Electronic Supplementary Material (ESI) for ChemComm.

Rhodium-catalyzed alkoxylation/acetalization of diazo compounds: One-step synthesis of highly functionalized quaternary carbon centers

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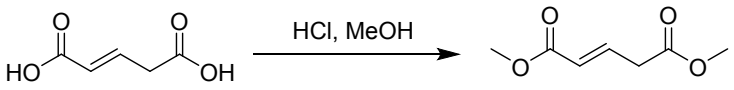
Supporting Information

General remarks

Catalytic reactions were carried out under a Ar-atmosphere using pre-dried glassware. Trimethylorthoformate was purchased from Sigma-Aldrich and distilled before use. The following starting materials were synthesized according to previously described methods: phenyl diazoacetates **1a-1k**,[1] estrone triflate **12**,[2] D_{10}-trimethylorthoformate (**[^{2}H]$_{10}$-2**).[3] Other chemicals were purchased from commercial sources and were used without any further purification. Unless otherwise stated, yields refer to isolated yields, estimated to be >95% pure according to ^{1}H-NMR spectroscopy or GC. GC-yields were calculated using hexadecane as internal standard. TLC: Macherey-Nagel, TLC plates Alugram® Sil G/UV254. Detection under UV light at 254 nm. The purification of the reaction products was carried out by flash chromatography using Merck Silica 60 (0.063–0.200 mm, 70–230 mesh ASTM). Infrared spectra were recorded using a BRUKER ALPHA-P spectrometer. Liquid probes were measured as film, solid probes were measured neat. Absorption is given in wave numbers (cm^{-1}). Spectra were recorded in the range of 4000–400 cm^{-1}. Following abbreviations were used for characterization: s (strong), m (medium), w (weak). MS: EI-MS: Finnigan MAT 95, 70 eV, DCI-MS: Finnigan MAT 95, 200 eV, reactant gas NH_3; ESI-MS: Finnigan LCQ. High resolution mass spectrometry (HRMS): APEX IV 7T FTICR, Bruker Daltonic. Melting points were measured using a BRUKER 540 melting point apparatus. Reported values are uncorrected. NMR (^{1}H, ^{13}C, ^{19}F, ^{11}B) spectra were recorded at 300 MHz (^{1}H), 75.5 MHz (^{13}C, APT (Attached Proton Test)) and 283 MHz (^{19}F), respectively, on Varian Unity-300 and AMX 300 instruments for $CDCl_3$ solutions if not otherwise specified, chemical shifts (δ) are given in ppm. Crystallographic data were collected on a BRUKER KAPPA APEX II DUO diffractometer. The structure was solved by direct methods and refined by full-matrix least-squares procedures on F_2 with the SHELXTL software package (Sheldrick, G. M. *Acta Crystallogr.* **2008**, *A64*, 112.). XP (BRUKER AXS) was used for graphical representation.

Preparation of starting materials 6 and 1l

Dimethyl (E)-4-diazopent-2-enedioate (6)

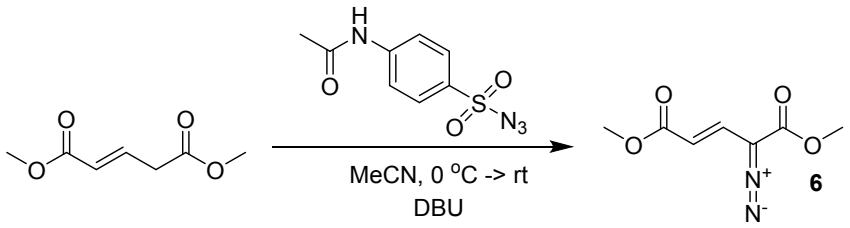


The carboxylic acid (20 mmol) was dissolved in dry MeOH (20 mL) and stirred whilst concentrated HCl (0.5 mL) was added dropwise. The solution was stirred overnight before concentrating under low pressure. Diethyl ether (20 mL) was added and the solution was washed with water (2 x 10 mL) and brine (10 mL) before being dried over anhydrous sodium sulfate, filtered and concentrated to give the title compound (4.07 g) in 95% yield.

^{1}H NMR (300 MHz, $CDCl_3$) δ = 6.99 (1H, td, ^{3}J = 7.1, 15.1 Hz), 5.93 (1H, td, ^{4}J = 1.5, ^{3}J = 15.7 Hz), 3.72 (3H, s), 3.70 (3H, s), 3.23 (2H, ^{3}J = 7.1 Hz, ^{4}J = 1.5 Hz);

^{13}C NMR (75 MHz, $CDCl_3$) δ = 170.25, 166.26, 139.83, 124.33, 52.22, 51.69, 37.21.

Data are in agreement with that previously published.[4]



4-Acetamidobenzenesulfonyl azide (5.5 mmol, 1.1 equiv., 1.32 g) was added to the ester (5 mmol, 1 equiv.) dissolved in dry MeCN (10 mL) at 0 °C and stirred. To this was added DBU (5.25 mol, 1.05 equiv., 0.78 mL) drop-wise and stirred for 2 hr, allowing it to slowly warm to room temperature. The darkened solution was concentrated under low pressure before being triturated with Et_2O:pentane (1:1) and filtered through a plug of silica gel, eluting with further portions of Et_2O:pentane (1:1). The volatile organics were removed under reduced pressure and the title compound (0.46 g) was isolated in a 50% yield.

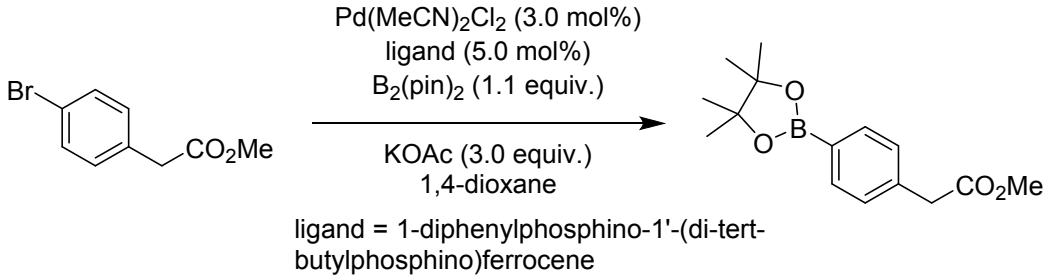
^{1}H NMR (300 MHz, $CDCl_3$) δ = 7.34 (1H, d, ^{3}J = 15.4), 5.72 (1H, d, ^{3}J = 15.4), 3.85 (3H, s), 3.75 (3H, s).);

IR (ATR, cm^{-1}) = 2953, 2103, 1699, 1614, 1435, 1165;

MS (EI) *m/z* (relative intensity %): 59 (100), 69 (80), 97 (89), 124 (87), 153 (66), 184 (48).

Data are in agreement with that previously published.[5]

Methyl 2-(4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)phenyl)acetate (1l)

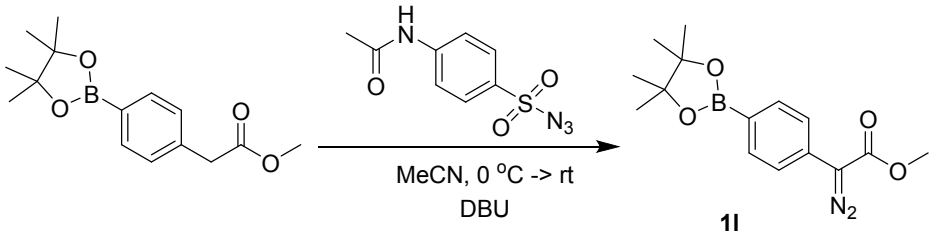


The palladium precursor (0.09 mmol, 0.03 equiv. 23 mg) and the ligand (0.15 mmol, 0.05 equiv., 77 mg) were dissolved in dry and degassed dioxane (25 mL) and stirred for 10 min under an inert atmosphere of argon. To this was added KOAc (9 mmol, 3 equiv., 0.792 g), $B_2(pin)_2$ (3.3 mmol, 1.1 equiv., 0.838 g) and methyl 2-(4-bromophenyl)acetate (3 mmol, 1 equiv., 0.687 g) and the solution was heated to 90 °C for 20 hr. After allowing the reaction mixture to cool, EtOAc (20 mL) was added, and washed with water (3 x 20 mL) and brine (1 x 10 mL), dried over anhydrous Na_2SO_4 filtered through a plug of silica and concentrated *in vacuo*. It was purified by column chromatography (pentane:Et_2O 9:1, Rf = 0.29) to give the title compound as a clear oil (0.68 g) in 83% yield.

^{1}H NMR (300 MHz, $CDCl_3$) δ =7.83 (2H, d, ^3J = 8.2 Hz), 7.34 (2H, d, ^3J = 8.2 Hz), 3.73 (3H, s), 3.70 (2H, s), 1.39 (12H, s);

^{13}C NMR (75 MHz, $CDCl_3$) δ = 171.2, 137.0, 135.0, 128.4, 83.3, 52.1, 41.3, 24.8.

Data are in agreement with that previously published.[6]



4-Acetamidobenzenesulfonyl azide (5.5 mmol, 1.1 equiv., 1.32 g) was added to the ester (5 mmol, 1 equiv.) dissolved in dry MeCN (10 mL) at 0 °C and stirred. To this was added DBU (5.25 mol, 1.05 equiv., 0.78 mL) drop-wise and stirred for 16 hr, allowing it to slowly warm to room temperature. The darkened solution was concentrated under low pressure before being triturated with Et_2O:pentane (1:1) and filtered through a plug of silica gel, eluting with further portions of Et_2O:pentane (1:1). The volatile organics were removed under reduced pressure and the title compound was isolated as an orange solid (0.293 g) in 49% yield.

^{1}H NMR (300 MHz, benzene-d_6) δ = 8.17 (2H, d , ^3J = 8.5 Hz) 7.54 (2H, d , ^3J = 8.5 Hz), 3.28 (3H, s), 1,.12 (12H, s);

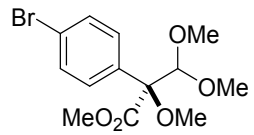
^{13}C NMR (75 MHz, benzene-d_6) δ = 162.5, 135.8, 125.2, 123.0, 83.6, 51.2, 24.8.

Data are in agreement with that previously published.[7]

General procedure for the rhodium-catalyzed synthesis of α-alkoxy-β-oxo-esters (3)

Over the course of one hour and under an atmosphere of argon, a solution of alkyl 2-(aryl)-2-diazoacetate (**1**) (1.0 equiv., 0.4 mmol) and trimethyl orthoformate (**2**) (2.5 equiv., 1 mmol) in dichloromethane (2 mL) was added drop-wise to a stirring solution of Rh_2(*S*-pttl)$_4$ (1.0 mol%, 0.004 mol) and trimethyl orthoformate (**2**) (2.5 equiv., 1 mmol) in dichloromethane (0.3 mL) at room temperature. The crude mixture was concentrated before being immediately subjected to flash chromatography purification.

Methyl 2-(4-bromophenyl)-2,3,3-trimethoxypropanoate (3a)



3a

Following the general procedure, the title compound (**3a**) (123 mg, 0.33 mmol, 84%) as isolated as a white solid. Purification was performed by flash chromatography (n-pentane:EtOAc = 20:1). The procedure was also performed on a 4.46 mmol scale following the general conditions but employing only 0.5 mol% catalyst and gave the title compound (1.29 g, 3.86 mmol, 86%).

m.p.: 83 °C

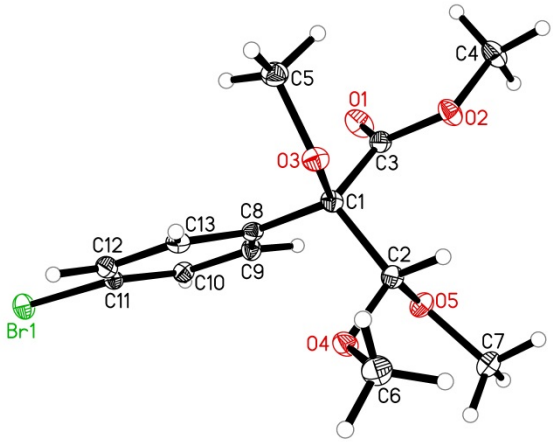
^{1}H NMR (300 MHz, Chloroform-*d*) δ 7.48 (d, *J* = 8.9 Hz, 1H, CH), 7.41 (d, *J* = 8.9 Hz, 1H, CH), 4.78 (s, 1H, CH_3), 3.83 (s, 3H, CH_3), 3.50 (s, 3H, CH_3), 3.41 (s, 3H, CH_3), 3.37 (s, 3H, CH_3).

^{13}C NMR (75 MHz, Chloroform-*d*) δ 170.3 (CO_2R), 134.0 (C_q), 130.9 (CH), 130.1 (CH), 122.6 (C_q), 108.4 (CH), 87.0 (C_q), 58.6 (CH_3), 58.0 (CH_3), 54.7 (CH_3), 52.5 (CH_3).

MS (GC-MS (EI)) *m/z* (relative intensity) = 301 (1) [M^+-31], 275 (2), 201 (7), 183 (10), 155 (5), 105 (3), 75 (100).

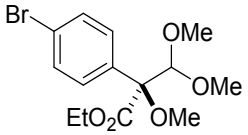
HRMS (ESI-TOF, m/z) calcd. For $C_{13}H_{17}Br_2O_2$ [M+Na]$^+$: 355.01516; found: 355.01527.

IR (ATR, neat, cm^{-1}): 2956 (w), 2935 (w), 1741 (s), 1226 (m), 1175 (m), 1097 (m), 1076 (s), 1008 (m), 975 (m), 910 (m), 800 (m).



Empirical formula	$C_{13}H_{17}BrO_5$	
CCDC number	1043341	
Formula weight	333.17	
Temperature	150(2) K	
Wavelength	0.71073 Å	
Crystal system	orthorhombic	
Space group	$Pna2_1$	
Unit cell dimensions	a = 14.3578(16) Å	α= 90°.
	b = 11.7005(14) Å	β= 90°.
	c = 8.2619(9) Å	γ = 90°.
Volume	1387.9(3) Å^3	
Z	4	
Density (calculated)	1.594 Mg/m^3	
Absorption coefficient	2.975 mm^{-1}	
F(000)	680	
Crystal size	0.490 x 0.298 x 0.145 mm	
Theta range for data collection	2.245 to 28.701°.	
Index ranges	-19<=h<=19, -15<=k<=15, -11<=l<=10	
Reflections collected	21187	
Independent reflections	3366 [R(int) = 0.0327]	
Completeness to theta = 25.242°	100.0 %	
Absorption correction	Semi-empirical from equivalents	
Max. and min. transmission	0.67 and 0.48	
Data / restraints / parameters	3366 / 1 / 176	
Goodness-of-fit on F²	1.018	
Final R indices [I>2sigma(I)]	R1 = 0.0219, wR2 = 0.0472	
R indices (all data)	R1 = 0.0262, wR2 = 0.0483	
Absolute structure parameter	0.021(5)	
Largest diff. peak and hole	0.377 and -0.281 e·Å^{-3}	

Ethyl 2-(4-bromophenyl)-2,3,3-trimethoxypropanoate (3b)



3b

Following the general procedure in a 0.4 mmol scale, the title compound (**3b**) (94 mg, 0.27 mmol, 68%) was isolated as a clear oil. Purification was performed by preparative TLC (*n*-pentane:EtOAc = 40:1).

^{1}H NMR (300 MHz, Chloroform-*d*) δ 7.48 (d, *J* = 9.0 Hz, 2H, CH), 7.42 (d, *J* = 8.9 Hz, 2H, CH), 4.78 (s, 1H, CH), 4.31 (d, *J* = 7.1 Hz, 2H, CH_2), 3.51 (s, 3H, CH_3), 3.41 (s, 3H, CH_3), 3.38 (s, 3H, CH_3), 1.33 (t, *J* = 7.1 Hz, 3H, CH_3).

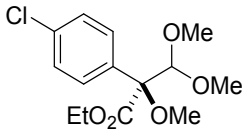
^{13}C NMR (75 MHz, Chloroform-*d*) δ 169.7 (CO), 134.1 (C_q), 130.9 (CH), 130.2 (CH), 122.5 (C_q), 108.4 (CH), 86.9 (C_q), 61.6 (CH_2), 58.6 (CH_3), 57.9 (CH_3), 54.6 (CH_3), 14.3 (CH_3).

MS (GC-MS (EI)) *m/z* (relative intensity) = 317 (1) [M^+-31], 273 (3), 244 (1), 227 (1), 199 (8), 183 (9), 75 (100).

HRMS (ESI-TOF, m/z) calcd. For $C_{14}H_{19}BrO_5$ $[M+Na]^+$: 369.0308; found: 369.0307.

IR (ATR, neat, cm^{-1}): 2937 (w), 2833 (w), 1734 (m), 1488 (m), 1181 (m), 1072 (s), 1009 (m), 937 (m), 731 (m), 503 (m).

Ethyl 2-(4-chlorophenyl)-2,3,3-trimethoxypropanoate (3c)



3c

Following the general procedure in a 0.2 mmol scale, the title compound (**3c**) (41 mg, 0.1,35 mmol, 68%) was obtained as a white solid. Purification was performed by flash chromatography (*n*-pentane:EtOAc = 20:1).

m.p.: 122-123 °C

^{1}H NMR (300 MHz, Chloroform-*d*) δ 7.48 (d, *J* = 8.9 Hz, 1H, CH), 7.32 (d, *J* = 8.8 Hz, 1H, CH), 4.78 (s, 1H, CH), 4.32 (qd, *J* = 7.1, 1.0 Hz, 2H, CH_2), 3.51 (s, 3H, CH_3), 3.41 (s, 3H, CH_3), 3.38 (s, 3H, CH_3), 1.33 (t, *J* = 7.1 Hz, 3H, CH_3).

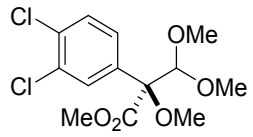
^{13}C NMR (75 MHz, Chloroform-*d*) δ 169.8 (C_q), 134.2 (C_q), 133.5 (C_q), 129.8 (CH), 127.9 ,(CH) 108.4 (CH), 86.8 (C_q), 61.6 (CH_2), 58.6 (CH_3), 57.9 (CH_3), 54.6 (CH_3), 14.3 (CH_3).

MS (GC-MS (EI)) *m/z* (relative intensity) = 271 (1) [M^+-31], 229 (5), 183 (3), 155 (16), 139 (16), 111 (11), 75 (100).

HRMS (ESI-TOF, m/z) calcd. For $C_{14}H_{19}Cl_2O_5$ $[M+Na]^+$: 325.0813; found: 325.0815.

IR (ATR, neat, cm^{-1}): 2938 (w), 2834 (w), 1731 (m), 1491 (m), 1181 (m), 1076 (s), 1038 (m), 1014 (s), 963 (m). 733 (m), 507 (m).

Methyl 2-(3,4-dichlorophenyl)-2,3,3-trimethoxypropanoate (3d)



3d

Following the general procedure, the title compound (**3d**) (46 mg, 0.14 mmol, 71%) was obtained as a white solid. Purification was performed by flash chromatography (*n*-pentane:EtOAc = 20:1).

m.p.: 78 °C

^{1}H NMR (300 MHz, Chloroform-*d*) δ 7.65 (dd, *J* = 2.1, 0.5 Hz, 1H, CH), 7.42 (dd, *J* = 8.5, 0.5 Hz, 1H, CH), 7.37 (dd, *J* = 8.5, 2.1 Hz, 1H, CH), 4.77 (s, 1H, CH), 3.85 (s, 3H, CH_3), 3.53 (s, 3H, CH_3), 3.42 (s, 3H, CH_3), 3.37 (s, 3H, CH_3).

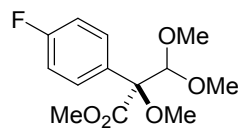
^{13}C NMR (75 MHz, Chloroform-*d*) δ 169.9 (CO), 135.1 (C_q), 132.4 (C_q), 132.0 (C_q), 130.6 (CH), 129.6 (CH), 128.0 (CH), 108.2 (CH), 86.6 (C_q), 58.9 (CH_3), 57.9 (CH_3), 54.7 (CH_3), 52.7 (CH_3).

MS (GC-MS (EI)) *m/z* (relative intensity) = 324 (1) [M^+], 291 (2), 263 (3), 219 (2), 189 (12), 173 (13), 75 (100).

HRMS (ESI-TOF, m/z) calcd. For $C_{13}H_{16}Cl_2O_5$ $[M+Na]^+$: 345.0267; found: 345.0268.

IR (ATR, neat, cm^{-1}): 2935 (w), 1898 (w), 2834 (w), 1742 (s), 1225 (m), 1191 (m), 1180 (m), 1106 (s), 1084 (s), 1049 (m), 979 (m), 921 (m), 797 (m), 718 (m), (674 (m), 517 (m).

Methyl 2-(4-fluorophenyl)-2,3,3-trimethoxypropanoate (3e)



3e

Following the general procedure, the title compound (**3e**) (104 mg, 0.38 mmol, 76%) was obtained as clear oil. Purification was performed by flash chromatography (*n*-pentane:EtOAc = 20:1).

^{1}H NMR (300 MHz, Chloroform-*d*) δ 7.51 (dd, *J* = 9.0, 5.4 Hz, 1H, CH), 7.04 (dd, *J* = 9.0, 8.5 Hz, 1H, CH), 4.78 (s, 1H, CH), 3.84 (s, 3H, CH_3), 3.50 (s, 3H, CH_3), 3.42 (s, 3H, CH_3), 3.37 (s, 3H, CH_3).

^{13}C NMR (75 MHz, Chloroform-*d*) δ 170.6 (CO), 162.7 (d, *J* = 246.9 Hz, C_q), 130.7 (d, *J* = 3.5 Hz, C_q), 130.1 (d, *J* = 8.1 Hz, CH), 114.8 (d, *J* = 21.3 Hz, CH), 108.5 (CH), 86.9 (C_q), 58.5 (CH_3), 58.0 (CH_3), 54.6 (CH_3), 52.5 (CH_3).

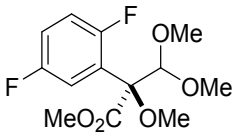
^{19}F NMR (282 MHz, Chloroform-*d*) δ -112.7 – -117.0 (m).

MS (GC-MS (EI)) *m/z* (relative intensity) = 271 (1) [M^+-31], 229 (5), 183 (3), 155 (16), 139 (16), 111 (11), 75 (100).

HRMS (ESI-TOF, m/z) calcd. For $C_{14}H_{19}Cl_2O_5$ [M+Na]$^+$: 325.0813; found: 325.0815.

IR (ATR, neat, cm^{-1}): 2952 (w), 2836 (w), 1735 (m), 1508 (m), 1225 (m), 1076 (s), 911 (m), 727 (s).

Methyl 2-(2,5-difluorophenyl)-2,3,3-trimethoxypropanoate (3f)



3f

Following the general procedure, the title compound (**3f**) (120 mg, 0.41 mmol, 83%) was obtained as a white solid. Purification was performed by flash chromatography (*n*-pentane:EtOAc = 20:1).

^{1}H NMR (300 MHz, Chloroform-*d*) δ 7.39 – 7.27 (m, 1H, CH), 7.06 – 6.90 (m, 2H, CH), 4.95 (d, *J* = 1.2 Hz, 1H, CH), 3.82 (s, 3H), 3.55 (s, 3H), 3.54 (s, 3H), 3.36 (d, *J* = 0.5 Hz, 3H).

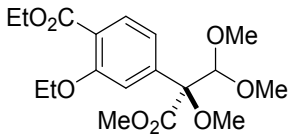
^{13}C NMR (75 MHz, Chloroform-*d*) δ 169.5 (C_q), 158.4 (dd, *J* = 241.6, 2.0 Hz, C_q), 156.7 (dd, *J* = 244.3, 2.5 Hz, C_q), 125.0 (dd, *J* = 14.6, 7.8 Hz, C_q), 117.1 (dd, *J* = 26.6, 4.0 Hz, CH), 116.7 (dd, *J* = 27.0, 8.8 Hz, CH), 116.7 (dd, *J* = 24.3, 9.3 Hz, CH), 106.5 (d, *J* = 2.7 Hz, CH), 83.9 (d, *J* = 3.2 Hz, C_q), 58.3 (CH_3), 57.9 (CH_3), 54.1 (CH_3), 52.6 (CH_3).

^{19}F NMR (282 MHz, Chloroform-*d*) δ -115.8 – -116.2 (m), -118.0 – -118.8 (m).

MS (GC-MS (EI)) *m/z* (relative intensity) = 259 (1) [M^+-31], 228 (2), 197 (8), 159 (10), 138 (18), 75 (100).

IR (ATR, neat, cm^{-1}): 3087 (w), 2954 (w), 2834 (w), 1733 (s), 1491 (m), 1248 (m), 1166 (m), 1069 (s), 986 (m), 818 (m), 768 (m), 718 (m).

Methyl 2-ethoxy-4-(1,1,2,3-tetramethoxy-3-oxopropan-2-yl)benzoate (3g)



3g

Following the general procedure, the title compound (**3g**) (123 mg, 0.33 mmol, 83%) was isolated as a clear oil. Purification was performed by flash chromatography (*n*-pentane:EtOAc = 10:1 → 5:1).

^{1}H NMR (300 MHz, Chloroform-*d*) δ 7.73 (d, *J* = 8.2 Hz, 1H, CH), 7.22 (d, *J* = 1.6 Hz, 1H, CH), 7.11 (dd, *J* = 8.2, 1.6 Hz, 1H, CH), 4.80 (s, 1H, CH), 4.34 (q, *J* = 7.1 Hz, 2H, CH_2), 4.13 (q, *J* = 7.0 Hz, 2H, CH_2), 3.82 (s, 3H, CH_3), 3.48 (s, 3H, CH_3), 3.42 (s, 3H, CH_3), 3.39 (s, 3H, CH_3), 1.44 (t, *J* = 7.0 Hz, 3H, CH_3), 1.36 (t, *J* = 7.1 Hz, 3H, CH_3).

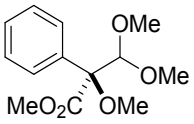
^{13}C NMR (75 MHz, Chloroform-*d*) δ 170.4 (C_q), 166.4 (C_q), 158.1 (C_q), 140.9 (C_q), 130.8 (CH), 120.6 (C_q), 119.6 (CH), 113.4 (CH), 108.7 (CH), 86.9 (C_q), 64.8 (CH_2), 60.9 (CH_2), 58.4 (CH_3), 58.2 (CH_3), 55.1 (CH_3), 52.5 (CH_3), 14.8 (CH_3), 14.4 (CH_3).

MS (GC-MS (EI)) *m/z* (relative intensity) = 370 (1) [M^+-31], 311 (2), 237 (6), 221 (4), 147 (3), 119 (5), 75 (100).

HRMS (ESI-TOF, m/z) calcd. For $C_{18}H_{26}O_8$ $[M+H]^+$: 371.17004; found: 371.17003.

IR (ATR, neat, cm^{-1}): 2981 (w), 2938 (w), 2835 (w), 1728 (s), 1610 (m), 1417 (m) 1293 (m), 1240 (s), 1074 (s), 1040 (m), 982 (m), 770 (m).

Methyl 2,3,3-trimethoxy-2-phenylpropanoate (3h)



3h

Following the general procedure but employing PhCl and conducting the reaction at 60 °C, the title compound (**3h**) (67 mg, 0.26 mmol, 66%) was isolated as a clear oil. Purification was performed by flash chromatography (*n*-pentane:EtOAc = 20:1).

^{1}H NMR (300 MHz, Chloroform-*d*) δ 7.58 – 7.48 (m, 2H), 7.42 – 7.28 (m, 3H), 4.83 (s, 1H, CH), 3.83 (s, 3H, CH_3), 3.49 (s, 3H, CH_3), 3.42 (s, 3H, CH_3), 3.40 (s, 3H, CH_3).

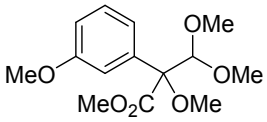
^{13}C NMR (75 MHz, Chloroform-*d*) δ 170.9 (C_q), 135.2 (C_q), 128.3 (CH), 128.0 (CH), 128.0 (CH), 108.8 (CH), 87.2 (C_q), 58.3 (CH_3), 58.0 (CH_3), 54.8 (CH_3), 52.4 (CH_3)

MS (GC-MS (EI)) *m/z* (relative intensity) = 223 (1) [M^+-31], 195 (5), 179 (2), 149 (4), 121 (20), 105 (25), 75 (100).

HRMS (ESI-TOF, m/z) calcd. For $C_{13}H_{18}O_5$ [M+Na]$^+$: 277.1046; found: 277.1046.

IR (ATR, neat, cm^{-1}): 2951 (w), 2834 (w), 1733 (m), 1190 (m), 1106 (m), 1076 (s), 910 (m), 726 (s), 698 (m), 646 (m).

Methyl 2,3,3-trimethoxy-2-(3-methoxyphenyl)propanoate (3i)



3i

Following the general procedure but employing PhCl and conducting the reaction at 80 °C with a total of 10 equiv of trimethylorthoformate (**2**) used, the title compound (**3i**) (84 mg, 0.30 mmol, 74%) was isolated as a pale yellow oil. Purification was performed by flash chromatograohy (*n*-pentane:EtOAc = 20:1).

^{1}H NMR (300 MHz, Chloroform-*d*) δ 7.27 (dd, *J* = 8.1 Hz, 1H, CH), 7.14 – 7.07 (m, 2H, CH), 6.86 (ddd, *J* = 8.1, 2.6, 1.0 Hz, 1H, CH), 4.82 (s, 1H, CH), 3.82 (s, 3H, CH_3), 3.80 (s, 3H, CH_3), 3.49 (s, 3H, CH_3), 3.42 (s, 3H, CH_3), 3.42 (s, 3H, CH_3).

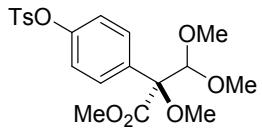
^{13}C NMR (75 MHz, Chloroform-*d*) δ 170.8 (CO), 159.3 (C_q), 137.0 (C_q), 128.9 (CH), 120.3 (CH), 113.9 (CH), 113.7 (CH), 108.8 (CH), 87.0 (C_q), 58.2 (CH_3), 58.1 (CH_3), 55.4 (CH_3), 55.0 (CH_3), 52.4 (CH_3).

MS (GC-MS (EI)) *m/z* (relative intensity) = 284 (1) [M^+], 253 (2), 225 (5), 209 (2), 151 (15), 135 (13), 75 (100).

HRMS (ESI-TOF, m/z) calcd. For $C_{14}H_{20}O_6$ [M+Na]$^+$: 307.1152; found: 307.1156.

IR (ATR, neat, cm^{-1}): 2952 (w), 2835 (w), 1727 (s), 1578 (m), 1435 (m), 1287 (m), 1248 (s), 1076 (s), 1037 (s), 874 (m), 780 (m), 714 (m).

Methyl (S)-2,3,3-trimethoxy-2-(4-(tosyloxy)phenyl)propanoate (3j)



3j

Following the general procedure on a 0.25 mmol scale, the title compound (**3j**) (97 mg, 0.23 mmol, 91%) was isolated as a colorless oil. Purification was performed by flash chromatography (*n*-pentane:EtOAc = 10:1→5:1).

^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.70 (d, *J* = 8.3 Hz, 2H, CH), 7.47 (d, *J* = 8.5 Hz, 2H, CH), 7.29 (d, *J* = 8.7 Hz, 2H, CH), 6.97 (d, *J* = 8.6 Hz, 2H, CH), 4.75 (s, 1H, CH), 3.81 (s, 3H, CH_3), 3.45 (s, 3H, CH_3), 3.36 (s, 3H, CH_3), 2.43 (s, 3H, CH_3).

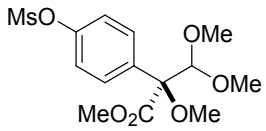
^{13}C NMR (101 MHz, Chloroform-*d*) δ 170.4 (C_q), 149.5 (C_q), 145.4 (C_q), 134.2 (C_q), 132.6 (C_q), 129.8 (CH), 129.5 (CH), 128.6 (CH), 121.6 (CH), 108.6 (CH), 86.7 (C_q), 58.4 (CH_3), 58.0 (CH_3), 54.8 (CH_3), 52.5 (CH_3), 21.8 (CH_3).

MS (GC-MS (EI)) *m/z* (relative intensity) = 424 (1) [M^+], 365 (3), 291 (5), 194 (3), 179 (8), 91 (27), 75 (100).

HRMS (ESI-TOF, m/z) calcd. For $C_{20}H_{24}O_8S$ [M+Na]$^+$: 424.1186; found: 424.1186.

IR (ATR, neat, cm^{-1}): 2951 (w), 2835 (w), 1740 (m), 1501 (m), 1371 (m), 1777 (m), 1153 (s), 1076 (s), 862 (s), 725 (m), 661 (m), 567 (s), 550 (s).

Methyl -2,3,3-trimethoxy-2-(4-((methylsulfonyl)oxy)phenyl)propanoate (3k)



3k

Following the general procedure on a 0.25 mmol scale, the title compound (**3k**) was isolated (76 mg, 0.22 mmol, 87%) as a white solid. Purification was performed by flash chromatography (*n*-pentane:EtOAc = 7:1→2:1).

^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.59 (d, *J* = 8.4 Hz, 2H, CH), 7.26 (d, *J* = 8.5 Hz, 2H, CH), 4.80 (s, 1H, CH), 3.84 (s, 3H, CH_3), 3.51 (s, 3H, CH_3), 3.42 (s, 3H, CH_3), 3.37 (s, 3H, CH_3), 3.13 (s, 3H, CH_3).

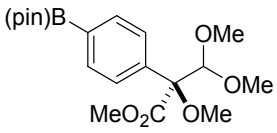
^{13}C NMR (101 MHz, Chloroform-*d*) δ 170.3 (C_q), 149.1 (C_q), 134.3 (C_q), 130.2 (CH), 121.2 (CH), 108.3 (CH), 86.9 (C_q), 58.7 (CH_3), 57.9 (CH_3), 54.7 (CH_3), 52.5 (CH_3), 37.5 (CH_3).

MS (GC-MS (EI)) *m/z* (relative intensity) = 347 (1) [M^+], 317 (1), 289 (3), 215 (7), 194 (3), 179 (8), 75 (100).

HRMS (ESI-TOF, m/z) calcd. For $C_{14}H_{20}O_8S$ $[M+Na]^+$: 371.0771; found: 371.0778.

IR (ATR, neat, cm^{-1}): 2935 (w), 2835 (w), 1744 (s), 1362 (s), 1149 (s), 1073 (s), 970 (s), 868 (s), 799 (m), 706 (m), 546 (s), 528 (s).

Methyl 2,3,3-trimethoxy-2-(4-(tosyloxy)phenyl)propanoate (3l)



3l

Following the general procedure on a 0.25 mmol scale, the title compound (**3l**) (97 mg, 0.23 mmol, 71%) was isolated as a clear oil. Purification was performed by flash chromatography (*n*-pentane:EtOAc = 15:1).

^{1}H NMR (300 MHz, Chloroform-*d*) δ 7.80 (d, *J* = 8.4 Hz, 1H, CH), 7.54 (d, *J* = 8.4 Hz, 1H, CH), 4.82 (s, 1H, CH), 3.82 (s, 3H, CH_3), 3.47 (s, 3H, CH_3), 3.40 (s, 3H, CH_3), 3.39 (s, 3H, CH_3), 1.33 (s, 12H, CH_3).

^{13}C NMR (75 MHz, Chloroform-*d*) δ 170.7 (C_q), 138.3 (C_q), 134.4 (CH), 127.3 (CH), 108.8 (C_q), 87.2 (CH_3), 83.9 (CH_3), 58.3 (CH_3), 58.1 (CH_3), 55.0 (CH_3), 52.4 (CH_3), 25.0 (C_q).

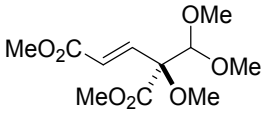
^{11}B NMR (96 MHz, Chloroform-*d*) 29.75 (s).

MS (GC-MS (EI)) *m/z* (relative intensity) = 365 (2) [M^+-15], 349 (1), 305 (4), 247 (8), 191 (5), 147 (5), 75 (100).

HRMS (ESI-TOF, m/z) calcd. For $C_{19}H_{29}O_7B$ $[M+Na]^+$: 403.1902; found: 403.1905.

IR (ATR, neat, cm^{-1}): 2977 (w), 2829 (w), 1734 (s), 1358 (s), 1271 (m), 1142 (m), 1090 (s), 1078 (s), 989 (m), 941 (m), 859 (m), 656 (m).

Dimethyl (*E*)-4-(dimethoxymethyl)-4-methoxypent-2-enedioate (7)



7

Following the general procedure on a 0.2 mmol scale, the title compound (5) (28 mg, 0.11 mmol, 53%) was obtained as a white solid. Purification was performed by flash chromatography (*n*-pentane:EtOAc = 5:1).

^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.09 (d, *J* = 16.1 Hz, 1H, CH), 6.17 (d, *J* = 16.1 Hz, 1H, CH), 4.54 (s, 1H, CH), 3.82 (s, 3H, CH_3), 3.76 (s, 3H, CH_3), 3.53 (s, 3H, CH_3), 3.45 (s, 3H, CH_3), 3.33 (s, 3H, CH_3).

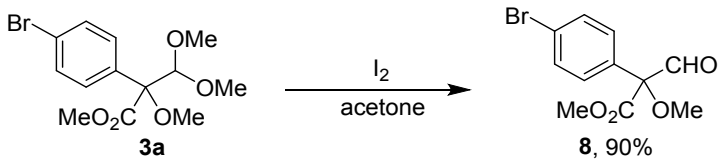
^{13}C NMR (126 MHz, Chloroform-*d*) δ 169.5 (C_q), 166.4 (C_q), 141.2 (CH), 124.5 (CH), 108.1 (CH), 86.3 (C_q), 58.6 (CH_3), 57.6 (CH_3), 54.2 (CH_3), 52.7 (CH_3), 51.9 (CH_3).

MS (GC-MS (EI)) *m/z* (relative intensity) = 230 (2) [M^+-31], 199 (8), 171 (4), 113 (13), 75 (100).

HRMS (ESI-TOF, m/z) calcd. For $C_{11}H_{18}O_7$ [M+Na]$^+$: 285.0945; found: 285.0946.

Derivatization of methyl 2-aryl-2,3,3-trimethoxypropanoates (3)

Methyl 2-(4-bromophenyl)-2-methoxy-3-oxopropanoate (8)

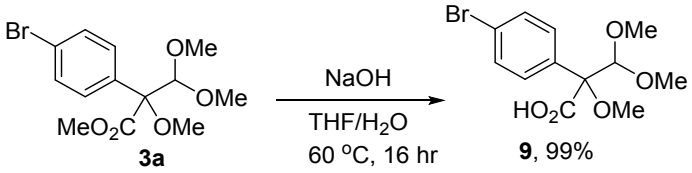


Dimethylacetale **3a** (50 mg, 0.15 mmol, 1.0 equiv.) was dissolved in acetone (3 mL). Iodine (114 mg, 0.45 mmol, 3.0 equiv.) was then added and the reaction mixture was stirred for 2 hours at 60 °C. The crude mixture was concentrated, quenched with $Na_2S_2O_3$ and extracted with Et_2O (3 x 20 mL). The combined organic layers were washed with brine (25 mL), dried over Na_2SO_4 and concentrated under reduced pressure. Purification by flash chromatography (*n*-pentane/EtOAc = 20:1) yielded the title compound **7** (39 mg, 0.14 mmol, 90%)

^{1}H NMR (300 MHz, Chloroform-*d*) δ 9.77 (s, 1H), 7.55 (d, *J* = 8.47 Hz, 2H), 7.35 (d, *J* = 8.51 Hz, 2H), 3.88 (s, 3H, CH_3), 3.49 (s, 3H, CH_3).

^{13}C NMR (75 MHz, Chloroform-*d*) δ 194.1 (CHO), 168.9 (CO_2R), 132.7 (CH), 132.5 (C_q), 129.0 (CH), 124.3 (C_q), 89.0 (C_q), 55.6 (CH_3), 54.8 (CH_3).

2-(4-Bromophenyl)-2,3,3-trimethoxypropanoic acid (9)



Dimethylacetale **3a** (66.6 mg, 0.2 mmol, 1.0 equiv.) and sodium hydroxide (32 mg, 0.8 mmol, 4.0 equiv.) were dissolved in THF (2.5 mL) and water (3 mL). The solution was heated to 60 °C and stirred for 16 h before H_2SO_4 was added dropwise until the pH was less than 2. The product was extracted into EtOAc (3 x 5 mL), dried over anhydrous $NaHCO_3$ and concentrated to give the carboxylic acid (62 mg, 0.22 mmol, 99%).

^{1}H NMR (400 MHz, Chloroform-*d*) δ 8.87 (s, 1H, CO_2H), 7.52 (d, *J* = 8.6 Hz, 2H, CH), 7.39 (d, *J* = 8.6 Hz, 2H, CH), 4.70 (s, 1H, CH), 3.57 (s, 1H, CH_3), 3.44 (s, 1H, CH_3), 3.39 (s, 2H, CH_3).

^{1}H NMR (300 MHz, Acetone-d_6) δ 7.46 (m, 4H, 2 CH_3), 4.87 (s, 1H, CH), 3.46 (s, 3H, CH_3), 3.36 (s, 3H, CH_3), 3.34 (s, 3H, CH_3).

^{13}C NMR (101 MHz, Chloroform-*d*) δ 171.0 (CO), 133.8 (C_q), 131.5 (CH), 129.9 (CH), 123.0 (C_q), 108.7 (CH), 86.2 (C_q), 58.8 (CH_3), 58.7 (CH_3), 54.7 (CH_3).

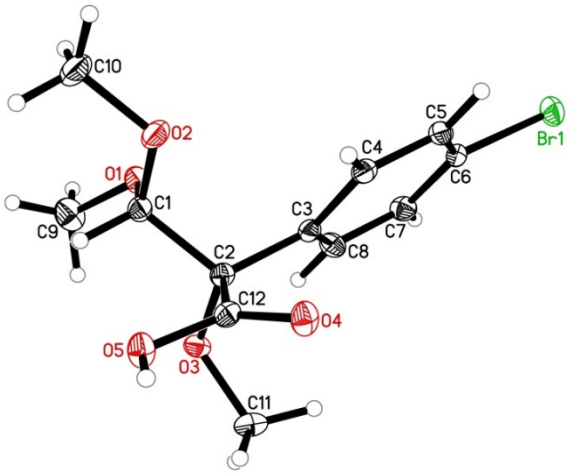
^{13}C NMR (75 MHz, Acetone-d_6) δ 170.7 (CO), 136.2 (C_q) , 131.4 (CH), 131.0 (CH), 122.1 (C_q), 109.0 (CH), 87.0 (C_q), 58.7 (CH_3), 57.6 (CH_3), 54.5 (CH_3).

MS (GC-MS (EI)) *m/z* (relative intensity) = 287 (1) [M^+-31], 275 (2), 242 (11), 227 (8), 183 (12), 148 (14), 75 (100).

HRMS (ESI-TOF, m/z) calcd. For $C_{12}H_{15}BrO_5$ $[M-H]^+$: 317.0030; found: 317.0035.

IR (ATR, neat, cm^{-1}): 2925 (w), 2832 (w), 1719 (s), 1285 (m), 1183 (m), 1074 (s), 1008 (s), 934 (s), 835 (m), 778 (m), 725 (m), 504 (m).

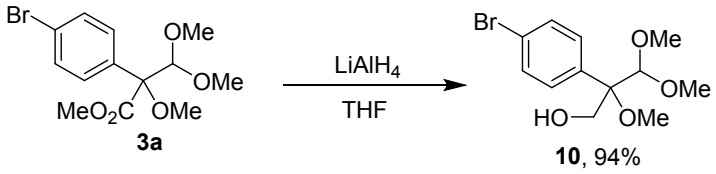
X-ray



Empirical formula	$C_{12}H_{15}BrO_5$	
CCDC number	1043343	
Formula weight	319.15	
Temperature	150(2) K	
Wavelength	0.71073 Å	
Crystal system	monoclinic	
Space group	$P2_1/c$	
Unit cell dimensions	a = 12.7047(6) Å	α= 90°.
	b = 8.5755(4) Å	β= 115.5461(7)°.
	c = 13.6576(6) Å	γ = 90°.
Volume	1342.52(11) $Å^3$	
Z	4	
Density (calculated)	1.579 Mg/m^3	
Absorption coefficient	3.072 mm^{-1}	
F(000)	648	
Crystal size	0.461 x 0.280 x 0.224 mm^3	
Theta range for data collection	1.777 to 27.995°.	
Index ranges	-16<=h<=15, -11<=k<=11, -17<=l<=18	
Reflections collected	20230	

Independent reflections	3240 [R(int) = 0.0239]
Completeness to theta = 25.242°	100.0 %
Absorption correction	Semi-empirical from equivalents
Max. and min. transmission	0.55 and 0.33
Data / restraints / parameters	3240 / 0 / 170
Goodness-of-fit on F^2	1.052
Final R indices [I>2sigma(I)]	R1 = 0.0336, wR2 = 0.0816
R indices (all data)	R1 = 0.0387, wR2 = 0.0842
Largest diff. peak and hole	1.693 and -1.243 e.Å^{-3}

2-(4-Bromophenyl)-2,3,3-trimethoxypropan-1-ol (10)



Dimethylacetale **3a** (50 mg, 0.15 mmol, 1.0 equiv.) was dissolved in dry THF (3 mL) and cooled to 0 °C. $LiAlH_4$ (23 mg, 0.6 mmol, 4.0 equiv.) was added in two portions. The reaction mixture was stirred for 0 °C for 30 min. The crude mixture was quenched by dropwise addition of MeOH (2 mL) and extracted with EtOAc (3 x 10 mL). The combined organic layers were washed with brine (25 mL), dried over Na_2SO_4 and concentrated under reduced pressure. Purification by flash chromatography (*n*-pentane/EtOAc = 20:1) yielded the title compound **10** (41 mg, 0.13 mmol, 90%) as a colourless oil.

^{1}H NMR (300 MHz, Chloroform-*d*) δ 7.41 (d, *J* = 8.5 Hz, 1H), 7.17 (d, *J* = 8.5 Hz, 2H), 4.35 (d, *J* = 11.9 Hz, 1H), 4.23 (d, *J* = 0.7 Hz, 1H), 3.85 (d, *J* = 11.9 Hz, 1H), 3.46 (s, 3H), 3.17 (s, 3H), 3.16 (s, 3H).

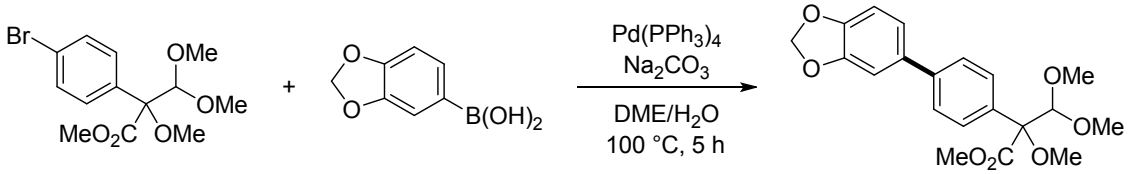
^{13}C NMR (75 MHz, Chloroform-*d*) δ 137.4 (C_q), 131.3 (CH), 129.0 (CH), 121.9 (C_q), 110.8 (CH), 81.5 (C_q), 61.7 (CH_2), 58.3 ($2CH_3$), 50.9 (CH_3).

MS (GC-MS (EI)) *m/z* (relative intensity) = 273 (1) [M^+-31], 229 (2), 199 (8), 183 (6), 155 (5), 118 (7), 75 (100).

HRMS (ESI-TOF, m/z) calcd. For $C_{12}H_{17}BrO_4$ $[M+Na]^+$: 327.0202; found: 327.0208.

IR (ATR, neat, cm^{-1}): 3456 (w), 2934 (w), 2832 (w), 1488 (w), 1189 (w), 1098 (m), 1071 (s), 1008 (m), 969 (w), 823 (w).

Methyl -2-(4-(benzo[*d*][1,3]dioxol-5-yl)phenyl)-2,3,3-trimethoxypropanoate (11)



3a **11**, 90%

Benzo[*d*][1,3]dioxol-5-ylboronic acid (52.3 mg, 0.32 mmol, 1.2 equiv.), Na_2CO_3 (89 mg, 0.84 mmol,4.0 equiv.) and $Pd(PPh_3)_4$ (24 mg, 10 mol%) were dissolved in DME (3.8 mL) and H_2O (0.8 mL). Methyl 2-(4-bromophenyl)-2,3,3-trimethoxypropanoate (**3a**) (70 mg, 0.21 mmol, 1.0 equiv.) was added in one portion. The reaction mixture was placed in a pre-heated oil bath and stirred at 100 °C for 5 hrs. The reaction mixture was quenched with EtOAc/H_2O (10 mL) and extracted with Et_2O (3 x 20 mL). The combined organic layers were washed with brine (25 mL), dried over Na_2SO_4 and concentrated under reduced pressure. Purification by flash chromatography (*n*-hexane/EtOAc = 20:1) yielded the title compound **11** (71 mg, 0.19 mmol, 90%) as a white solid.

m.p.: 122 °C

^{1}H NMR (300 MHz, Chloroform-*d*) δ 7.6 (d, *J* = 8.8 Hz, 2H), 7.5 (d, *J* = 8.8 Hz, 2H), 7.1 – 7.0 (m, 2H), 6.9 (d, *J* = 8.6 Hz, 1H), 6.0 (s, 2H), 4.9 (s, 1H), 3.9 (s, 3H), 3.5 (s, 3H), 3.5 (s, 3H), 3.4 (s, 3H).

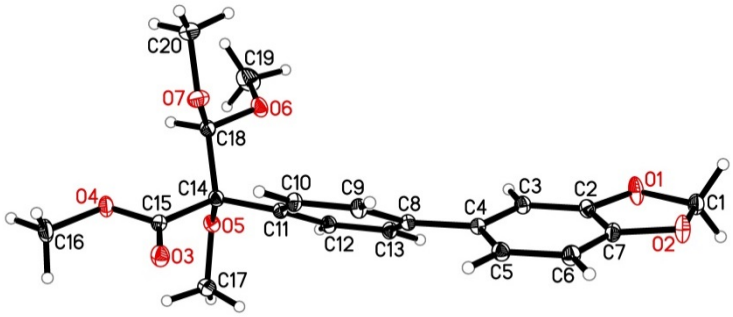
^{13}C NMR (75 MHz, Chloroform-*d*) δ 170.8 (C_q), 148.2 (C_q), 147.2 (C_q), 140.7 (C_q), 135.1 (C_q), 133.7 (C_q), 128.6 (CH), 126.3 (CH), 125.1 (C_q), 120.8 (CH), 108.7 (CH), 107.7 (CH), 101.3 (CH_2), 87.2 (C_q), 58.5 (CH_3), 58.0 (CH_3), 54.7 (CH_3), 52.4 (CH_3).

MS (GC-MS (EI)) *m/z* (relative intensity) = 374 (1) [M^+], 343 (2), 299 (6), 241 (8), 139 (25), 75 (100).

HRMS (ESI-TOF, m/z) calcd. For $C_{20}H_{22}O_7$ [M+Na]$^+$: 397.1258; found: 397.1259.

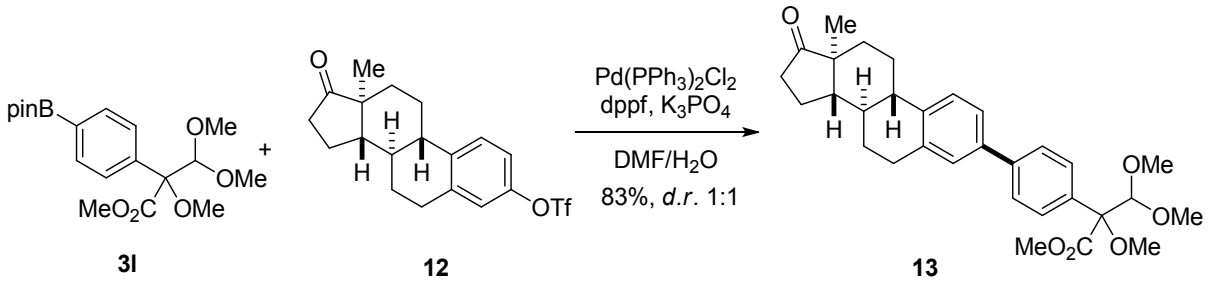
IR (ATR, neat, cm^{-1}): 2884 (w), 2827 (w), 1741 (s), 1477 (m), 1227 (s), 1178 (m), 1103 (s), 1085 (s), 1036 (m), 935 (m), 911 (m), 811 (s), 799 (s), 535 (m).

X-ray



Empirical formula	$C_{20}H_{22}O_7$	
CCDC number	1043342	
Formula weight	374.37	
Temperature	150(2) K	
Wavelength	0.71073 Å	
Crystal system	monoclinic	
Space group	$P2_1/n$	
Unit cell dimensions	a = 9.7096(3) Å	α= 90°.
	b = 7.1009(2) Å	β= 100.031(1)°.
	c = 26.6401(7) Å	γ = 90°.
Volume	1808.67(9) $Å^3$	
Z	4	
Density (calculated)	1.375 Mg/m^3	
Absorption coefficient	0.104 mm^{-1}	
F(000)	792	
Crystal size	0.478 x 0.440 x 0.162 mm	
Theta range for data collection	2.136 to 28.000°.	
Index ranges	-12<=h<=12, -9<=k<=9, -35<=l<=35	
Reflections collected	35963	
Independent reflections	4368 [R(int) = 0.0314]	
Completeness to theta = 25.242°	100.0 %	
Absorption correction	Semi-empirical from equivalents	
Max. and min. transmission	0.98 and 0.91	
Data / restraints / parameters	4368 / 0 / 248	
Goodness-of-fit on F^2	1.034	
Final R indices [I>2sigma(I)]	R1 = 0.0445, wR2 = 0.1103	
R indices (all data)	R1 = 0.0555, wR2 = 0.1182	
Largest diff. peak and hole	0.515 and -0.231 $e·Å^{-3}$	

Methyl -2,3,3-trimethoxy-2-(4-((8R,9S,13S,14S)-13-methyl-17-oxo-7,8,9,11,12,13, 14,15,16,17-decahydro-6*H*-cyclopenta[*a*]phenanthren-3-yl)phenyl)propanoate (13)



3l (50 mg, 0.15 mmol, 1.1 eq.) and K_3PO_4 (76 mg, 0.45 mmol, 3.0 eq.) were dissolved in H_2O (0.2 mL) and DMF (2 mL). The mixture was degassed and stirred at room temperature for 20 min. $Pd(PPh_3)_2Cl_2$ (3.0 mol%) and dppf (3.0 mol%) were added. The reaction mixture was stirred at 90 °C for 14 hours and allowed to cool down before it was quenched with H_2O (2 mL) and EtOAc (3 mL), extracted with EtOAc (3 x 10 mL), washed with brine and dried over Na_2SO_4. Concentration under reduced pressure and purification by flash chromatography (*n*-pentane: EtOAc = 20:1 → 4:1) yielded the title compound (63 mg, 0.124 mmol, 83%, *d.r.* 1:1) as a white solid.

^{1}H NMR (300 MHz, Chloroform-*d*) δ 7.60 – 7.54 (m, 4H), 7.44 – 7.29 (m, 3H), 4.86 (s, 1H), 3.86 (s, 3H), 3.53 (s, 3H), 3.46 (s, 3H), 3.43 (s, 3H), 2.99 (dd, *J* = 9.1, 4.4 Hz, 2H), 2.61 – 2.42 (m, 2H), 2.36 (td, *J* = 10.6, 4.3 Hz, 1H), 2.25 – 1.85 (m, 4H), 1.77 – 1.39 (m, 6H), 0.93 (s, 3H).

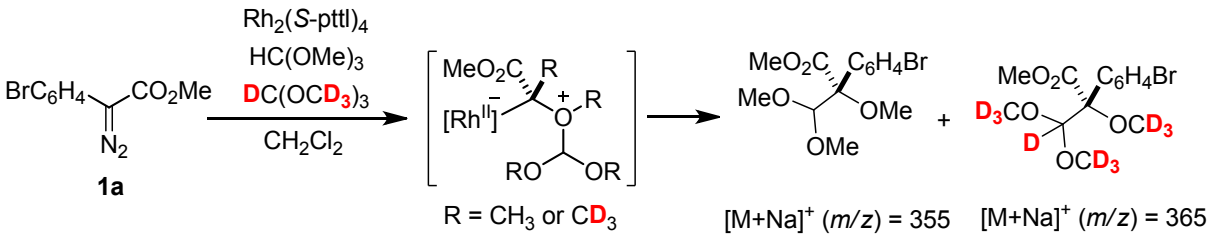
^{13}C NMR (75 MHz, Chloroform-*d*) δ 221.0 (C_q), 140.8 (C_q), 139.1 (C_q), 138.4 (C_q), 136.9 (C_q), 133.9 (C_q), 128.5 (CH), 127.8 (CH), 126.5 (CH), 125.9 (CH), 124.7 (CH), 108.7 (CH), 87.2 (C_q), 58.4 (CH_3), 58.0 (CH_3), 54.8 (CH_3), 52.4 (CH_3), 50.7 (CH), 48.1 (C_q), 44.5 (CH), 38.3 (CH), 36.0 (CH_2), 31.7 (CH_2), 29.7 (CH_2), 26.7 (CH_2), 25.9 (CH_2), 21.7 (CH_2), 14.0 (CH_3).

MS (GC-MS (EI)) *m/z* (relative intensity) = 506 (1) [M^+], 475 (8), 444 (76), 431 (68), 373 (58), 357 (66), 75 (100).

HRMS (ESI-TOF, m/z) calcd. For $C_{31}H_{38}O_6$ $[M+Na]^+$: 529.2561; found: 529.2565.

IR (ATR, neat, cm^{-1}): 2929 (w), 2832 (w), 1735 (s), 1252 (m), 1189 (m), 1106 (s), 1083 (s), 985 (m), 801 (m).

Intermolecular competition experiment H_9- *vs.* D_{10}-trimethylorthoformate

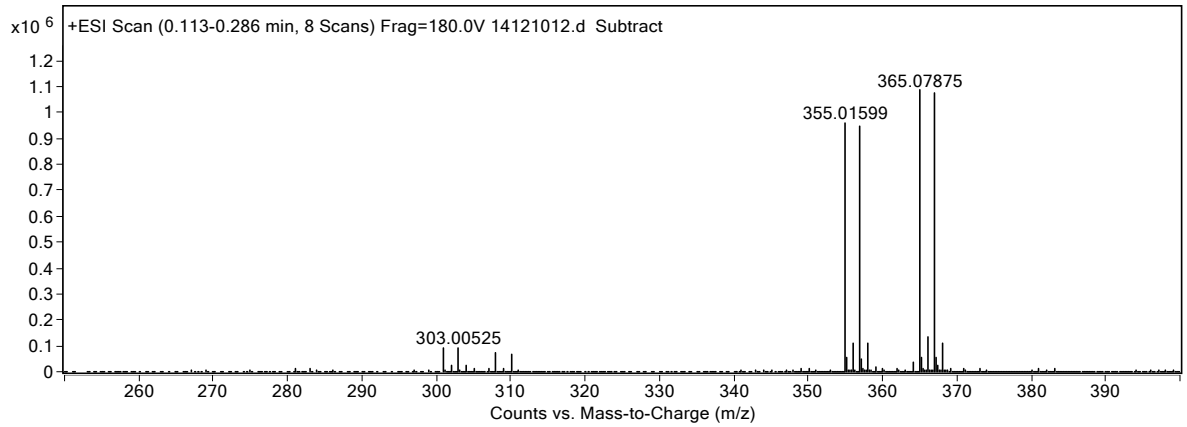


Representative Procedure using CH_2Cl_2: Over the course of 20 min and under an atmosphere of argon, a 0.2 M solution of alkyl 2-4-bromophenyl-2-diazoacetate **1a** (10 mg, 0.4 mmol, 1.0 equiv.) and a mixture of $HC(OMe)_3/DC(OCD_3)_3$ (1:1, 20 mg) in dichloromethane (0.2 mL) was added drop-wise to a stirring solution of Rh_2(*S*-pttl)$_4$ (0.5 mg, 1.0 mol%) and a mixture of $HC(OMe)_3/DC(OCD_3)_3$ (1:1, 20 mg) in dichloromethane (0.1 mL) at room temperature. The crude mixture was concentrated and analyzed by GC and ESI-MS.

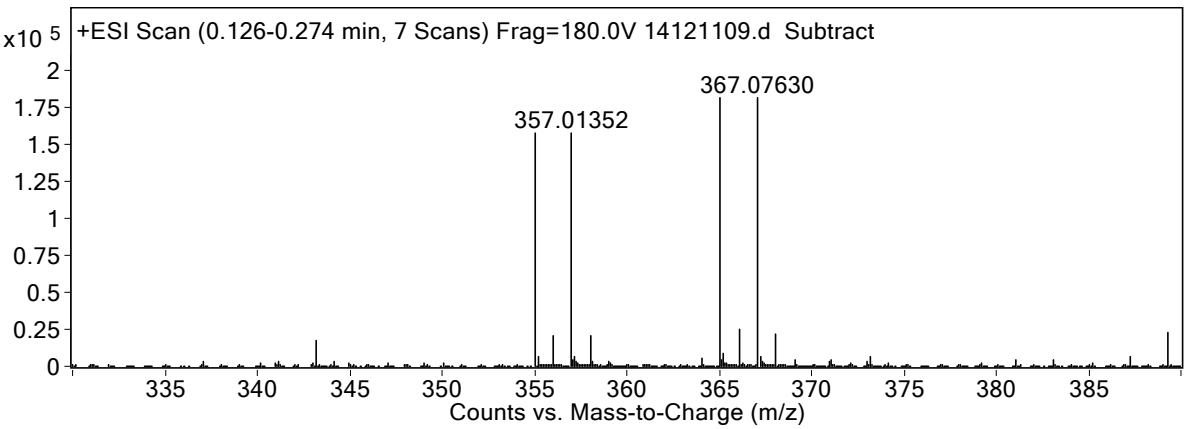
HRMS (ESI-TOF, m/z) calcd. For $C_{13}H_{17}Br_2O_2$ $[M+Na]^+$: 355.0152; found: 355.0153.

HRMS (ESI-TOF, m/z) calcd. For $C_{13}H_7D_{10}Br_2O_2$ $[M+Na]^+$: 365.0785; found: 365.0780.

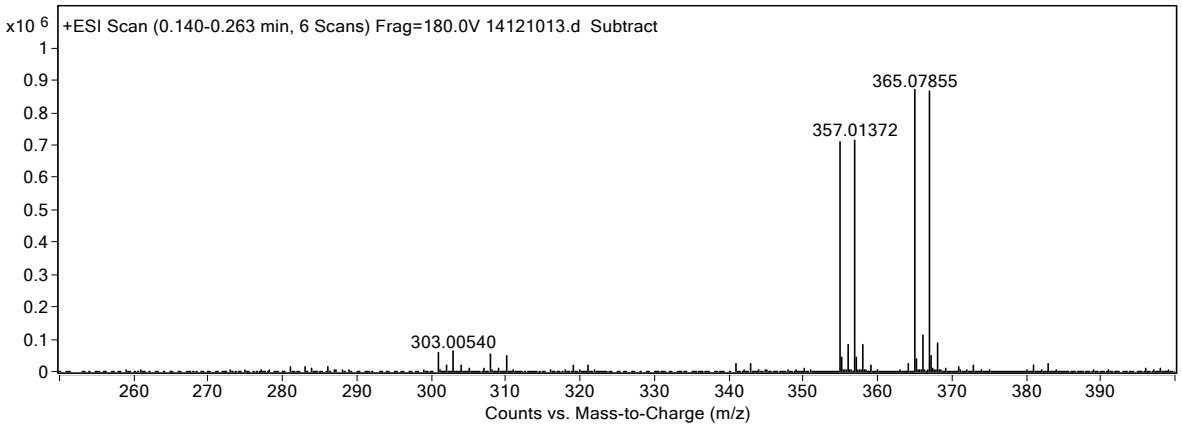
Dichloromethane:



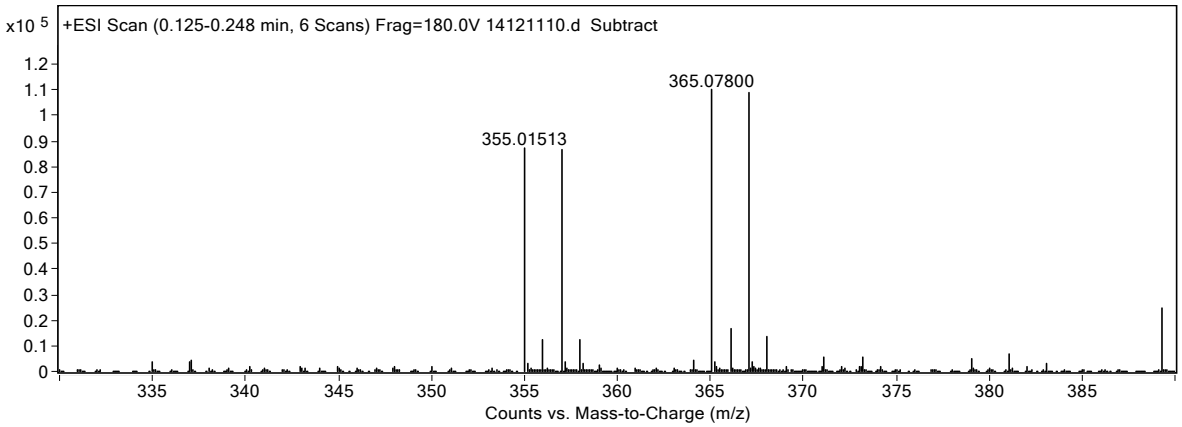
Chlorobenzene:



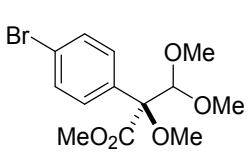
Toluene:



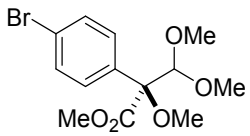
***n*-heptane:**



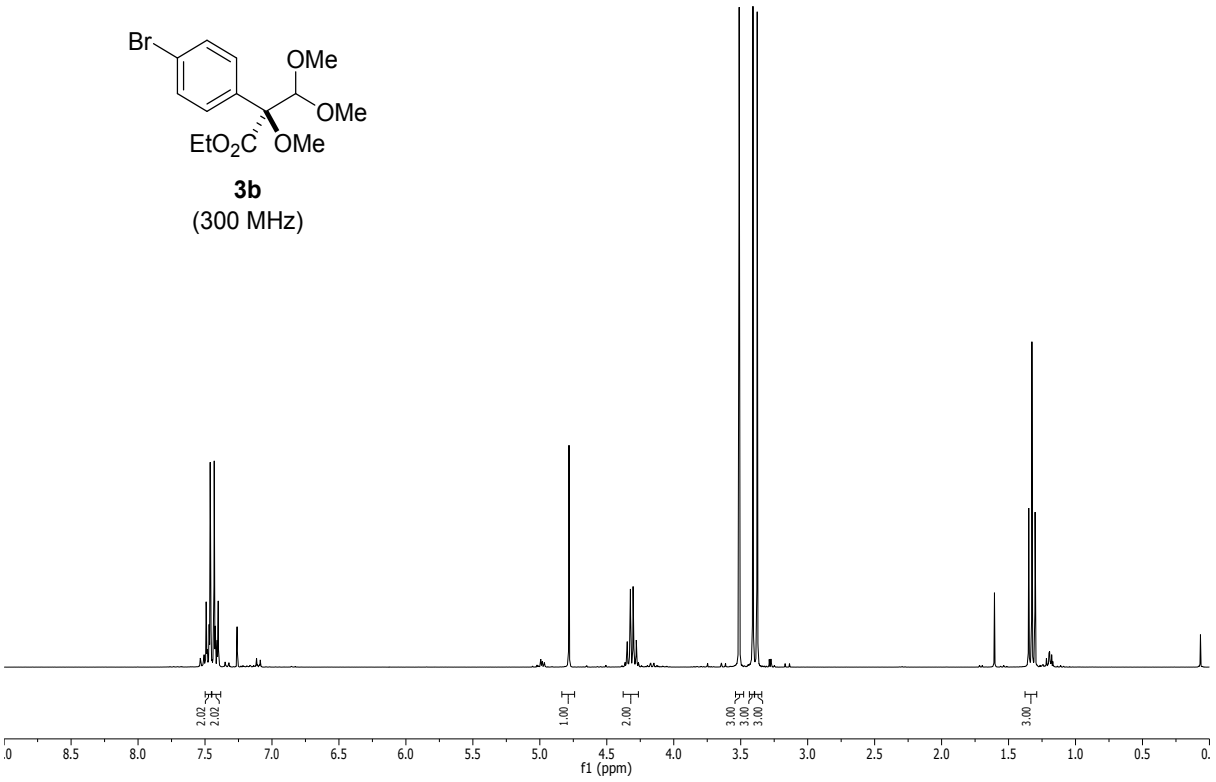
^{1}H-NMR and ^{13}C-NMR spectra of compounds

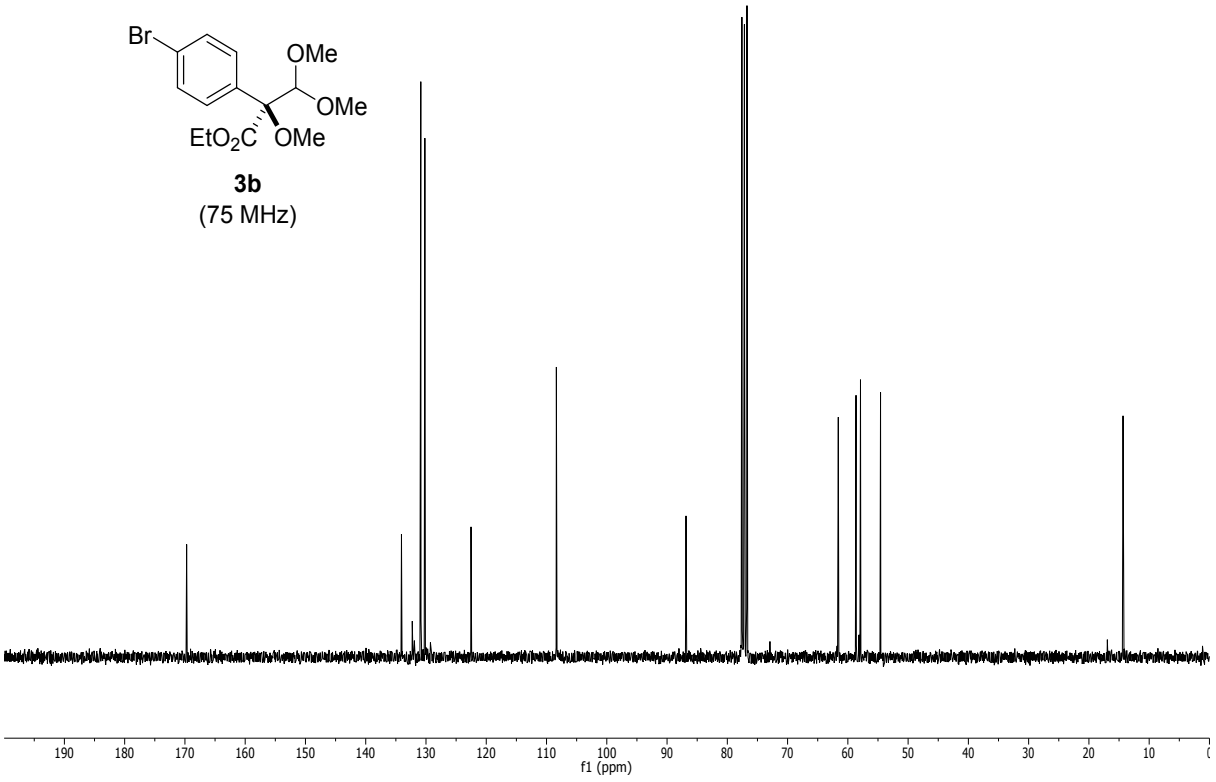


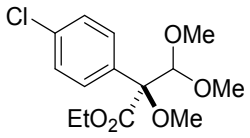
3a
(500 MHz)



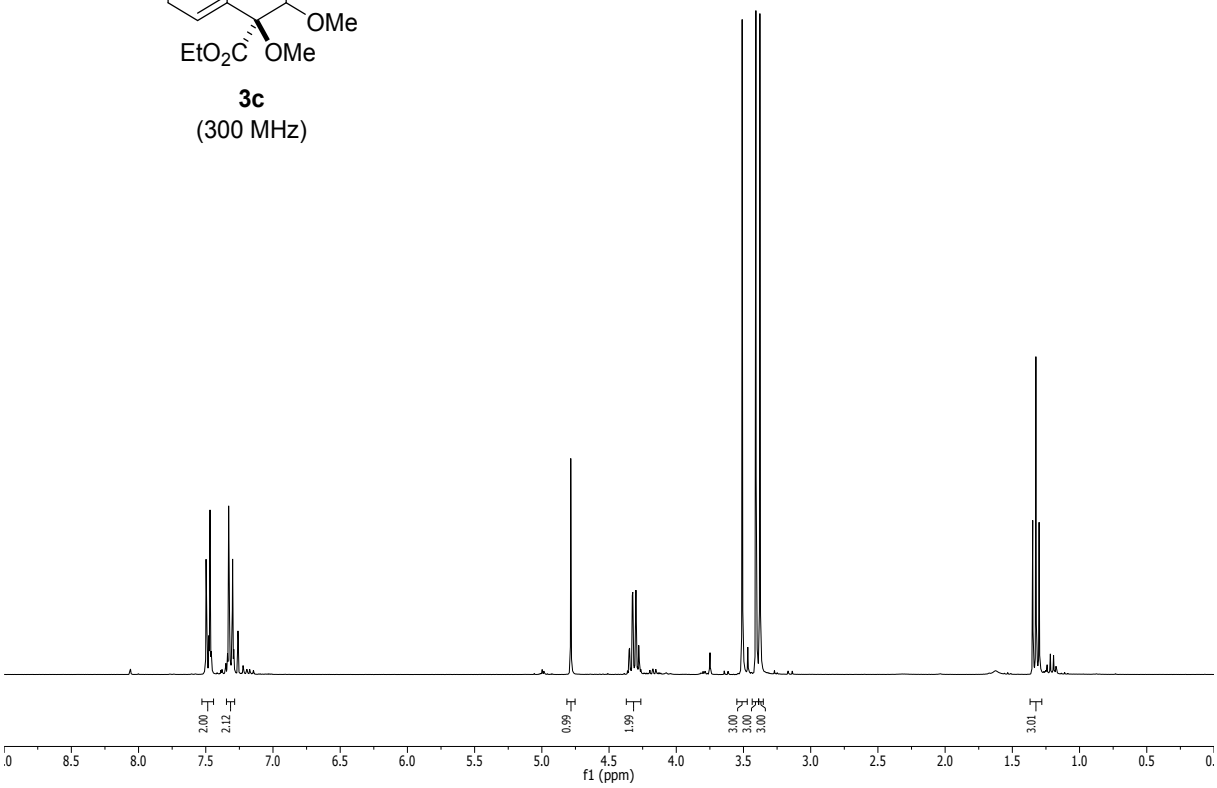
3a
(125 MHz)

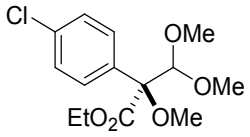

Br
OMe
OMe
EtO2C
OMe
3b
(300 MHz)
2.02
2.02
1.00
2.00
3.00
3.00
3.00
3.00
f1 (ppm)


Br
OMe
OMe
EtO2C
OMe
3b
(75 MHz)
f1 (ppm)

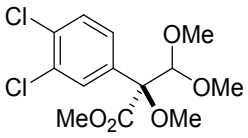


3c
(300 MHz)

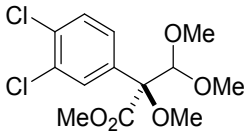




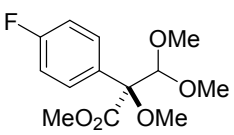
3c
(75 MHz)



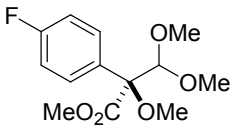
3d
(300 MHz)



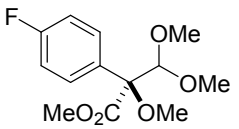
3d
(75 MHz)



3e
(300 MHz)

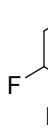


3e
(75 MHz)

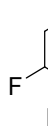

F
OMe
OMe
MeO2C
OMe

3e
(128 MHz)

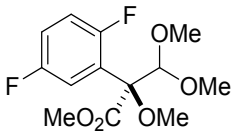
-55
-60
-65
-70
-75
-80
-85
-90
-95
-100
-105
-110
-115
-120
-125
-130
-135
-140
-145
-150
-155
-160
-165
-170
-175
f1 (ppm)



3f
(300 MHz)

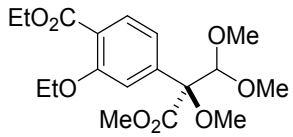


3f
(75 MHz)

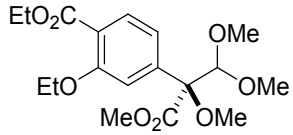

F
OMe
F
OMe
MeO2C
OMe

3f
(128 MHz)

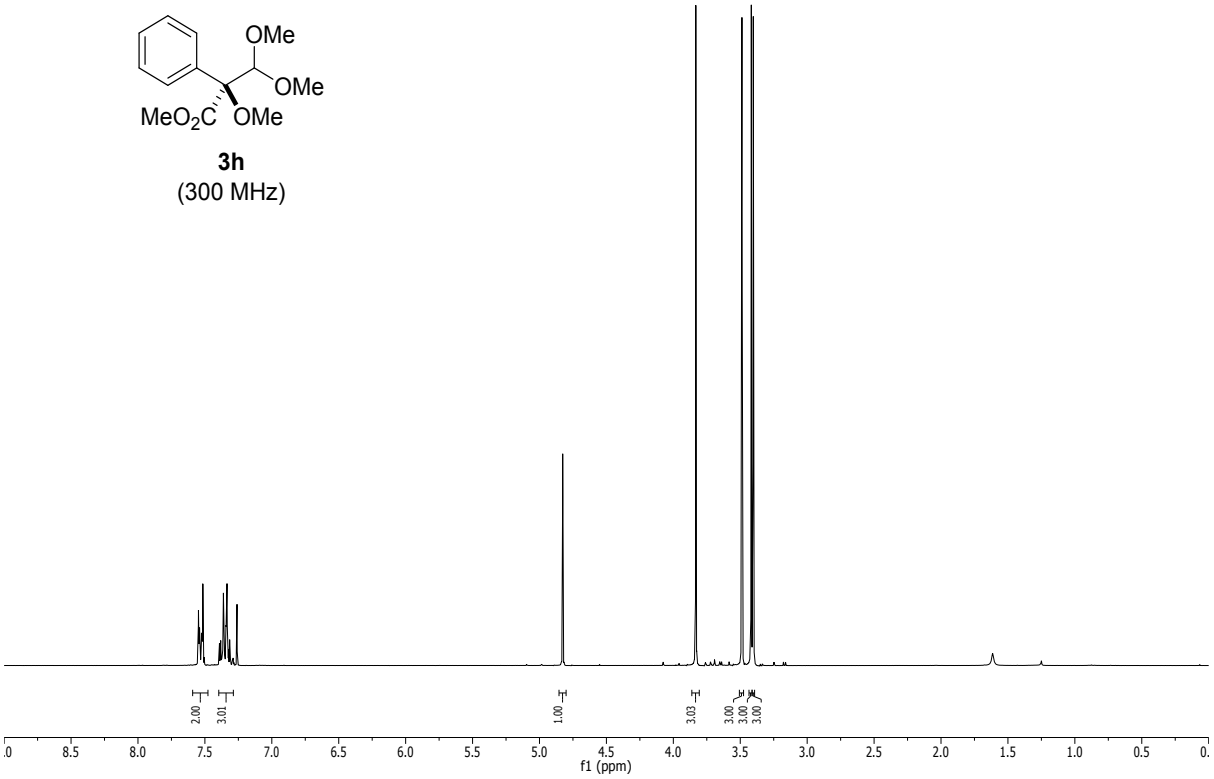
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
-150
-160
-170
-180
-190
f1 (ppm)

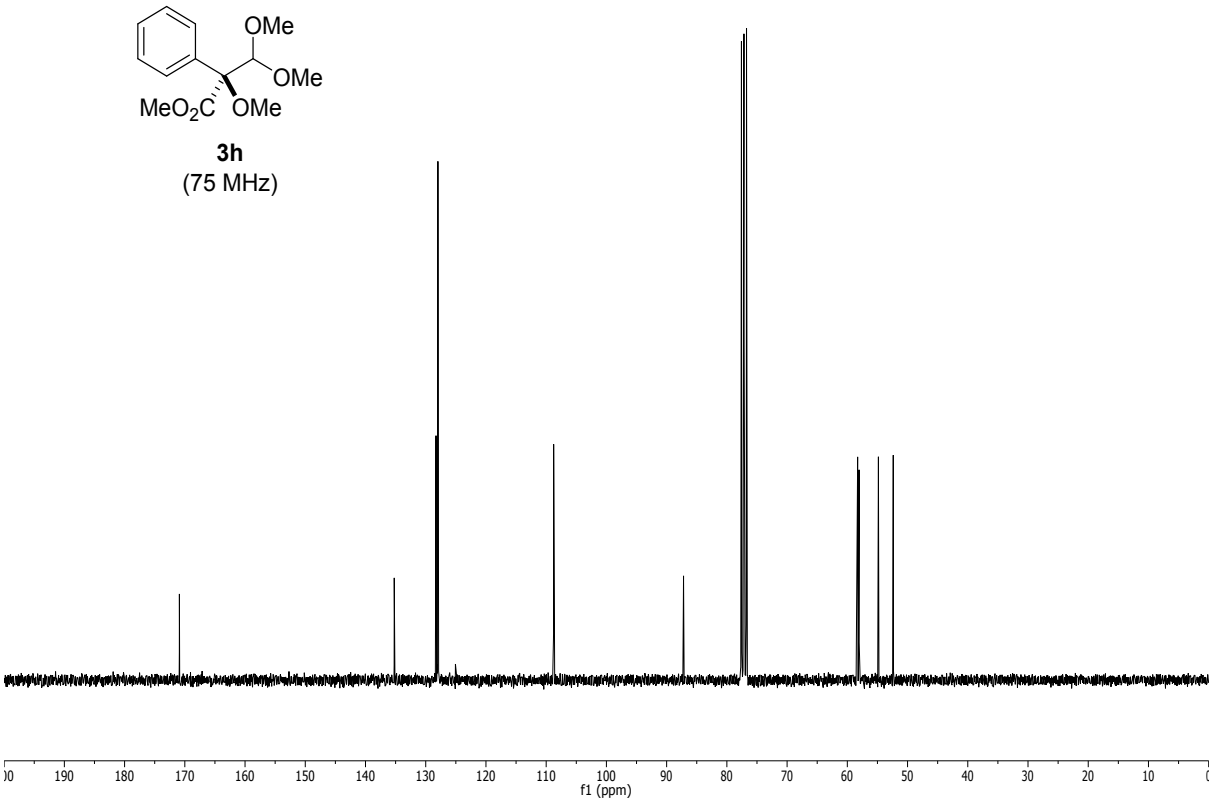


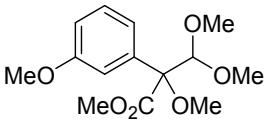
3g
(300 MHz)



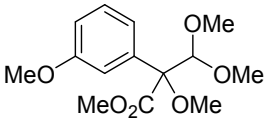
3g
(75 MHz)


OMe
OMe
MeO2C OMe
3h
(300 MHz)
2.00
3.01
1.00
3.03
3.00
3.00
3.00
f1 (ppm)

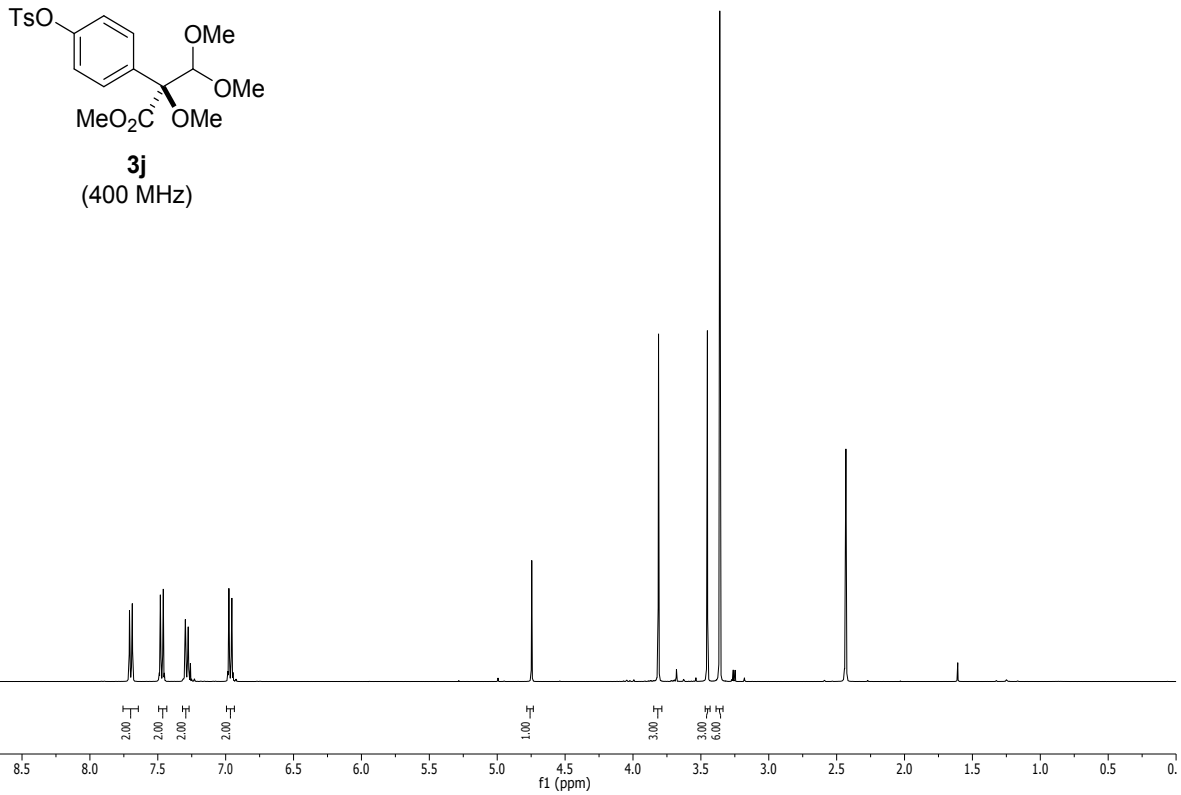

OMe
OMe
MeO2C OMe
3h
(75 MHz)
f1 (ppm)

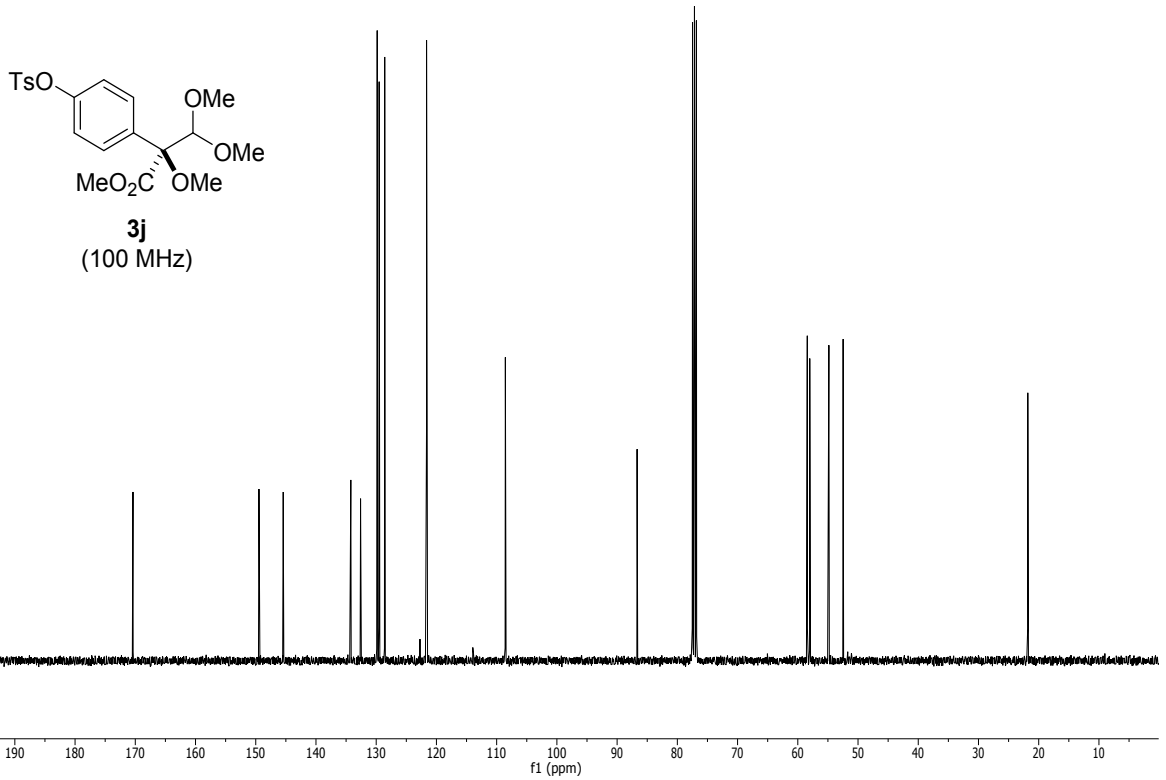


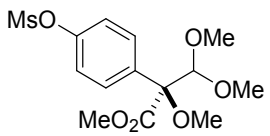
3i
(300 MHz)



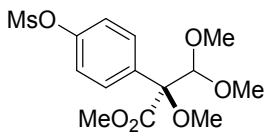
3i
(75 MHz)


TsO
OMe
OMe
MeO2C
OMe
3j
(400 MHz)
2.00
2.00
2.00
2.00
1.00
3.00
3.00
6.00
f1 (ppm)

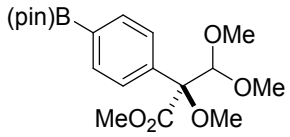

TsO
OMe
OMe
MeO2C
OMe
3j
(100 MHz)
f1 (ppm)



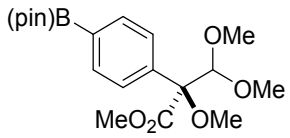
3k
(300 MHz)



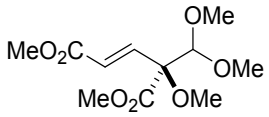
3k
(75 MHz)



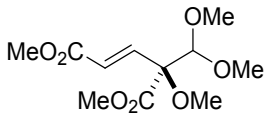
3l
(300 MHz)



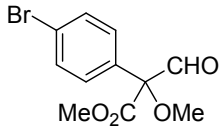
3l
(75MHz)



7
(500 MHz)

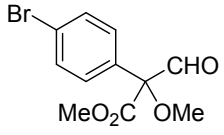


7
(125 MHz)



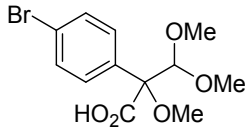
8

(300 MHz)



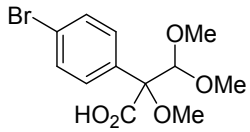
8

(75 MHz)



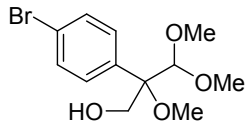
9

(400 MHz)

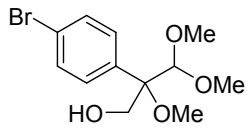


9

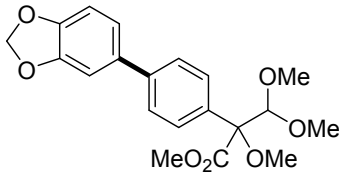
(100 MHz)



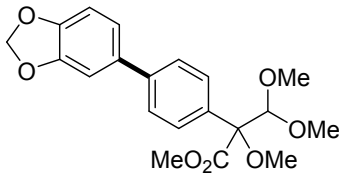
10
(300 MHz)



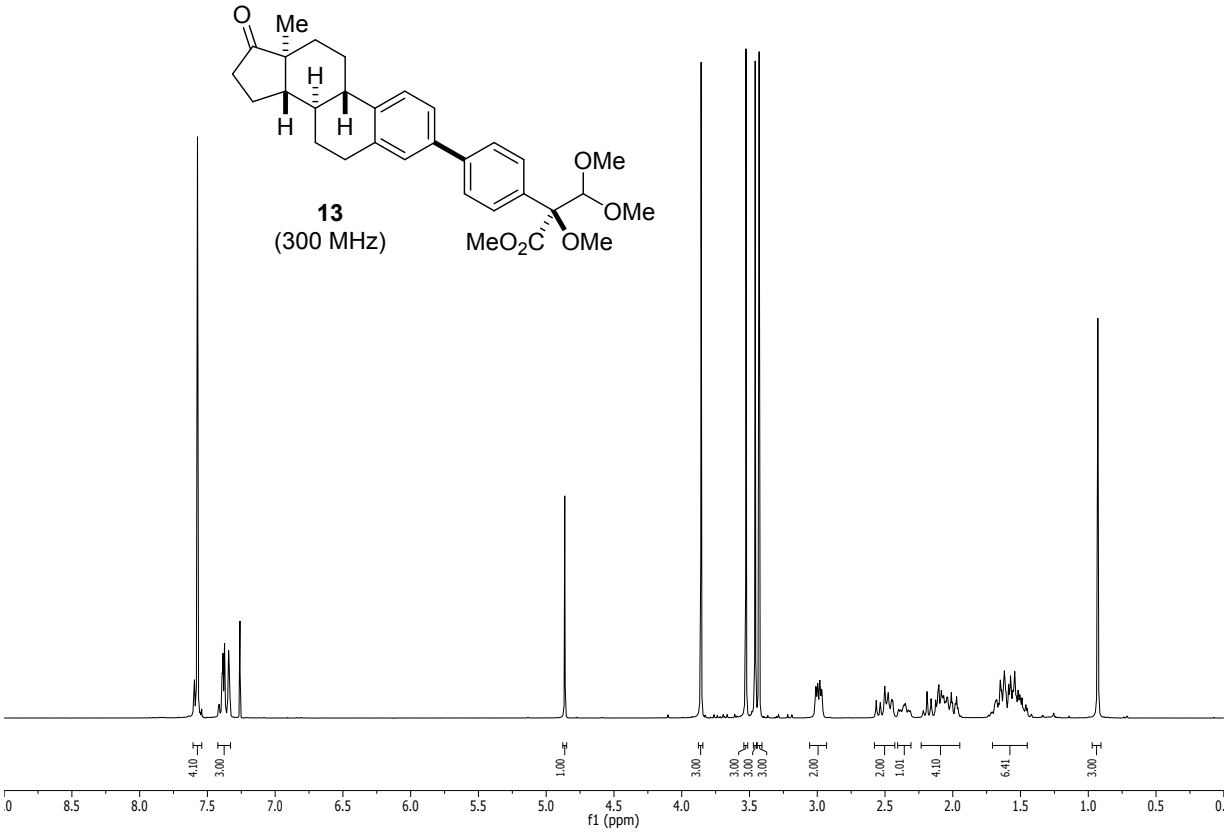
10
(75 MHz)

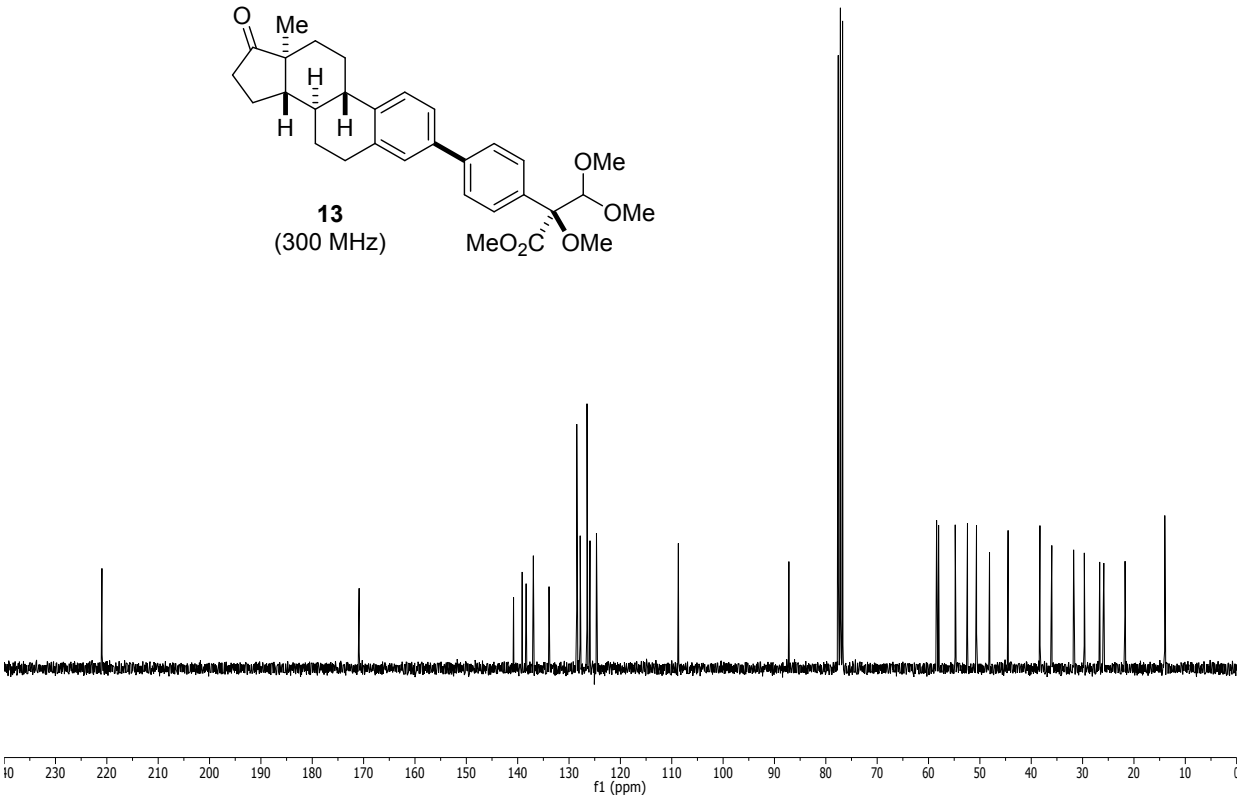


11
(300 MHz)



11
(300 MHz)


O
Me
H
H
H
OMe
OMe
MeO2C
OMe
13
(300 MHz)
4.10
3.00
1.00
3.00
3.00
3.00
3.00
2.00
2.00
1.01
4.10
6.41
3.00
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)


O
Me
H
H
H
OMe
OMe
MeO2C
OMe
13
(300 MHz)
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

References

[1] H. M. L. Davies, T. Hansen, M. R. Churchill, *J. Am. Chem. Soc.* **2000**, *122*, 3063–3070.

[2] X. Zhang, Z. Sui, *Tetrahedron* **2003**, *44*, 3071–3073.

[3] P. P. T. Sah, T. S. Ma, *J. Am. Chem. Soc.* **1932**, *54*, 2964–2966.

[4] I. J.S. Fairlamb, A. F. Lee, F. E.M. Loe-Mie, E. H. Niemelä, C. T. O'Brien, A. C. Whitwood, *Tetrahedron*, **2005**, 61, 9827-9838

[5] N. S. Y. Loy, A. Singh, X. Xu, C.-M. Park, *Angew. Chem. Int. Ed.* **2013**, 52, 2212 –2216

[6] A. Ni , J. E. France , H. M. L. Davies*, J. Org. Chem*., **2006**, 71, 5594–5598