-butoxide.[3] β-keto esters **1g** and **1h** were prepared by the condensation of the corresponding acid chloride with Meldrum's acid[4] followed by addition of the appropriate allylic alcohol.[5] ^{1}H NMR spectra were referenced to residual protio solvent signals. Structural assignments are based on ^{1}H, ^{13}C, DEPT-135, COSY, and HMQC spectroscopies. Enantioselectivities were determined on a Diacel Chiralpak AD or OD-H HPLC column.

General procedure for catalytic Carroll rearrangements: In a Schlenk tube under argon, $[RuCp^*Cl]_4$ (2.5 mol%) and bipyridine (10 mol%) were dissolved in 2 mL of methylene chloride. The resulting deep purple solution was allowed to stir briefly before addition of allyl-β-keto ester (0.5 mmole) in 3 mL of methylene chloride *via* cannula. The reaction was allowed to stir under Ar until the resulting dark burnt orange solution returned to purple. Following solvent evaporation the crude product was purified *via* flash chromatography (SiO_2, 5% Et_2O:Hex), providing products in > 95% purity as determined by ^{1}H NMR spectroscopy.

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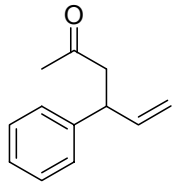
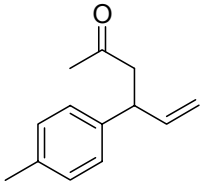
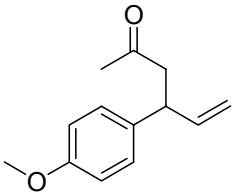
[1] S. Wilson and C. Augelli, *Org. Synth.*, 1990, **68**, 210.
[2] (a) K. Burgess and L. Jennings, *J. Am. Chem. Soc.*, 1990, **112**, 7434; (b) K. Burgess and L. Jennings, *J. Am. Chem. Soc.*, **113**, 6129.
[3] H. Lee, J. Park, B. Kim and S. Gellman, *J. Org. Chem.*, 2003, **68**, 1575.
[4] N. Svenstrup, K. Simonsen, N. Thorup, J. Brodersen, W. Dehaen and J. Becher, *J. Org. Chem.*, 1999, **64**, 2814.
[5] F. Yuste, F. Brena, H. Barrios, R. Sanchez-Obregon, B. Ortiz and F. Walls, *Synth. Commun.* 1988, **18**, 735.



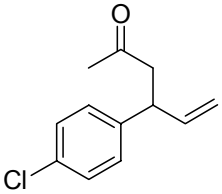
1a:[6] Separated enantiomers on Diacel Chiralpak AD HPLC column (99.0% Hexane/IPA, 0.5 mL/min) t_r = 13.3, 14.7 min.



1b:[6] Separated enantiomers on Diacel Chiralpak AD HPLC column (99.0% Hexane/IPA, 0.5 mL/min) - t_r = 12.9, 14.4 min.



1c:[6] Separated enantiomers on Diacel Chiralpak AD HPLC column (97.0% Hexane/IPA, 1.0 mL/min) - t_r = 6.8, 7.7 min.



1d:[6] Separated enantiomers on Diacel Chiralpak AD HPLC column (99.0% Hexane/IPA, 1.0 mL/min) - t_r = 7.7, 8.9 min.

[6] E. Burger and J. Tunge, *Org. Lett.*, 2004, **6**, 2603.

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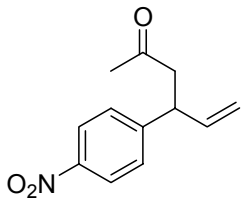

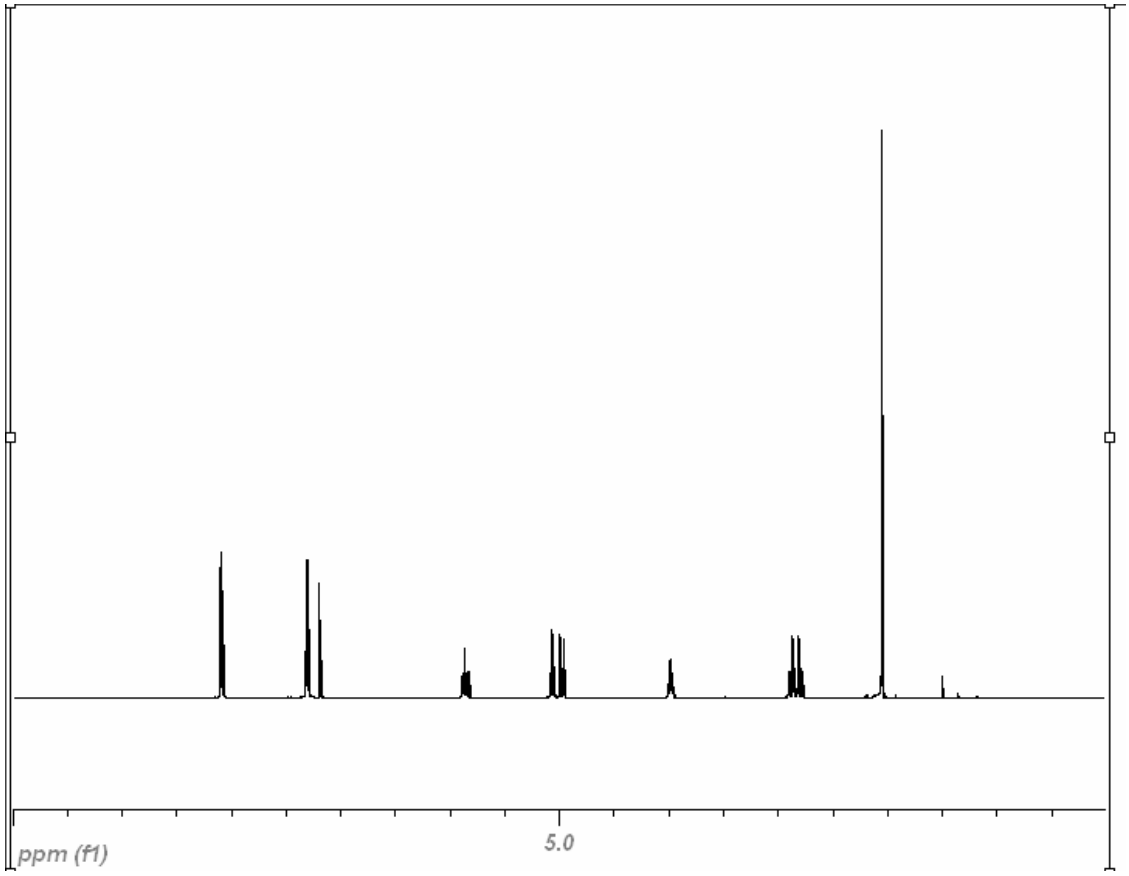

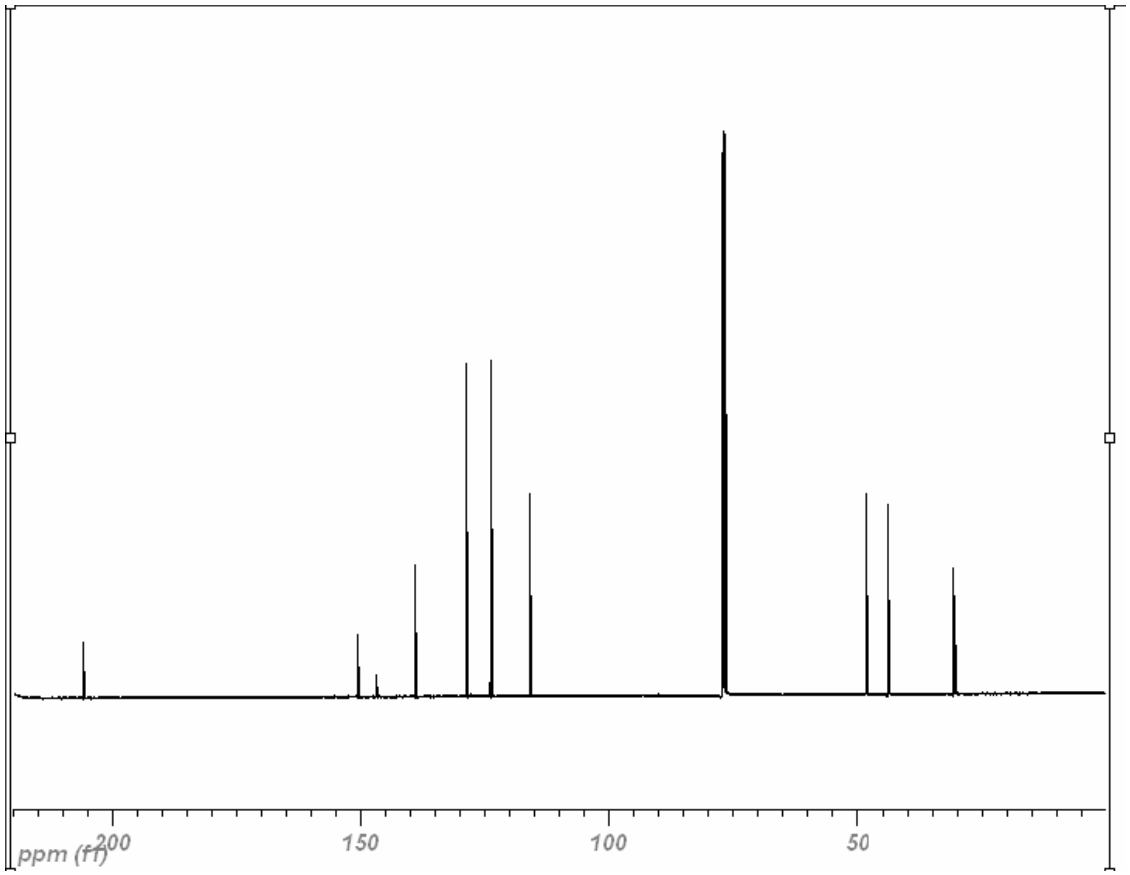

1e: ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.10 (d, J = 9 Hz, 2H: arom. H), 7.31 (d, J = 9 Hz, 2H: arom. H), 5.87 (ddd, J = 7 Hz, 10 Hz, 17 Hz, 1H: C*H*=CH_2), 5.07 (d, J = 10 Hz, 1H: CH=CH(*H*)$_{cis}$), 4.98 (d, J = 17 Hz, 1H: CH=CH(*H*)$_{trans}$), 3.98 (app. q, J = 7 Hz, 1H: CH), 2.88 (dd, J = 7 Hz, 17 Hz, 1H: diastereotopic CH_2), 2.80 (dd, J = 7 Hz, 17 Hz, 1H: diastereotopic CH_2), 2.05 (s, 3H: CH_3). ^{13}C NMR (75 MHz, $CDCl_3$) δ 205.76 (C=O), 150.57 (arom. C), 146.72 (arom. C), 139.06 (*C*H=CH_2), 128.66 (arom. CH), 124.08 (arom. CH), 116.02 (CH=*C*H_2), 48.52 (CH_2), 43.94 (CH), 30.63 (CH_3). IR ($CDCl_3$): ν_{max} 1716, 1522, 1348. HRMS calcd for $C_{12}H_{14}NO_3$ [M+H] = 220.0974, found 220.0976. Separated enantiomers on Diacel Chiralpak AD HPLC column (94.0% Hexane/IPA, 1.0 mL/min) - t_r = 10.3, 11.5 min.

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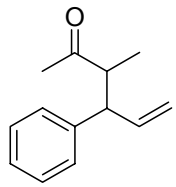
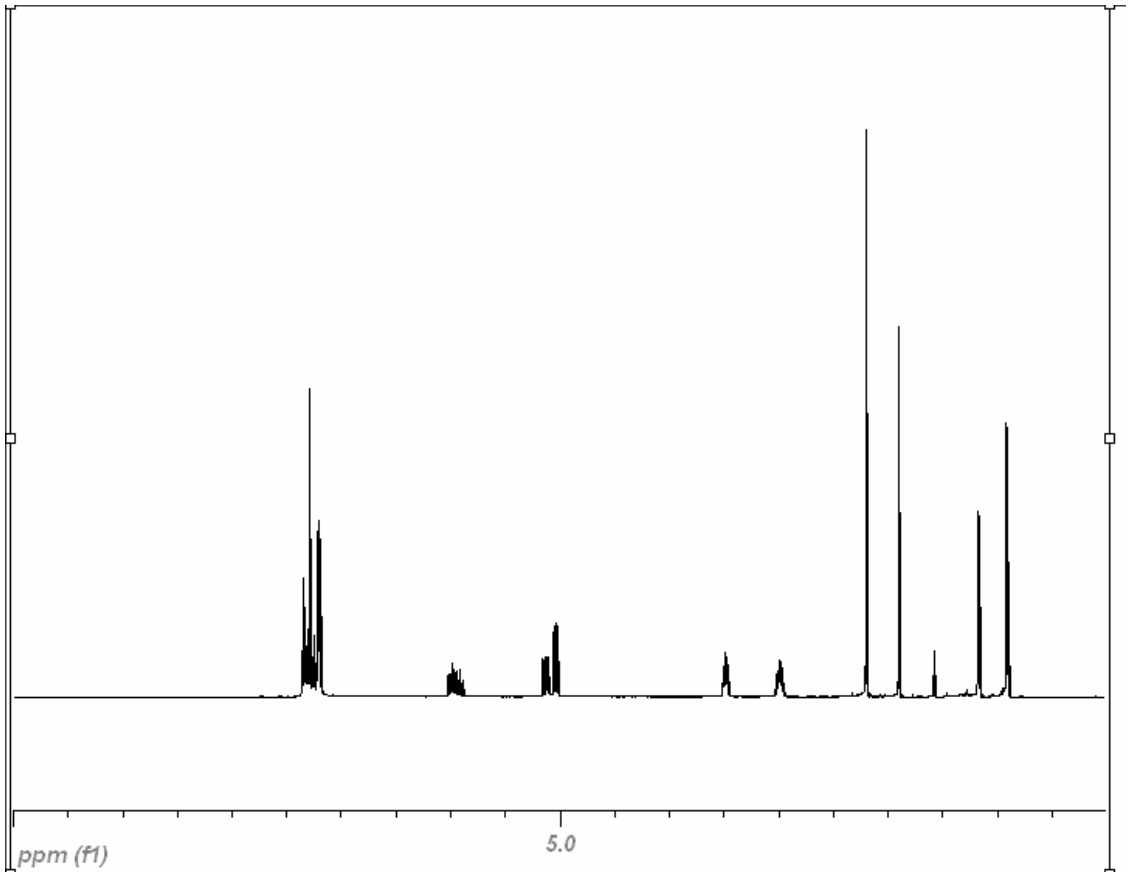
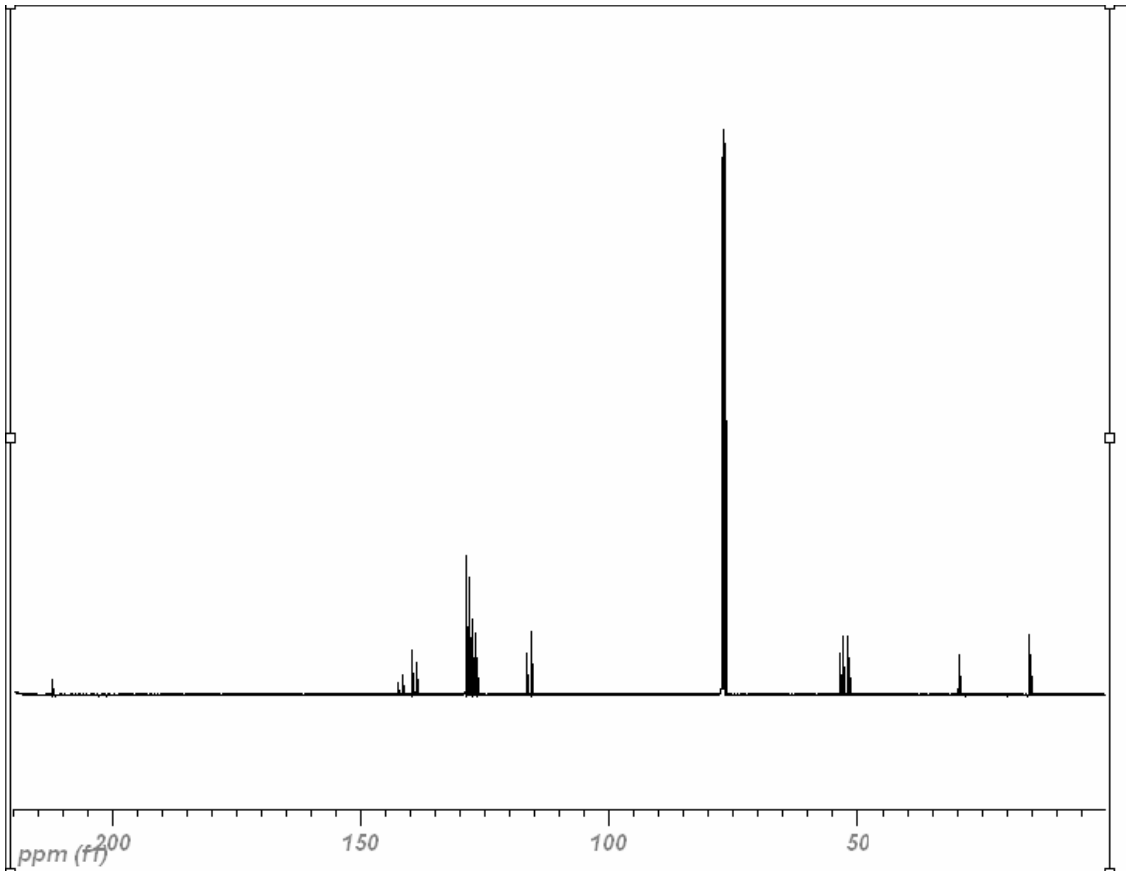


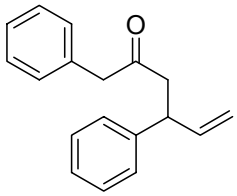


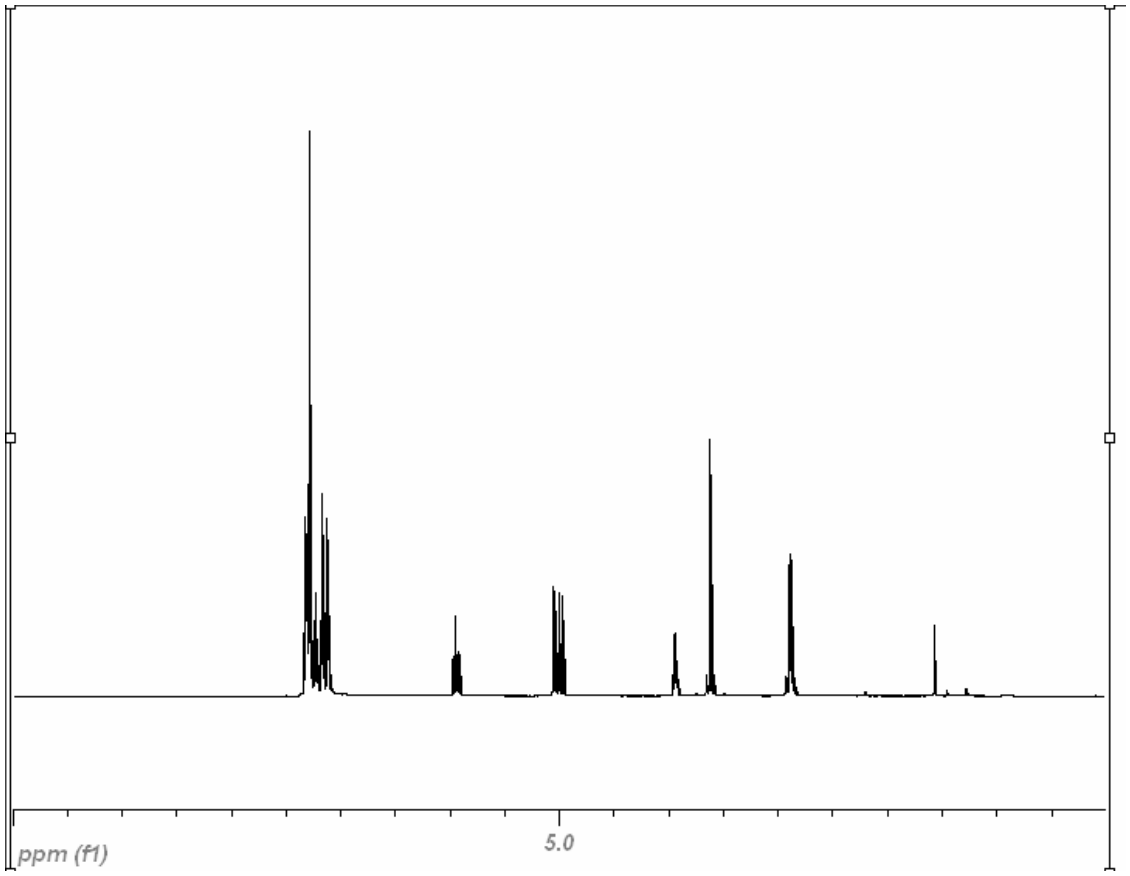


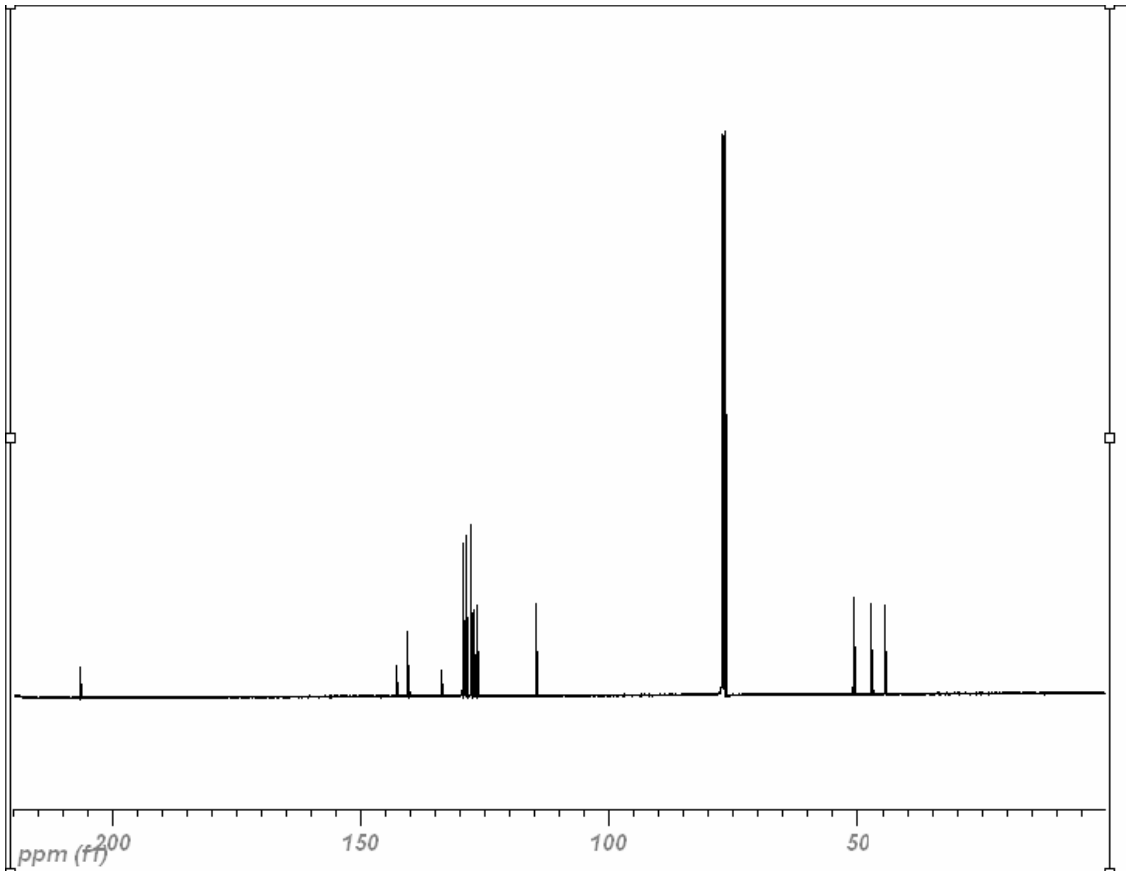
1f:[7] ^{1}H NMR (500 MHz, $CDCl_3$) Major diastereomer: δ 7.28 (broad overlapping m, 5H: arom. H), 5.96 (overlapping m, 1H: C*H*=CH_2), 5.09 (overlapping m, 1H: CH=CH(H)$_{cis}$), 5.09 (overlapping m, 1H: CH=CH(H)$_{trans}$), 3.49 (overlapping m, 1H: Ph-CH), 2.99 (overlapping dq, J = 7 Hz, 10 Hz, 1H: C*H*-CH_3), 2.20 (s, 3H: (CO)CH_3), 0.91 (d, J = 7 Hz, 3H: CH-CH_3). ^{13}C NMR (75 MHz, $CDCl_3$) δ 212.17 (C=O), 141.44 (arom. C), 139.69 (*C*H=CH_2), 128.71 (arom. CH), 128.10 (arom. CH), 126.73 (arom. CH), 115.68 (CH=*C*H_2), 53.07 (CH-Ph), 52.00 (*C*H-CH_3), 29.48 (*C*H_3-(CO)), 15.58 (CH-*C*H_3).
Minor diastereomer: δ 7.28 (broad overlapping m, 5H: arom. H), 5.96 (overlapping m, 1H: C*H*=CH_2), 5.09 (overlapping m, 1H: CH=CH(H)$_{cis}$), 5.09 (overlapping m, 1H: CH=CH(H)$_{trans}$), 3.49 (overlapping m, 1H: Ph-CH), 2.99 (overlapping dq, J = 7 Hz, 10 Hz, 1H: C*H*-CH_3), 1.90 (s, 3H: (CO)CH_3), 1.74 (d, J = 7 Hz, 3H: CH-CH_3). ^{13}C NMR (75 MHz, $CDCl_3$) δ 212.00 (C=O), 142.52 (arom. C), 138.85 (*C*H=CH_2), 128.53 (arom. CH), 127.63 (arom. CH), 126.08 (arom. CH), 116.57 (CH=*C*H_2), 53.41 (CH-Ph), 51.60 (*C*H-CH_3), 29.68 (*C*H_3-(CO)), 15.33 (CH-*C*H_3). IR ($CDCl_3$): ν_{max} 1711, 1454, 1356. HRMS calcd for $C_{13}H_{17}O$ [M+H] = 189.1279, found 189.1278. Separated

[7] (a) W. Daub, J. Edwards, C. Okada, J. Allen, C. Maxey, M. Wells, A. Goldstein, M. Dibley, C. Wang, D. Ostercamp, S. Chung, P. Cunningham and M. Berliner, *J. Org. Chem.*, 1997, **62**, 1976; (b) W. Daub, M. McCoy, M. Sanchez, and J. Carter, *J. Org. Chem.*, 1983, **48**, 3876; (c) W. Daub, M. Sanchez, R. Cromer and L. Gibson, *J. Org. Chem*, 1982, **47**, 743; (d) D. McGreer and J. McKinley, *Can. J. Chem.*, 1971, **49**, 105.

enantiomers on Diacel Chiralpak OD-H HPLC column (99.8% Hexane/IPA, 0.5 mL/min) - t_r (major) = 21.7, 22.9 min, t_r (minor) = 25.4, 25.9 min.







1g: ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.32 (m, 5H: arom. H), 7.24 (m, 1H: arom. CH), 7.17 (d, J = 7 Hz, 2H: arom. CH), 7.12 (d, J = 7 Hz, 2H: arom. CH), 5.95 (ddd, J = 7 Hz, 10 Hz, 17 Hz, 1H: C*H*=CH_2), 5.05 (d, J = 10 Hz, 1H: CH=CH(*H*)$_{cis}$), 4.98 (d, J = 17 Hz, 1H: CH=CH(*H*)$_{trans}$), 3.94 (app. q, J = 7 Hz, 1H: CH), 3.64 (d, J = 15 Hz, 1H: diastereotopic Ph-CH_2), 3.61 (d, J = 15 Hz, 1H: diastereotopic Ph-CH_2), 2.91 (dd, J = 7 Hz, 16 Hz, 1H: diastereotopic (CO)CH_2), 2.86 (dd, J = 7 Hz, 16 Hz, 1H: diastereotopic (CO)CH_2). ^{13}C NMR (75 MHz, $CDCl_3$) δ 206.40 (C=O), 142.71 (arom. C), 140.45 (*C*H=CH_2), 133.82 (arom. CH), 129.47 (arom. CH), 128.72 (arom. CH), 128.60 (arom. CH), 127.65 (arom. CH), 127.04 (arom. CH), 126.60 (arom. CH), 114.65 (CH=*C*H_2), 50.89 (Ph-CH_2), 47.17 ((CO)*C*H_2), 44.49 (CH). IR ($CDCl_3$): ν_{max} 1715, 1495, 1454. HRMS calcd for $C_{18}H_{19}O$ [M+H] = 251.1436, found 251.1432. Separated enantiomers on Diacel Chiralpak AD HPLC column (99.0% Hexane/IPA, 0.5 mL/min) - t_r = 18.4, 20.2 min.

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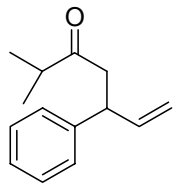

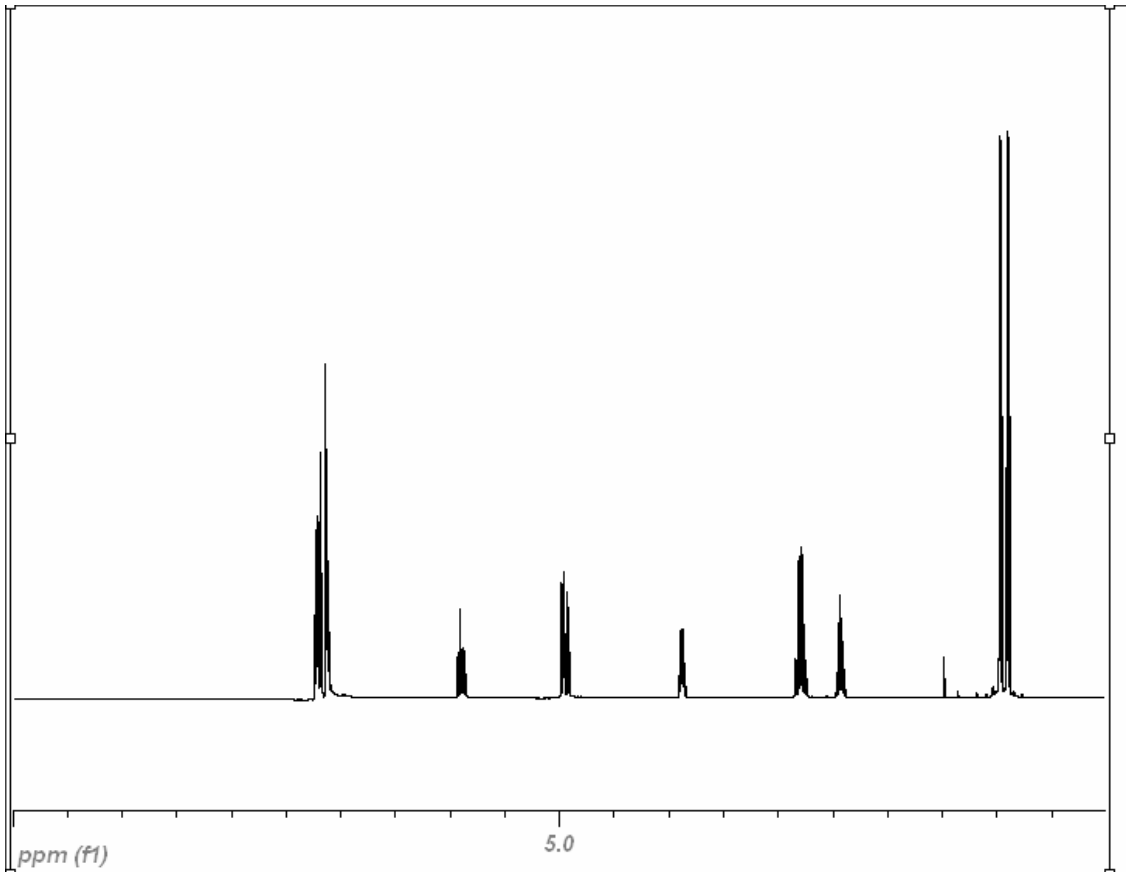

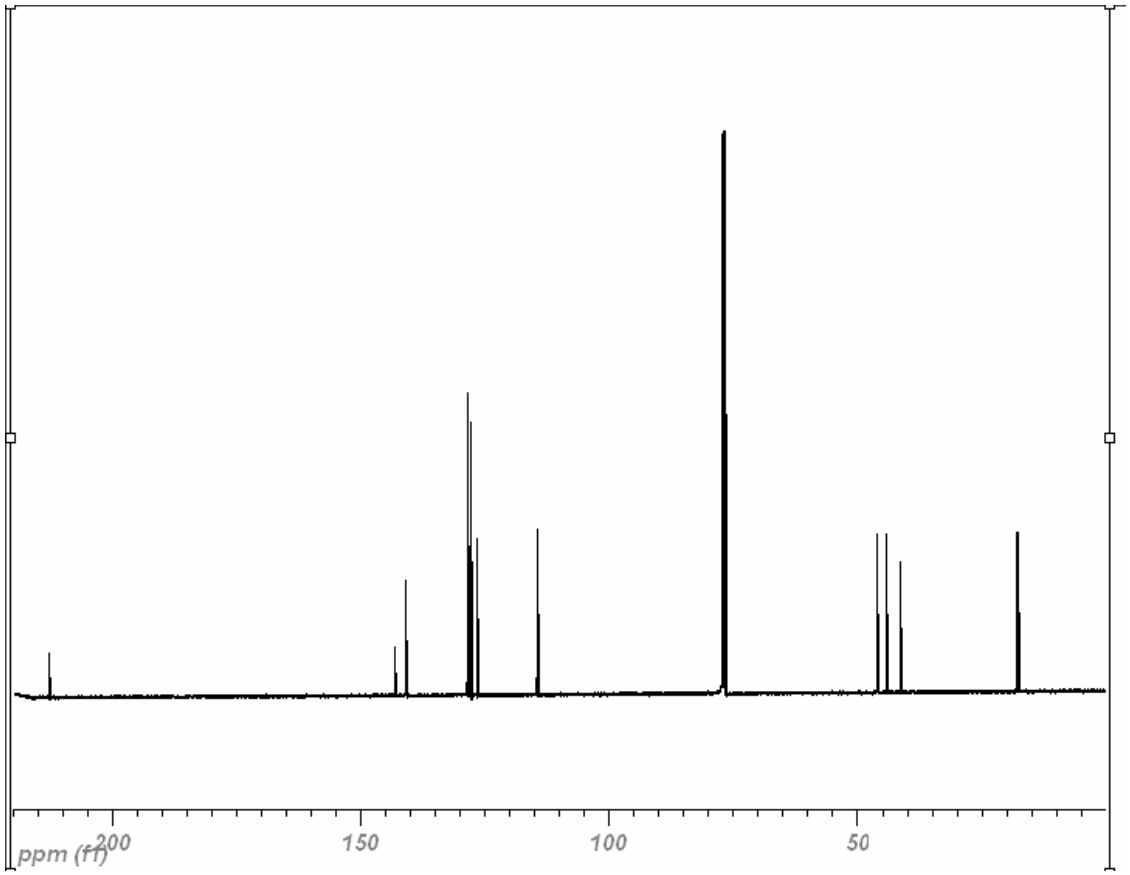

1h:[8,7b,7c] ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.21 (m, 2H: arom. H), 7.13 (m, 3H: arom. H), 5.91 (ddd, J = 7 Hz, 10 Hz, 17 Hz, 1H: C*H*=CH_2), 4.98 (d, J = 10 Hz, 1H: CH=CH(*H*)$_{cis}$), 4.94 (d, J = 17 Hz, 1H: CH=CH(*H*)$_{trans}$), 3.88 (app. q, J = 7 Hz, 1H: Ph-CH), 2.83 (dd, J = 7 Hz, 17 Hz, 1H: diastereotopic CH_2), 2.77 (dd, J = 7 Hz, 17 Hz, 1H: diastereotopic CH_2), 2.43 (sep., J = 7 Hz, 1H: C*H*-$(CH_3)_2$), 0.97 (d, J = 7 Hz, 3H: diastereotopic CH_3), 0.90 (d, J = 7 Hz, 3H: diastereotopic CH_3). ^{13}C NMR (75 MHz, $CDCl_3$) δ 212.65 (C=O), 143.15 (arom. C), 140.77 (*C*H=CH_2), 128.56 (arom. CH), 127.69 (arom. CH), 126.52 (arom. CH), 114.53 (CH=*C*H_2), 45.94 (CH_2), 44.30 (*C*H-$(CH_3)_2$), 41.37 (PhCH), 17.94 (diastereotopic CH_3), 17.83 (diastereotopic CH_3). IR ($CDCl_3$): ν_{max} 1709, 1452, 1385, 1364. HRMS calcd for $C_{14}H_{19}O$ [M+H] = 203.1436, found 203.1433. Separated enantiomers on Diacel Chiralpak AD HPLC column (99.0% Hexane/IPA, 0.5 mL/min) - t_r = 9.5, 10.5 min.

[8] T. Hirao, T. Fujii and Y. Ohshiro, *Tetrahedron*, 1994, **50**, 10207.

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Determination of the absolute configuration of 3a.
3a (0.4 mmol) was cleanly hydrogenated under *ca*. 1 atm. H_2 at 50 ^oC overnight using catalytic Pd on charcoal (20 mg) in ethanol. A clear oil was produced following filtration through Celite and concentration under reduced pressure. A specific rotation of $[\alpha]_D^{24}$ = -18.5 was determined in ethanol, thus establishing the formation of (*R*)-(-)-4-phenyl hexanone which corresponds to an (*S*)-configuration for substrate **3a**. It should be noted that the specific rotation was calculated assuming 100% product isolation after hydrogenation, so the ee calculated using this number is not accurate.

Regioselectivities:

Substrate	**R_t branched**	**R_t linear**	**Branched:linear**
3a	7.7 min	9.9 min	75:1
3b	8.9 min	11.5 min	101:1
3c	11.0 min	15.4 min	19:1
3d	10.1 min	13.4 min	89:1
3f	8.1,8.3 min	10.5 min	59:1
3g	16.6 min	20.4 min	20:1
3h	12.2 min	9.4 min	38:1

Isomers separated on a Restek Rtx-5 GC column. Substrates **3a-f** and **3h**: injector temp = 200 ^oC, detector temp = 250 ^oC, ramp 50 ^oC to 150 C at 10 ^{o}/min. Substrate **3g**: injector temp = 200 ^oC, detector temp = 250 ^oC, ramp 100 ^oC to 200 ^oC at 5 ^{o}/min.