

Scalable and Chemoselective Synthesis of γ -Keto Esters and Acids *via* Pd-Catalyzed Carbonylation of Cyclic β -Chloro Enones

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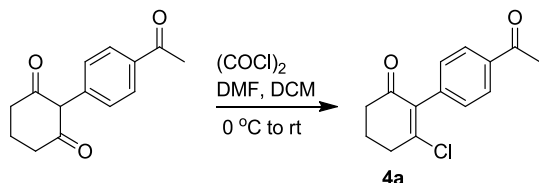
Supporting Information

Table of Contents

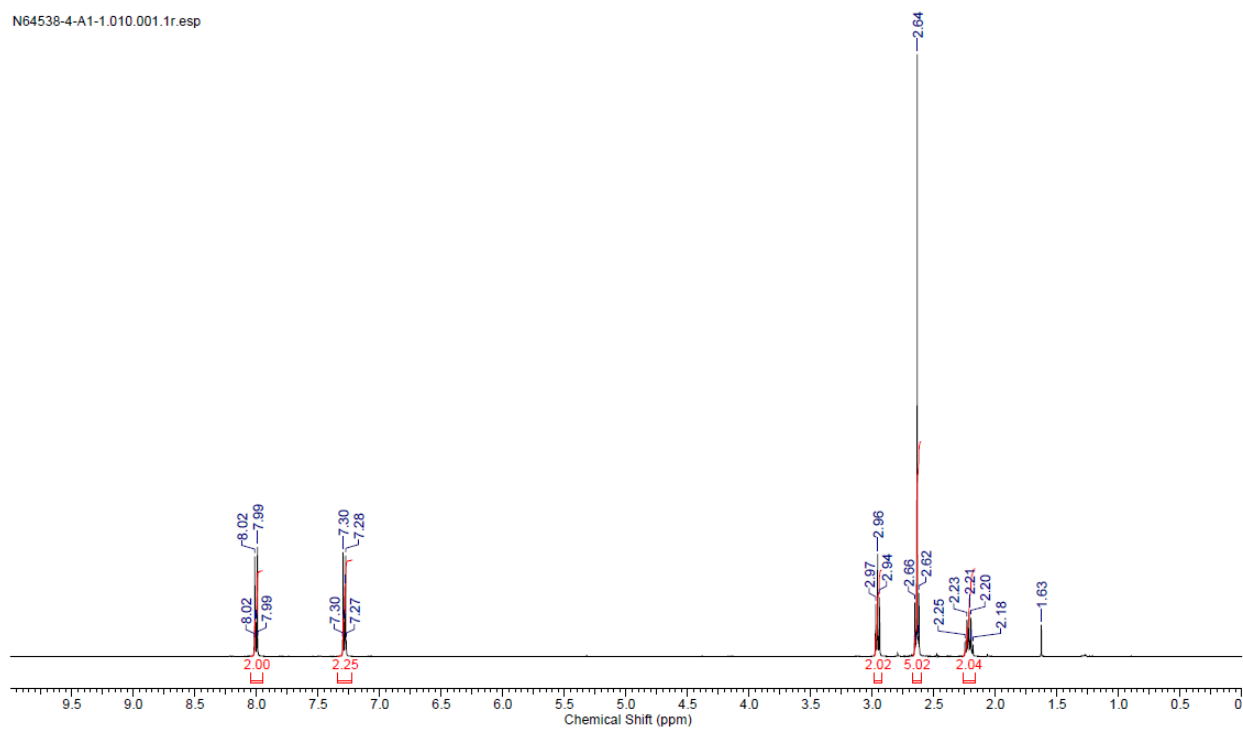
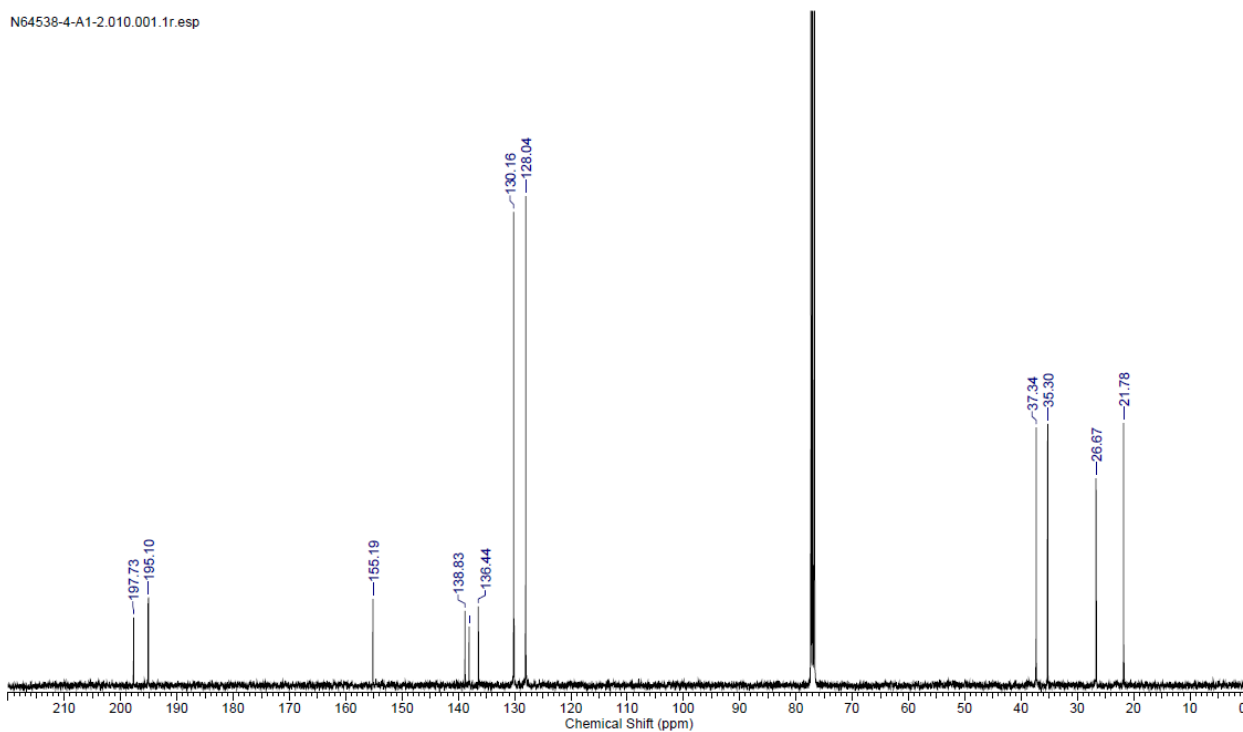
I: Preparation of Substrates.....	S2
General.....	S2
Synthesis of 4a	S2
Synthesis of 6a	S5
Synthesis of 7a	S8
Synthesis of 8a	S11
II: High-Throughput Screening.....	S17
Screen 1 (from Figure 1, Main Text).....	S17
Screen 2 (from Figure 2, Main Text).....	S25
III: Preparative-Scale Carbonylations.....	S37
Characterization of Products.....	S37
Large-Scale Preparation of 1b	S102
IV: Mechanistic Studies.....	S106
Reaction Profile Curves.....	S106
Synthesis of 1m	S113
Oxidative Addition Studies.....	S114
Characterization Data for 11	S123
Characterization Data for 12	S129
V: X-Ray Crystallography.....	S133
VI: References.....	S151

I: Preparation of Substrates

General: The following substrates are known compounds, and were prepared using literature procedures: **1a**,¹ **2a**,¹ **3a**,¹ and **5a**.¹



Synthesis of 4a: This compound was prepared in an analogous fashion to **1a** using the literature protocol¹ from the known² dione: 2-(4-acetylphenyl)cyclohexane-1,3-dione (1.40 g, 6.08 mmol) was added to a 40 mL vial containing a stirbar and dissolved in dichloromethane (10 mL). The vial was cooled to 0 °C. *N,N*-dimethylformamide (0.511 g, 0.54 mL, 6.99 mmol) was added via syringe. Oxalyl chloride (0.810 g, 0.56 mL, 6.38 mmol) was dissolved in DCM (5 mL). This solution was added dropwise via syringe to the stirring solution of the dione/DMF. After addition was complete, the vial was warmed to room temperature. The reaction mixture was stirred for one hour, and reaction progress assessed by analysing an aliquot by LCMS, which indicated complete consumption of the starting material. Water (15 mL) was added to quench the reaction, and the layers mixed. The aqueous phase was removed, and the organic phase concentrated under vacuum. The residue was redissolved in ethyl acetate (15 mL), and washed with water (5 x 15 mL). The organic phase was then dried over MgSO₄. After filtration, the solvent was removed under vacuum to give a suspension of a tan-coloured solid in a dark red liquid phase. Addition of hexanes further precipitated the tan solid, which was collected by filtration and washed with hexanes to give **4a** (1.33 g, 88% yield). ¹H NMR (400 MHz, CDCl₃) δ ppm 2.18 - 2.25 (m, 2 H) 2.62 - 2.66 (m, 2 H) 2.64 (s, 3 H) 2.96 (t, *J* = 6.2 Hz, 2 H) 7.27 - 7.30 (m, 2 H) 7.99 - 8.02 (m, 2 H). ¹³C{¹H} NMR (101 MHz, CDCl₃) δ ppm 21.78, 26.67, 35.30, 37.34, 128.04, 130.16, 136.44, 138.12, 138.83, 155.19, 195.10, 197.73 (s, 1 C). LRMS (ESI): *m/z* = 249 / 251 [M+H]⁺; 290 / 292 [M+H+CH₃CN]⁺.

Figure S1: ¹H NMR spectrum of 4a.Figure S2: ¹³C{¹H} NMR spectrum of 4a.

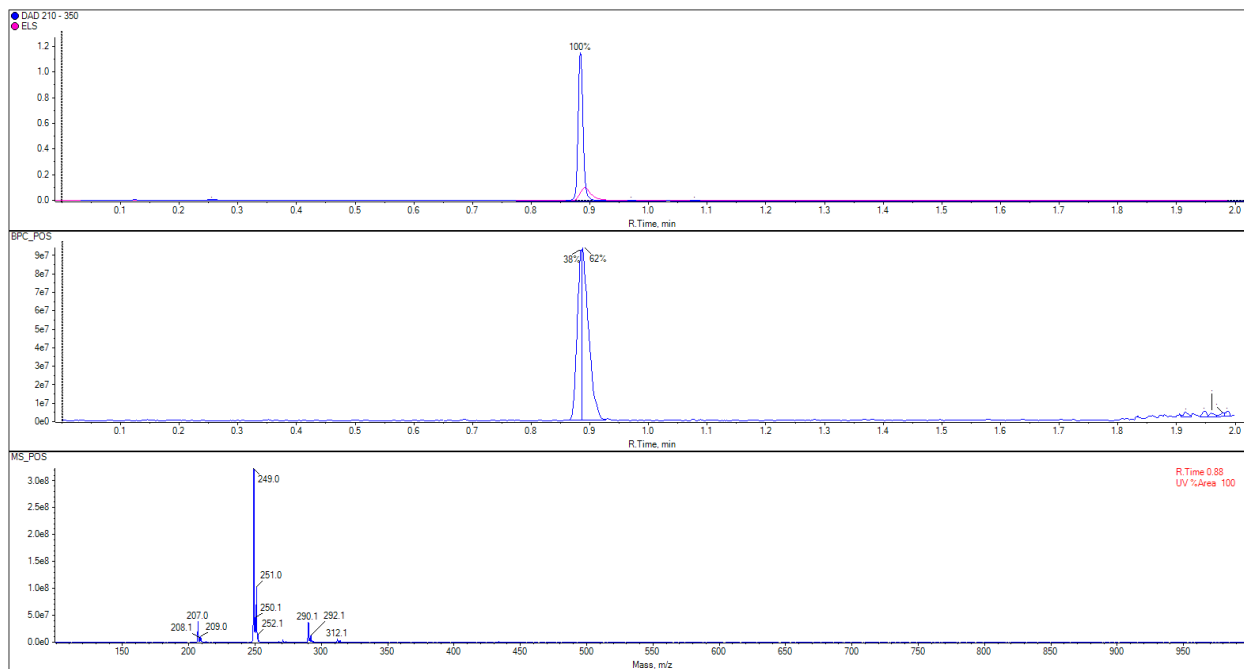
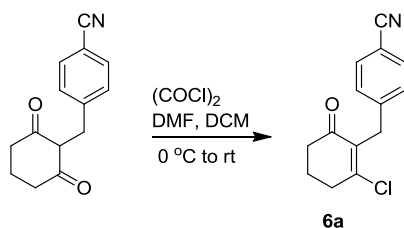


Figure S3: LCMS trace of 4a.



Synthesis of 6a: This compound was prepared in an analogous fashion to **1a** using the literature protocol¹ from the known³ dione: A 3-necked 250 mL round-bottomed flask was charged with a stirbar. 2-(4-Cyanobenzyl)cyclohexane-1,3-dione (10 g, 44.0 mmol) was slurried in 75 mL DCM with stirring in the flask, which was cooled to 0 °C. *N,N*-dimethylformamide (4.09 mL, 52.8 mmol) was added via syringe. An addition funnel was charged with oxalyl chloride (4.24 mL, 48.4 mmol) and 25 mL DCM. The funnel was fitted to the middle neck of the flask, while the other two necks were left open to ensure efficient venting of evolved gases. The oxalyl chloride solution was added dropwise over 15 minutes to the stirring reaction mixture. The reaction mixture remains heterogeneous throughout. The mixture was warmed to room temperature, which resulted in complete dissolution. The addition funnel was filled with 50 mL water, which was added slowly to the stirring reaction mixture. After the addition was complete, stirring was stopped and the layers allowed to settle. The phases were separated in a separatory funnel. The volatiles were removed from the organic phase in vacuo, and the crude residue redissolved in TBME (100 mL). This solution was washed with water (3 x 100 mL), 1:1 brine/water (100 mL total), dried over MgSO₄, filtered, and concentrated in vacuo to give a pale orange oil that solidified on standing at -20 °C. Isolated yield: 10.40 g (96%). ¹H NMR (400 MHz, CDCl₃) δ ppm 2.08 (quin, *J* = 6.5 Hz, 2 H), 2.46 - 2.53 (m, 2 H), 2.83 (t, *J* = 6.2 Hz, 2 H), 3.85 (s, 2 H), 7.38 (d, *J* = 8.0 Hz, 2 H), 7.56 (dt, *J* = 8.0, 2.0 Hz, 2 H). ¹³C{¹H} NMR (101 MHz, CDCl₃) δ ppm 21.79, 32.46, 35.11, 37.10 (s, 1 C), 110.04, 119.06, 129.59, 132.15, 135.80, 144.58, 155.58, 195.81 (C=O). LRMS (ESI): *m/z* = 246 / 248 [M+H]⁺.

N59767-64.010.001.1r.esp

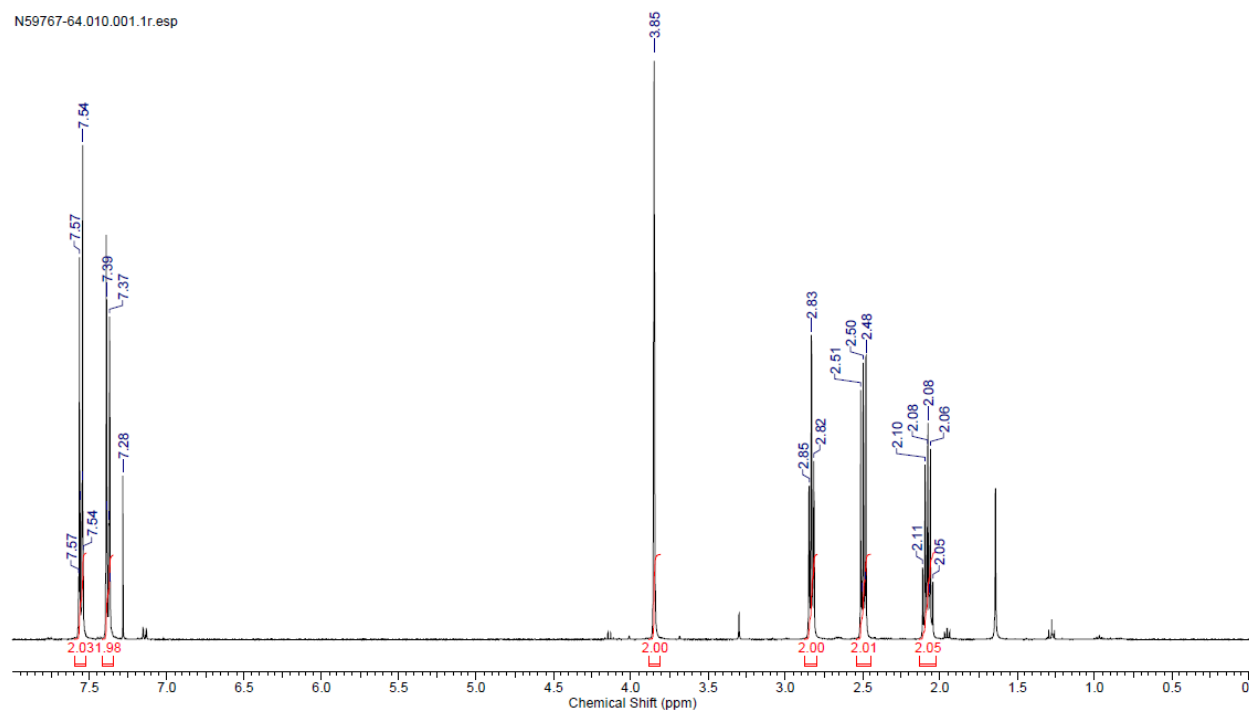


Figure S4: ¹H NMR spectrum of 6a.

N59767-64.021.001.1r.esp

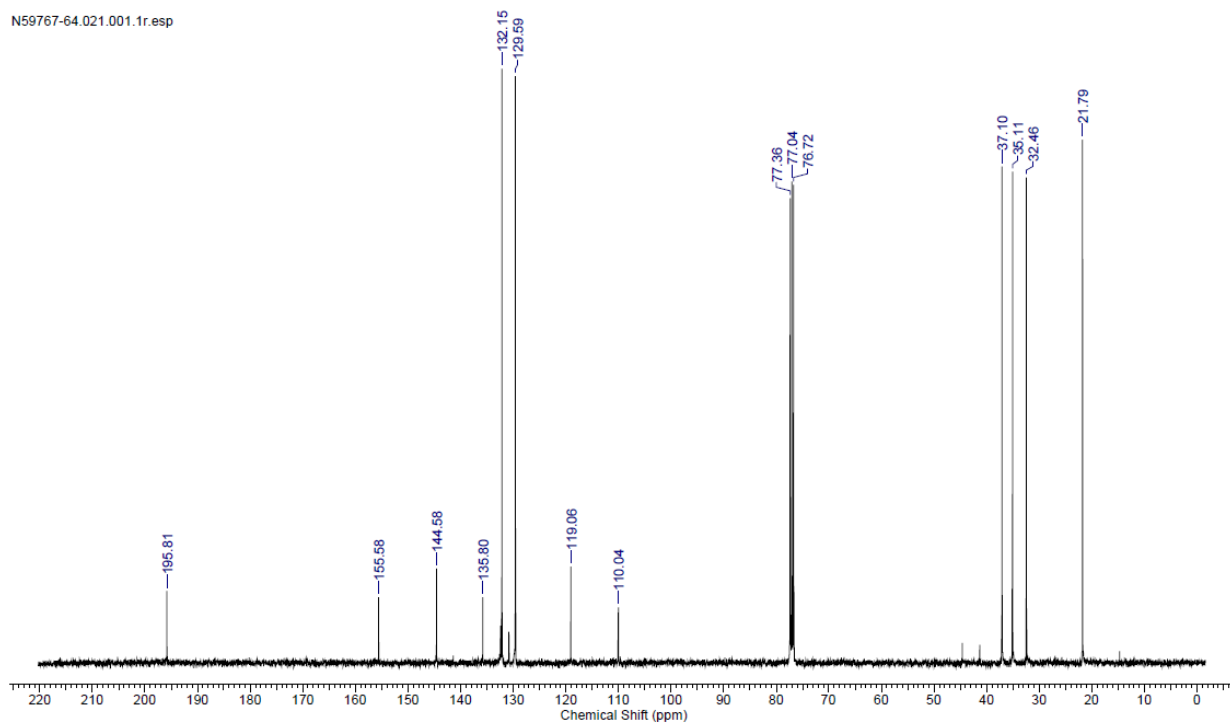


Figure S5: ¹³C{¹H} NMR spectrum of 6a.

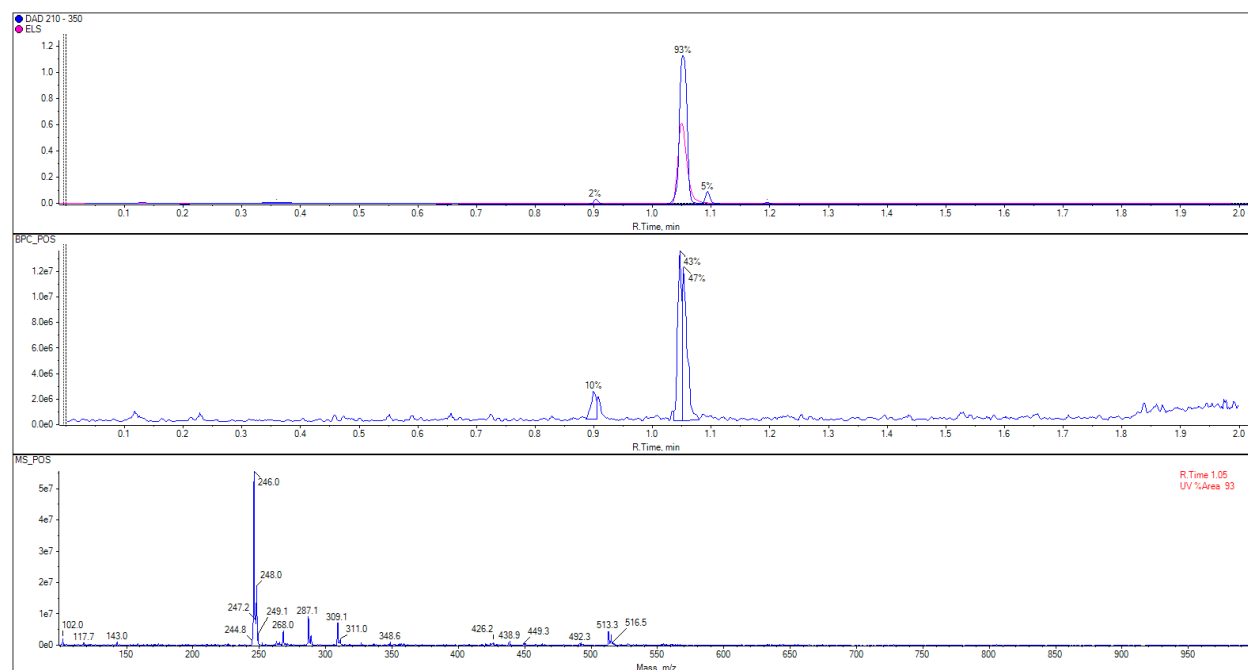
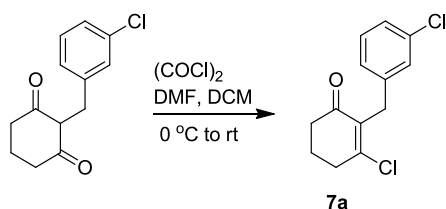


Figure S6: LCMS trace of 6a.



Synthesis of 7a: This compound was prepared in an analogous fashion to **1a** using the literature protocol¹ from the known⁴ dione: A 3-necked 100 mL round-bottomed flask was charged with a stirbar. 2-(3-Chlorobenzyl)cyclohexane-1,3-dione (4.0 g, 16.90 mmol) was slurried in 40 mL DCM with stirring in the flask, which was cooled to 0 °C. *N,N*-dimethylformamide (1.570 mL, 20.28 mmol) was added via syringe to the tan suspension. Oxalyl chloride (1.627 mL, 18.59 mmol) was added dropwise via syringe through a rubber septum over 15 minutes; the other two necks of the flask were left open to ensure venting of the evolved gases. Once the addition was complete, the reaction mixture was warmed to room temperature with stirring. The reaction was quenched by slow addition of water (40 mL) with thorough mixing for 10-15 minutes. The stirring was stopped to allow the layers to settle, followed by separation of the phases in a separatory funnel. The organic phase was dried over MgSO₄, filtered, and the solvent removed *in vacuo*. The resulting residue was redissolved in TBME (50 mL), washed with water (3 x 50 mL), 1:1 brine/water (50 mL total), dried over MgSO₄, filtered, and the solvent removed. The resulting pale yellow oil solidified on standing at -20 °C. Isolated yield: 4.10 g (95%). ¹H NMR (400 MHz, CDCl₃) δ ppm 1.98 (quin, *J* = 6.5 Hz, 2 H) 2.40 (dd, *J* = 6.5, 6.2 Hz, 2 H) 2.73 (t, *J* = 6.2 Hz, 2 H) 3.69 (s, 2 H) 7.04 - 7.14 (m, 3 H) 7.17 (s, 1 H). ¹³C{¹H} NMR (101 MHz, CDCl₃) δ ppm 21.83, 31.92, 35.12, 37.18, 126.36, 127.09, 128.81, 129.50, 134.01, 136.30, 140.94, 155.07, 195.89. LRMS (ESI): *m/z* = 255 / 257 / 259 [M+H]⁺.

N59767-66.010.001.1r.esp

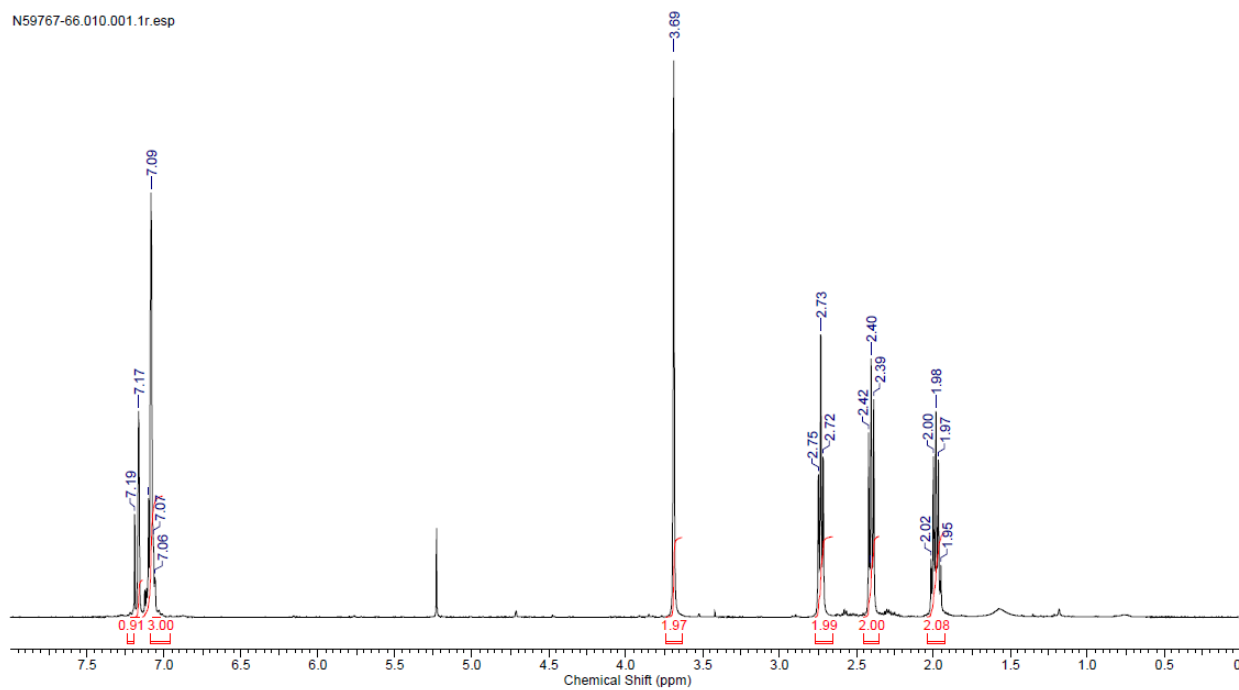


Figure S7: ¹H NMR spectrum of 7a.

N59767-66.011.001.1r.esp

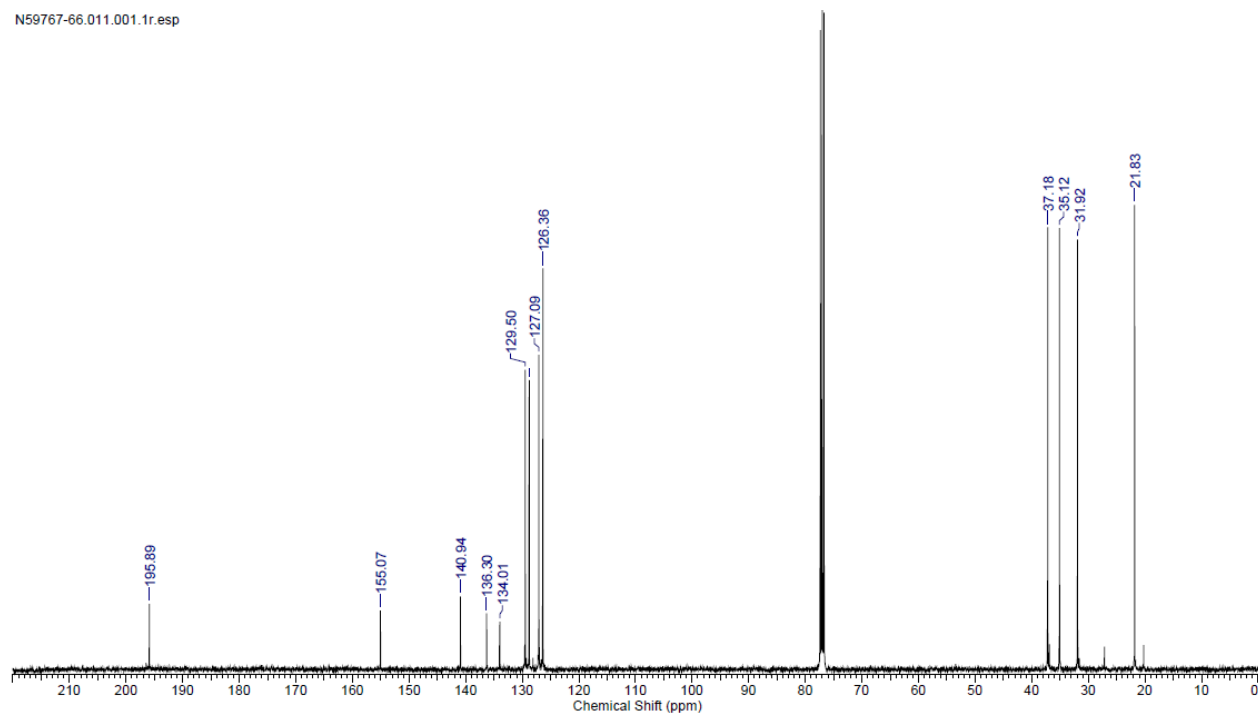


Figure S8: ¹³C{¹H} NMR spectrum of 7a.

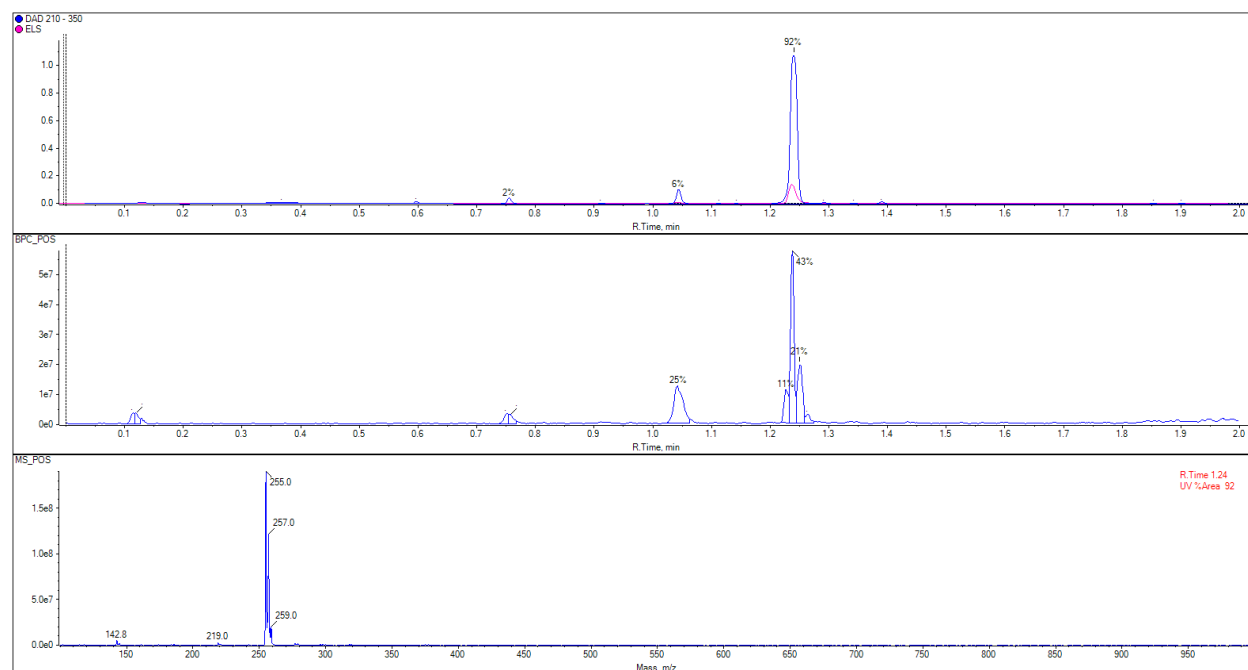
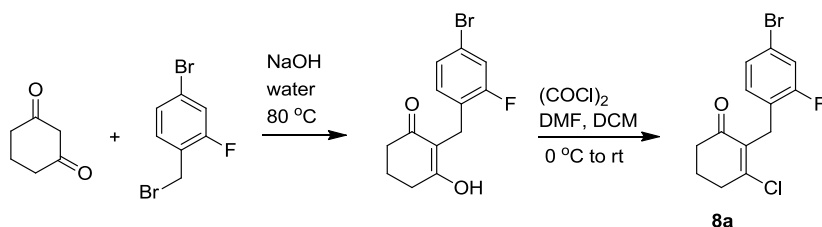


Figure S9: LCMS trace of **7a**.

Synthesis of 8a:



Synthesis of 2-(4-bromo-2-fluorobenzyl)cyclohexane-1,3-dione: Cyclohexane-1,3-dione (4.49 g, 40 mmol) was dissolved in 1 M sodium hydroxide (40.0 mL, 40 mmol) in a 250 mL round-bottomed flask containing a stirbar. 4-Bromo-1-(bromomethyl)-2-fluorobenzene (11.25 g, 42.0 mmol) was added as a solid to the stirring solution. The flask was fitted with a condenser cooled with a stream of compressed air. The reaction mixture was heated to 80 °C and stirred overnight. The next morning, the mixture was dilute with water to ensure all of the solids are slurried in solution, and the flask cooled to room temperature. A white globular solid was observed in the bottom of the solution after cooling. This material was filtered using vacuum suction, and dried for several hours. The solid was washed with 20 mL TBME without suction to give a yellow/orange filtrate and a cream-white solid. The solid was dried *in vacuo*, giving 7.80 g (65% yield) of the dione (100% area by LCMS). ¹H and ¹³C{¹H} NMR spectroscopy in CD₃OD reveals the compound exists as the enol tautomer (shown above), but exhibiting symmetry, indicative of rapid exchange on the NMR timescale. ¹H NMR (400 MHz, CD₃OD) δ ppm 2.02 (quin, *J* = 6.5 Hz, 2 H, -CH₂-CH₂-CH₂-), 2.49 (t, *J* = 6.5 Hz, 4 H, 2 x -CH₂-C=O), 3.57 (s, 2 H, -CH₂-Ar), 7.00 (t, *J* = 8.1 Hz, 1 H, Ar-*H*), 7.15 - 7.24 (m, 2 H, 2 x Ar-*H*). ¹⁹F{¹H} NMR (376 MHz, CD₃OD) δ ppm -116.68. ¹³C{¹H} NMR (101 MHz, CD₃OD) δ ppm 19.40 (d, *J* = 3.8 Hz), 20.53, 32.35 (br), 112.46, 117.71 (d, *J* = 26.1 Hz), 118.39 (d, *J* = 9.5 Hz), 126.52 (d, *J* = 3.4 Hz), 127.41 (d, *J* = 15.8 Hz), 130.85 (d, *J* = 5.1 Hz), 160.82 (d, *J* = 248.5 Hz, C-F), carbonyl/enol carbons not observed, likely due to exchange on NMR time scale, and low S/N due to poor solubility. LRMS (ESI): *m/z* = 299 / 301 [M+H]⁺.

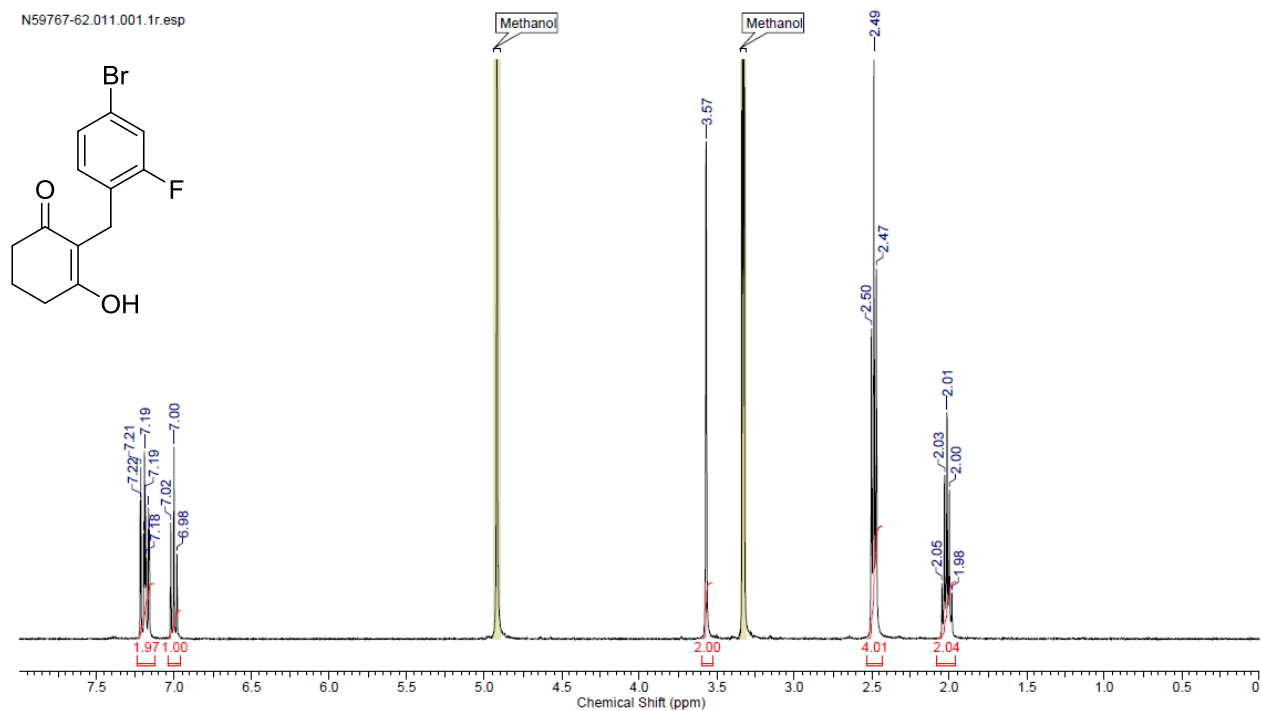


Figure S10: ¹H NMR spectrum of 2-(4-bromo-2-fluorobenzyl)cyclohexane-1,3-dione.

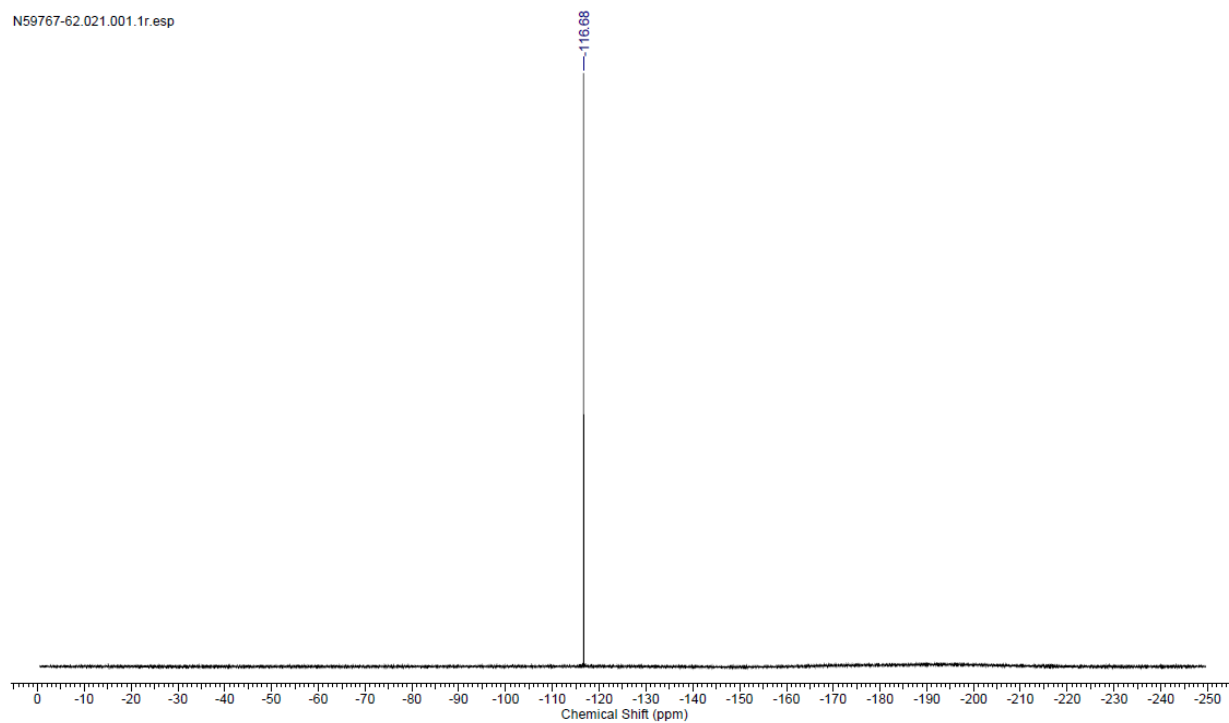


Figure S11: ¹⁹F NMR spectrum of 2-(4-bromo-2-fluorobenzyl)cyclohexane-1,3-dione.

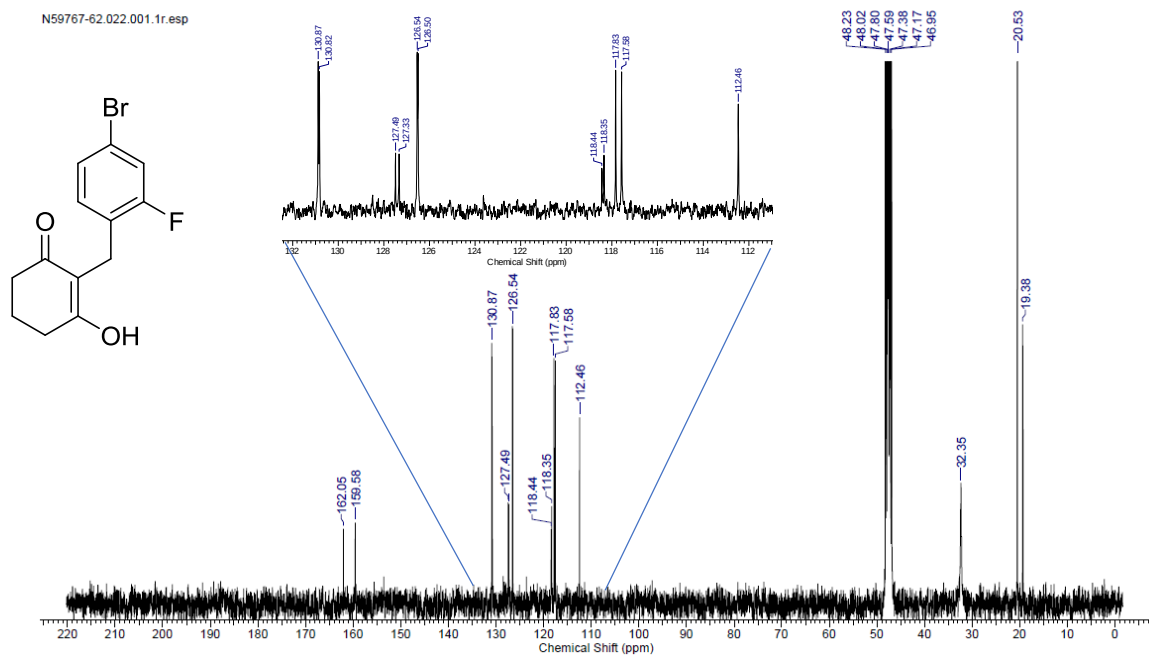


Figure S12: ¹³C{¹H} NMR spectrum of 2-(4-bromo-2-fluorobenzyl)cyclohexane-1,3-dione.

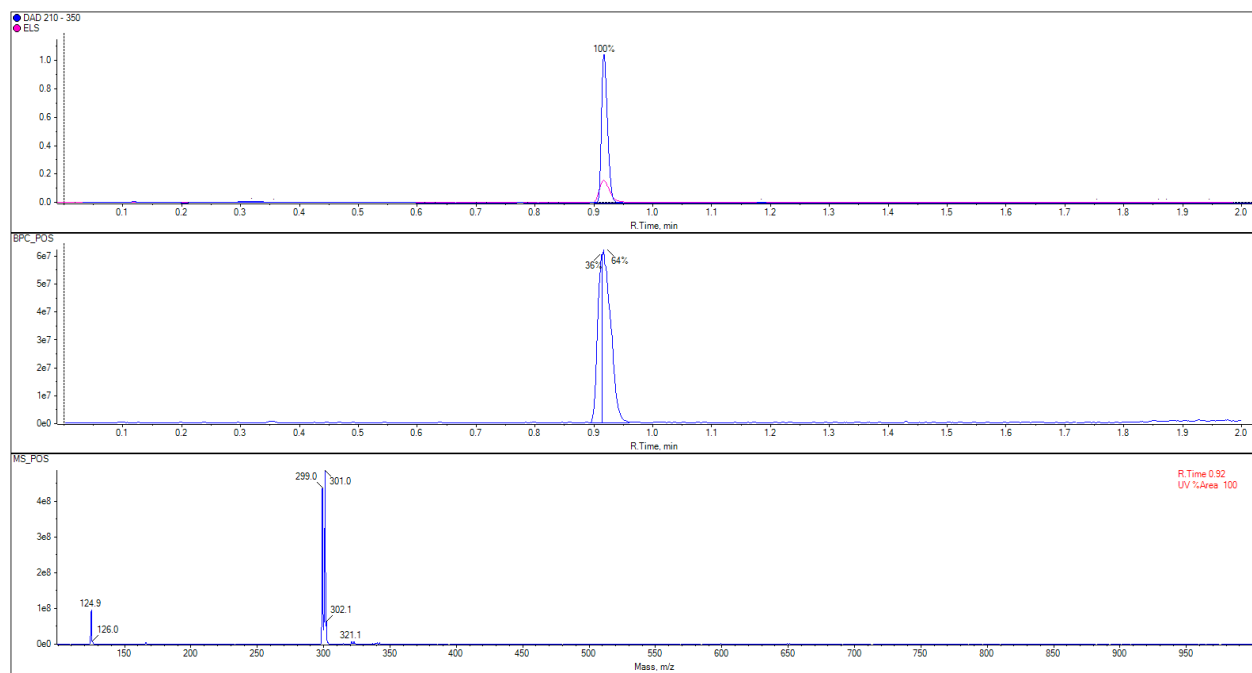


Figure S13: LCMS trace of 2-(4-bromo-2-fluorobenzyl)cyclohexane-1,3-dione.

Synthesis of 8a: This compound was prepared in an analogous fashion to **1a** using the literature protocol¹ from the above dione: A 3-necked 250 mL round-bottomed flask was charged with a stirbar. 2-(4-Bromo-2-fluorobenzyl)cyclohexane-1,3-dione (5 g, 16.71 mmol) was slurried in 35 mL DCM in the flask, which was then cooled to 0 °C. *N,N*-dimethylformamide (1.553 mL, 20.06 mmol) was added via syringe with stirring. An addition funnel was charged with oxalyl chloride (1.609 mL, 18.39 mmol) and 15 mL DCM. The addition funnel was attached to the center neck of the 3-necked flask, while the other two necks were left open to ensure efficient venting of the evolved gases. The oxalyl chloride solution was added dropwise to stirring reaction mixture over 15 minutes. During this time, the mixture became homogeneous. Once the addition was complete, the addition funnel was rinsed with 10 mL DCM, and then the reaction mixture warmed to room temperature. The addition funnel was filled with 50 mL water, which was added slowly to the stirring reaction mixture. Once addition was complete, the stirring was stopped to allow the two layers to settle. The phases were separated in a separatory funnel, and the volatiles removed *in vacuo*. The resulting yellow oil was dissolved in 50 mL TBME, and washed with water (3 x 50 mL), 1:1 brine/water (50 mL total), and finally dried over MgSO₄. The suspension was filtered and the solvent removed *in vacuo* to give a clear, viscous oil that solidified on standing at -20 °C. Isolated yield: 4.80 g (90%). ¹H NMR (400 MHz, CDCl₃) δ ppm 2.09 (quin, *J* = 6.5 Hz, 2 H) 2.51 (dd, *J* = 6.5, 6.2 Hz, 2 H) 2.83 (t, *J* = 6.2 Hz, 2 H) 3.78 (s, 2 H) 7.00 (t, *J* = 8.0 Hz, 1 H) 7.14 - 7.22 (m, 2 H). ¹³C{¹H} NMR (101 MHz, CDCl₃) δ ppm 21.85, 25.03 (d, *J* = 3.4 Hz), 35.18, 37.11, 118.82 (d, *J* = 25.6 Hz), 119.84 (d, *J* = 9.5 Hz), 124.88 (d, *J* = 15.7 Hz), 127.12 (d, *J* = 3.8 Hz), 131.22 (d, *J* = 5.1 Hz), 135.13, 155.81, 160.64 (d, *J* = 251 Hz, C-F), 195.73. ¹⁹F NMR (376 MHz, CDCl₃) δ ppm -113.66 (t, *J* = 8.6 Hz, 1 F). LRMS (ESI): *m/z* = 317 / 319 / 321 [M+H]⁺.

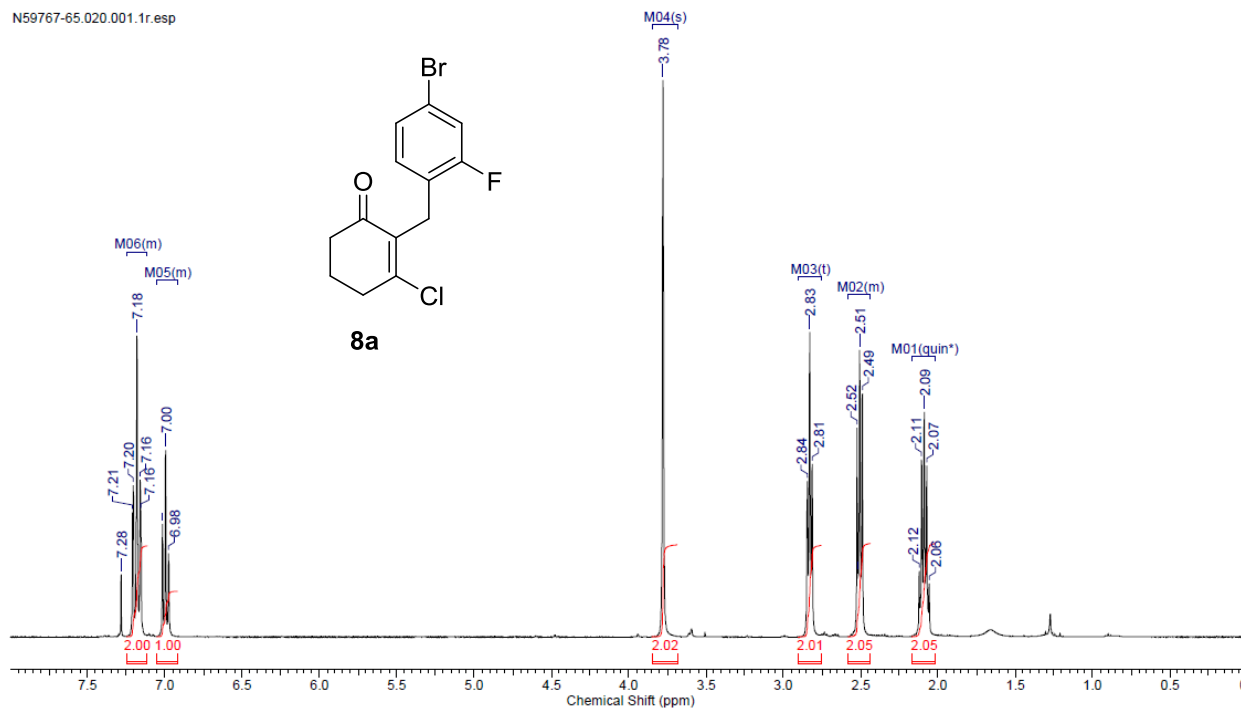
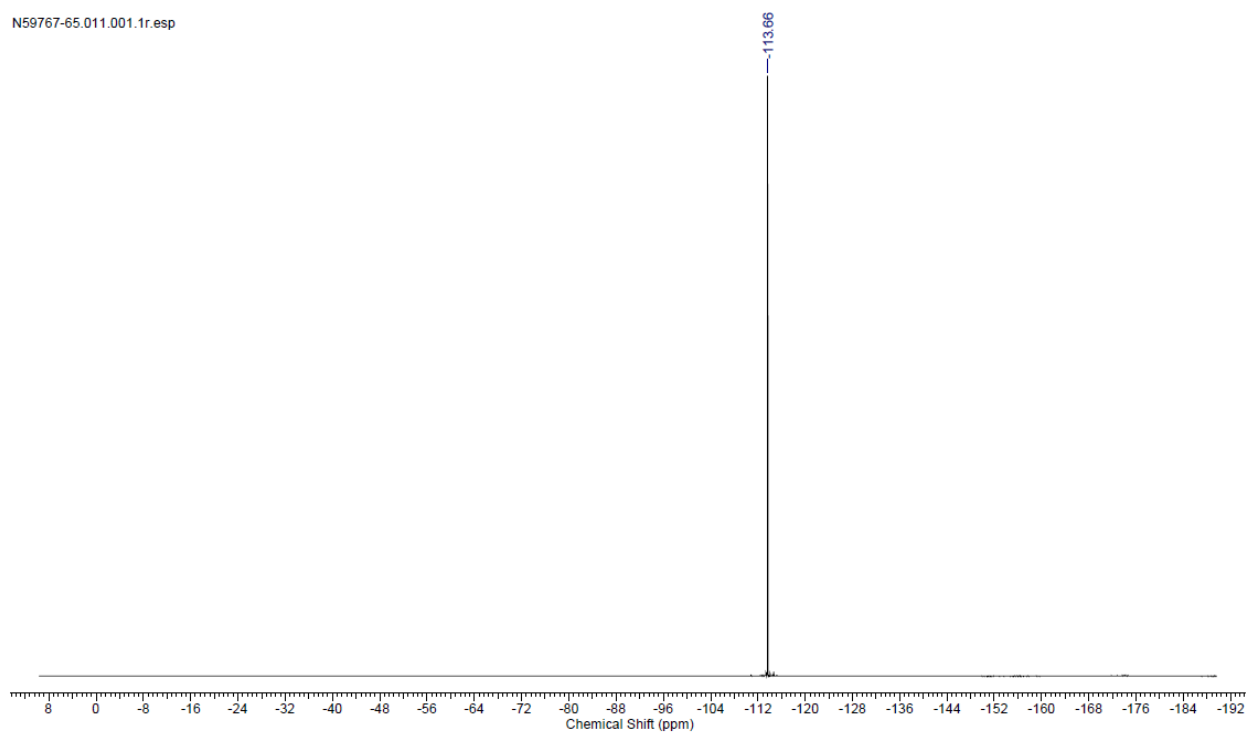
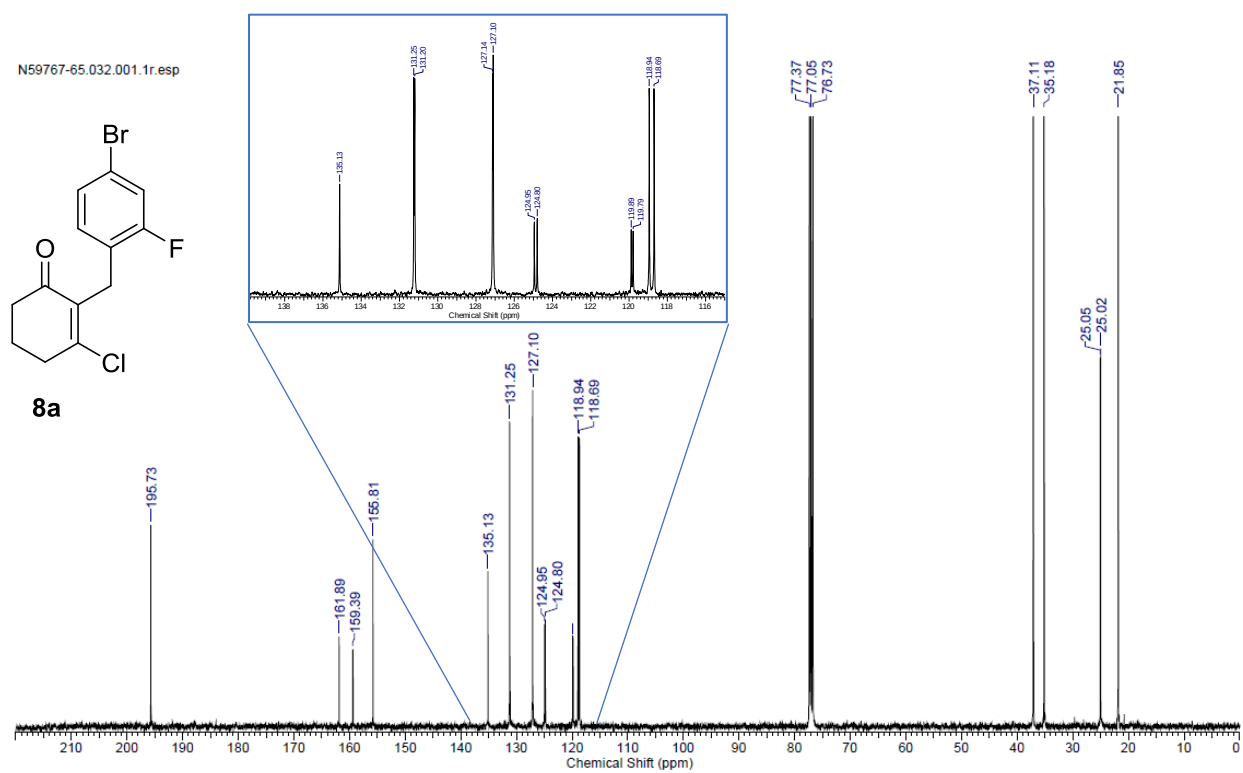


Figure S14: ¹H NMR spectrum of **8a**.

Figure S15: ^{19}F NMR spectrum of **8a**.Figure S16: $^{13}\text{C}\{^1\text{H}\}$ NMR spectrum of **8a**.

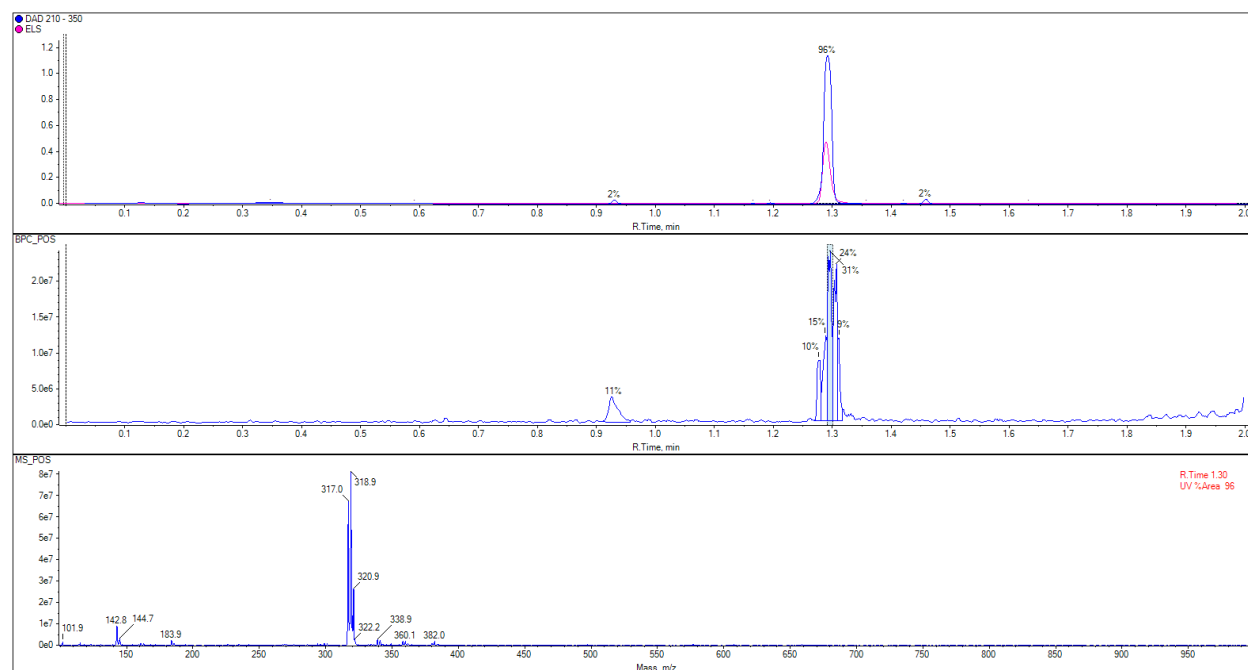
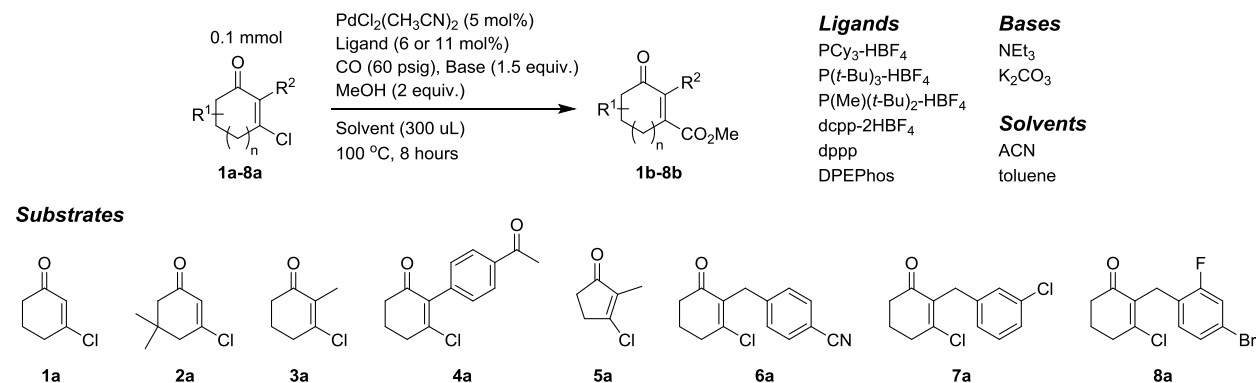


Figure S17: LCMS trace of **8a**.

II: High-Throughput Screening

Screen 1 (from Figure 1, Main Text):



Each reaction vial was charged with the following materials in this order:

- $\text{PdCl}_2(\text{CH}_3\text{CN})_2$: 1.3 mg, 0.0050 mmol
- Phosphine ligand: 0.010 mmol (monodentate ligands) or 0.0050 mmol (bidentate ligands)
- K_2CO_3 (if present): 20.7 mg, 0.150 mmol
- Substrate **1a** through **8a**: 0.100 mmol as a solution in either toluene or acetonitrile (300 μL solvent) that also contains biphenyl internal standard (3.1 mg, 0.020 mmol)
- Triethylamine (if present): 15.2 mg, 20.9 μL , 0.150 mmol
- Methanol: 6.4 mg, 8.1 μL , 0.200 mmol

Reaction conditions: 100 $^\circ\text{C}$, 60 psig CO, 8 hours.

Determining solution assays: This screen was analysed using HPLC Method B, with detection at 220 nm. In order to determine the mol% of remaining starting material, negative control vials containing only the starting material and internal standard were analyzed to establish a ratio of absolute peak areas between the peak for substrate and standard. All reactions that were dispensed from the same stock solution were calibrated against this relative response factor to obtain correct %conversion values. For calculating the mol% of product, several wells were subject to NMR analysis to obtain solution yields relative to internal standard. The volatiles in the original reaction vials were removed in a GeneVac prior to redissolution in CDCl_3 ; this solution was then passed through a 0.45 μm syringe filter if needed (to remove insoluble inorganics and/or palladium-black). By determining the solution yields for representative examples, the ratio of peak areas for the product and internal standard were calibrated across the plate. In other words, the product to internal standard response factor was determined by obtaining these NMR solutions yields, and this response factor was applied to the HPLC-derived results of the plate as a whole. The results are collated in Table S1.

Table S1: Full Set of Results from Screen 1

Entry	Substrate	Ligand	Base	Solvent	% Conv. (HPLC)	% Yield (HPLC)	% Yield (NMR)
1	1a	dcpp-2HBF ₄	K ₂ CO ₃	CH ₃ CN	99%	77%	92%
2	1a	dcpp-2HBF ₄	K ₂ CO ₃	Toluene	56%	45%	
3	1a	dcpp-2HBF ₄	NEt ₃	CH ₃ CN	97%	66%	
4	1a	dcpp-2HBF ₄	NEt ₃	Toluene	1%	1%	
5	1a	DPEPhos	K ₂ CO ₃	CH ₃ CN	100%	56%	
6	1a	DPEPhos	K ₂ CO ₃	Toluene	62%	47%	
7	1a	DPEPhos	NEt ₃	CH ₃ CN	42%	29%	
8	1a	DPEPhos	NEt ₃	Toluene	84%	80%	
9	1a	dppp	K ₂ CO ₃	CH ₃ CN	97%	69%	
10	1a	dppp	K ₂ CO ₃	Toluene	66%	47%	
11	1a	dppp	NEt ₃	CH ₃ CN	95%	57%	
12	1a	dppp	NEt ₃	Toluene	38%	31%	
13	1a	P(Me)(<i>t</i> -Bu) ₂ -HBF ₄	K ₂ CO ₃	CH ₃ CN	100%	63%	94%
14	1a	P(Me)(<i>t</i> -Bu) ₂ -HBF ₄	K ₂ CO ₃	Toluene	100%	73%	
15	1a	P(Me)(<i>t</i> -Bu) ₂ -HBF ₄	NEt ₃	CH ₃ CN	99%	71%	
16	1a	P(Me)(<i>t</i> -Bu) ₂ -HBF ₄	NEt ₃	Toluene	100%	94%	
17	1a	P(<i>t</i> -Bu) ₃ -HBF ₄	K ₂ CO ₃	CH ₃ CN	100%	76%	
18	1a	P(<i>t</i> -Bu) ₃ -HBF ₄	K ₂ CO ₃	Toluene	97%	73%	
19	1a	P(<i>t</i> -Bu) ₃ -HBF ₄	NEt ₃	CH ₃ CN	100%	69%	
20	1a	P(<i>t</i> -Bu) ₃ -HBF ₄	NEt ₃	Toluene	100%	94%	
21	1a	PCy ₃ -HBF ₄	K ₂ CO ₃	CH ₃ CN	80%	31%	
22	1a	PCy ₃ -HBF ₄	K ₂ CO ₃	Toluene	28%	26%	
23	1a	PCy ₃ -HBF ₄	NEt ₃	CH ₃ CN	81%	56%	
24	1a	PCy ₃ -HBF ₄	NEt ₃	Toluene	99%	91%	
25	2a	dcpp-2HBF ₄	K ₂ CO ₃	CH ₃ CN	97%	70%	75%
26	2a	dcpp-2HBF ₄	K ₂ CO ₃	Toluene	65%	70%	
27	2a	dcpp-2HBF ₄	NEt ₃	CH ₃ CN	92%	84%	
28	2a	dcpp-2HBF ₄	NEt ₃	Toluene	1%	3%	
29	2a	DPEPhos	K ₂ CO ₃	CH ₃ CN	97%	74%	
30	2a	DPEPhos	K ₂ CO ₃	Toluene	82%	71%	
31	2a	DPEPhos	NEt ₃	CH ₃ CN	100%	82%	
32	2a	DPEPhos	NEt ₃	Toluene	0%	13%	
33	2a	dppp	K ₂ CO ₃	CH ₃ CN	78%	82%	
34	2a	dppp	K ₂ CO ₃	Toluene	11%	30%	
35	2a	dppp	NEt ₃	CH ₃ CN	95%	95%	
36	2a	dppp	NEt ₃	Toluene	1%	14%	
37	2a	P(Me)(<i>t</i> -Bu) ₂ -HBF ₄	K ₂ CO ₃	CH ₃ CN	91%	72%	99%
38	2a	P(Me)(<i>t</i> -Bu) ₂ -HBF ₄	K ₂ CO ₃	Toluene	85%	78%	
39	2a	P(Me)(<i>t</i> -Bu) ₂ -HBF ₄	NEt ₃	CH ₃ CN	83%	93%	
40	2a	P(Me)(<i>t</i> -Bu) ₂ -HBF ₄	NEt ₃	Toluene	87%	99%	

41	2a	P(<i>t</i> -Bu) ₃ -HBF ₄	K ₂ CO ₃	CH ₃ CN	71%	68%	
42	2a	P(<i>t</i> -Bu) ₃ -HBF ₄	K ₂ CO ₃	Toluene	40%	53%	
43	2a	P(<i>t</i> -Bu) ₃ -HBF ₄	NEt ₃	CH ₃ CN	93%	83%	
44	2a	P(<i>t</i> -Bu) ₃ -HBF ₄	NEt ₃	Toluene	4%	11%	
45	2a	PCy ₃ -HBF ₄	K ₂ CO ₃	CH ₃ CN	24%	33%	
46	2a	PCy ₃ -HBF ₄	K ₂ CO ₃	Toluene	43%	71%	
47	2a	PCy ₃ -HBF ₄	NEt ₃	CH ₃ CN	73%	52%	
48	2a	PCy ₃ -HBF ₄	NEt ₃	Toluene	1%	0%	
49	3a	dcpp-2HBF ₄	K ₂ CO ₃	CH ₃ CN	98%	91%	91%
50	3a	dcpp-2HBF ₄	K ₂ CO ₃	Toluene	45%	41%	
51	3a	dcpp-2HBF ₄	NEt ₃	CH ₃ CN	40%	36%	
52	3a	dcpp-2HBF ₄	NEt ₃	Toluene	1%	0%	
53	3a	DPEPhos	K ₂ CO ₃	CH ₃ CN	54%	39%	
54	3a	DPEPhos	K ₂ CO ₃	Toluene	10%	5%	
55	3a	DPEPhos	NEt ₃	CH ₃ CN	4%	4%	
56	3a	DPEPhos	NEt ₃	Toluene	1%	1%	
57	3a	dppp	K ₂ CO ₃	CH ₃ CN	66%	52%	91%
58	3a	dppp	K ₂ CO ₃	Toluene	6%	8%	
59	3a	dppp	NEt ₃	CH ₃ CN	48%	23%	
60	3a	dppp	NEt ₃	Toluene	4%	0%	
61	3a	P(Me)(<i>t</i> -Bu) ₂ -HBF ₄	K ₂ CO ₃	CH ₃ CN	99%	77%	
62	3a	P(Me)(<i>t</i> -Bu) ₂ -HBF ₄	K ₂ CO ₃	Toluene	12%	0%	
63	3a	P(Me)(<i>t</i> -Bu) ₂ -HBF ₄	NEt ₃	CH ₃ CN	92%	92%	
64	3a	P(Me)(<i>t</i> -Bu) ₂ -HBF ₄	NEt ₃	Toluene	86%	90%	
65	3a	P(<i>t</i> -Bu) ₃ -HBF ₄	K ₂ CO ₃	CH ₃ CN	20%	4%	
66	3a	P(<i>t</i> -Bu) ₃ -HBF ₄	K ₂ CO ₃	Toluene	10%	6%	
67	3a	P(<i>t</i> -Bu) ₃ -HBF ₄	NEt ₃	CH ₃ CN	10%	9%	
68	3a	P(<i>t</i> -Bu) ₃ -HBF ₄	NEt ₃	Toluene	0%	0%	
69	3a	PCy ₃ -HBF ₄	K ₂ CO ₃	CH ₃ CN	6%	5%	
70	3a	PCy ₃ -HBF ₄	K ₂ CO ₃	Toluene	50%	45%	
71	3a	PCy ₃ -HBF ₄	NEt ₃	CH ₃ CN	8%	7%	
72	3a	PCy ₃ -HBF ₄	NEt ₃	Toluene	0%	0%	
73	4a	dcpp-2HBF ₄	K ₂ CO ₃	CH ₃ CN	95%	52%	
74	4a	dcpp-2HBF ₄	K ₂ CO ₃	Toluene	75%	53%	
75	4a	dcpp-2HBF ₄	NEt ₃	CH ₃ CN	26%	12%	
76	4a	dcpp-2HBF ₄	NEt ₃	Toluene	7%	1%	
77	4a	DPEPhos	K ₂ CO ₃	CH ₃ CN	100%	23%	
78	4a	DPEPhos	K ₂ CO ₃	Toluene	73%	22%	
79	4a	DPEPhos	NEt ₃	CH ₃ CN	13%	7%	
80	4a	DPEPhos	NEt ₃	Toluene	0%	1%	
81	4a	dppp	K ₂ CO ₃	CH ₃ CN	100%	44%	
82	4a	dppp	K ₂ CO ₃	Toluene	85%	78%	
83	4a	dppp	NEt ₃	CH ₃ CN	16%	7%	
84	4a	dppp	NEt ₃	Toluene	7%	1%	

85	4a	P(Me)(<i>t</i> -Bu) ₂ -HBF ₄	K ₂ CO ₃	CH ₃ CN	100%	30%	
86	4a	P(Me)(<i>t</i> -Bu) ₂ -HBF ₄	K ₂ CO ₃	Toluene	5%	0%	
87	4a	P(Me)(<i>t</i> -Bu) ₂ -HBF ₄	NEt ₃	CH ₃ CN	100%	71%	71%
88	4a	P(Me)(<i>t</i> -Bu) ₂ -HBF ₄	NEt ₃	Toluene	100%	72%	65%
89	4a	P(<i>t</i> -Bu) ₃ -HBF ₄	K ₂ CO ₃	CH ₃ CN	86%	16%	
90	4a	P(<i>t</i> -Bu) ₃ -HBF ₄	K ₂ CO ₃	Toluene	74%	55%	
91	4a	P(<i>t</i> -Bu) ₃ -HBF ₄	NEt ₃	CH ₃ CN	50%	31%	
92	4a	P(<i>t</i> -Bu) ₃ -HBF ₄	NEt ₃	Toluene	54%	37%	
93	4a	PCy ₃ -HBF ₄	K ₂ CO ₃	CH ₃ CN	75%	15%	
94	4a	PCy ₃ -HBF ₄	K ₂ CO ₃	Toluene	100%	4%	
95	4a	PCy ₃ -HBF ₄	NEt ₃	CH ₃ CN	49%	33%	
96	4a	PCy ₃ -HBF ₄	NEt ₃	Toluene	38%	26%	
97	5a	dcpp-2HBF ₄	K ₂ CO ₃	CH ₃ CN	49%	22%	
98	5a	dcpp-2HBF ₄	K ₂ CO ₃	Toluene	44%	38%	
99	5a	dcpp-2HBF ₄	NEt ₃	CH ₃ CN	6%	4%	36%
100	5a	dcpp-2HBF ₄	NEt ₃	Toluene	6%	4%	
101	5a	DPEPhos	K ₂ CO ₃	CH ₃ CN	75%	33%	
102	5a	DPEPhos	K ₂ CO ₃	Toluene	27%	18%	
103	5a	DPEPhos	NEt ₃	CH ₃ CN	0%	0%	
104	5a	DPEPhos	NEt ₃	Toluene	3%	2%	
105	5a	dppp	K ₂ CO ₃	CH ₃ CN	90%	49%	
106	5a	dppp	K ₂ CO ₃	Toluene	19%	13%	
107	5a	dppp	NEt ₃	CH ₃ CN	33%	19%	
108	5a	dppp	NEt ₃	Toluene	1%	0%	
109	5a	P(Me)(<i>t</i> -Bu) ₂ -HBF ₄	K ₂ CO ₃	CH ₃ CN	64%	25%	
110	5a	P(Me)(<i>t</i> -Bu) ₂ -HBF ₄	K ₂ CO ₃	Toluene	18%	9%	
111	5a	P(Me)(<i>t</i> -Bu) ₂ -HBF ₄	NEt ₃	CH ₃ CN	64%	62%	62%
112	5a	P(Me)(<i>t</i> -Bu) ₂ -HBF ₄	NEt ₃	Toluene	22%	19%	19%
113	5a	P(<i>t</i> -Bu) ₃ -HBF ₄	K ₂ CO ₃	CH ₃ CN	35%	16%	
114	5a	P(<i>t</i> -Bu) ₃ -HBF ₄	K ₂ CO ₃	Toluene	8%	5%	
115	5a	P(<i>t</i> -Bu) ₃ -HBF ₄	NEt ₃	CH ₃ CN	9%	8%	
116	5a	P(<i>t</i> -Bu) ₃ -HBF ₄	NEt ₃	Toluene	29%	29%	
117	5a	PCy ₃ -HBF ₄	K ₂ CO ₃	CH ₃ CN	4%	0%	
118	5a	PCy ₃ -HBF ₄	K ₂ CO ₃	Toluene	6%	0%	
119	5a	PCy ₃ -HBF ₄	NEt ₃	CH ₃ CN	3%	0%	
120	5a	PCy ₃ -HBF ₄	NEt ₃	Toluene	7%	5%	
121	6a	dcpp-2HBF ₄	K ₂ CO ₃	CH ₃ CN	75%	37%	
122	6a	dcpp-2HBF ₄	K ₂ CO ₃	Toluene	50%	46%	
123	6a	dcpp-2HBF ₄	NEt ₃	CH ₃ CN	30%	21%	
124	6a	dcpp-2HBF ₄	NEt ₃	Toluene	2%	0%	
125	6a	DPEPhos	K ₂ CO ₃	CH ₃ CN	94%	51%	
126	6a	DPEPhos	K ₂ CO ₃	Toluene	64%	62%	
127	6a	DPEPhos	NEt ₃	CH ₃ CN	2%	6%	
128	6a	DPEPhos	NEt ₃	Toluene	9%	5%	

129	6a	dppp	K ₂ CO ₃	CH ₃ CN	69%	44%	
130	6a	dppp	K ₂ CO ₃	Toluene	61%	59%	
131	6a	dppp	NEt ₃	CH ₃ CN	22%	9%	
132	6a	dppp	NEt ₃	Toluene	1%	0%	
133	6a	P(Me)(<i>t</i> -Bu) ₂ -HBF ₄	K ₂ CO ₃	CH ₃ CN	100%	67%	
134	6a	P(Me)(<i>t</i> -Bu) ₂ -HBF ₄	K ₂ CO ₃	Toluene	62%	66%	
135	6a	P(Me)(<i>t</i> -Bu) ₂ -HBF ₄	NEt ₃	CH ₃ CN	99%	89%	89%
136	6a	P(Me)(<i>t</i> -Bu) ₂ -HBF ₄	NEt ₃	Toluene	95%	97%	97%
137	6a	P(<i>t</i> -Bu) ₃ -HBF ₄	K ₂ CO ₃	CH ₃ CN	29%	8%	
138	6a	P(<i>t</i> -Bu) ₃ -HBF ₄	K ₂ CO ₃	Toluene	21%	16%	
139	6a	P(<i>t</i> -Bu) ₃ -HBF ₄	NEt ₃	CH ₃ CN	10%	13%	
140	6a	P(<i>t</i> -Bu) ₃ -HBF ₄	NEt ₃	Toluene	40%	36%	
141	6a	PCy ₃ -HBF ₄	K ₂ CO ₃	CH ₃ CN	13%	16%	
142	6a	PCy ₃ -HBF ₄	K ₂ CO ₃	Toluene	47%	47%	
143	6a	PCy ₃ -HBF ₄	NEt ₃	CH ₃ CN	14%	16%	
144	6a	PCy ₃ -HBF ₄	NEt ₃	Toluene	52%	52%	
145	7a	dcpp-2HBF ₄	K ₂ CO ₃	CH ₃ CN	58%	32%	
146	7a	dcpp-2HBF ₄	K ₂ CO ₃	Toluene	23%	24%	
147	7a	dcpp-2HBF ₄	NEt ₃	CH ₃ CN	21%	14%	
148	7a	dcpp-2HBF ₄	NEt ₃	Toluene	2%	4%	
149	7a	DPEPhos	K ₂ CO ₃	CH ₃ CN	76%	38%	
150	7a	DPEPhos	K ₂ CO ₃	Toluene	46%	45%	
151	7a	DPEPhos	NEt ₃	CH ₃ CN	9%	7%	
152	7a	DPEPhos	NEt ₃	Toluene	4%	5%	
153	7a	dppp	K ₂ CO ₃	CH ₃ CN	69%	44%	
154	7a	dppp	K ₂ CO ₃	Toluene	23%	18%	
155	7a	dppp	NEt ₃	CH ₃ CN	16%	9%	
156	7a	dppp	NEt ₃	Toluene	4%	2%	
157	7a	P(Me)(<i>t</i> -Bu) ₂ -HBF ₄	K ₂ CO ₃	CH ₃ CN	100%	66%	
158	7a	P(Me)(<i>t</i> -Bu) ₂ -HBF ₄	K ₂ CO ₃	Toluene	100%	96%	97%
159	7a	P(Me)(<i>t</i> -Bu) ₂ -HBF ₄	NEt ₃	CH ₃ CN	94%	86%	86%
160	7a	P(Me)(<i>t</i> -Bu) ₂ -HBF ₄	NEt ₃	Toluene	75%	75%	75%
161	7a	P(<i>t</i> -Bu) ₃ -HBF ₄	K ₂ CO ₃	CH ₃ CN	11%	10%	
162	7a	P(<i>t</i> -Bu) ₃ -HBF ₄	K ₂ CO ₃	Toluene	13%	11%	
163	7a	P(<i>t</i> -Bu) ₃ -HBF ₄	NEt ₃	CH ₃ CN	3%	10%	
164	7a	P(<i>t</i> -Bu) ₃ -HBF ₄	NEt ₃	Toluene	32%	32%	
165	7a	PCy ₃ -HBF ₄	K ₂ CO ₃	CH ₃ CN	3%	12%	
166	7a	PCy ₃ -HBF ₄	K ₂ CO ₃	Toluene	91%	88%	
167	7a	PCy ₃ -HBF ₄	NEt ₃	CH ₃ CN	2%	13%	
168	7a	PCy ₃ -HBF ₄	NEt ₃	Toluene	0%	0%	
169	8a	dcpp-2HBF ₄	K ₂ CO ₃	CH ₃ CN	89%	22%	
170	8a	dcpp-2HBF ₄	K ₂ CO ₃	Toluene	87%	10%	
171	8a	dcpp-2HBF ₄	NEt ₃	CH ₃ CN	48%	13%	
172	8a	dcpp-2HBF ₄	NEt ₃	Toluene	10%	1%	

173	8a	DPEPhos	K ₂ CO ₃	CH ₃ CN	78%	5%	
174	8a	DPEPhos	K ₂ CO ₃	Toluene	31%	8%	
175	8a	DPEPhos	NEt ₃	CH ₃ CN	23%	1%	
176	8a	DPEPhos	NEt ₃	Toluene	13%	4%	
177	8a	dppp	K ₂ CO ₃	CH ₃ CN	87%	10%	
178	8a	dppp	K ₂ CO ₃	Toluene	48%	20%	
179	8a	dppp	NEt ₃	CH ₃ CN	43%	5%	
180	8a	dppp	NEt ₃	Toluene	0%	2%	
181	8a	P(Me)(<i>t</i> -Bu) ₂ -HBF ₄	K ₂ CO ₃	CH ₃ CN	100%	36%	
182	8a	P(Me)(<i>t</i> -Bu) ₂ -HBF ₄	K ₂ CO ₃	Toluene	100%	73%	73%
183	8a	P(Me)(<i>t</i> -Bu) ₂ -HBF ₄	NEt ₃	CH ₃ CN	70%	61%	61%
184	8a	P(Me)(<i>t</i> -Bu) ₂ -HBF ₄	NEt ₃	Toluene	24%	22%	28%
185	8a	P(<i>t</i> -Bu) ₃ -HBF ₄	K ₂ CO ₃	CH ₃ CN	55%	4%	
186	8a	P(<i>t</i> -Bu) ₃ -HBF ₄	K ₂ CO ₃	Toluene	44%	5%	
187	8a	P(<i>t</i> -Bu) ₃ -HBF ₄	NEt ₃	CH ₃ CN	53%	5%	
188	8a	P(<i>t</i> -Bu) ₃ -HBF ₄	NEt ₃	Toluene	86%	7%	
189	8a	PCy ₃ -HBF ₄	K ₂ CO ₃	CH ₃ CN	33%	13%	
190	8a	PCy ₃ -HBF ₄	K ₂ CO ₃	Toluene	93%	72%	
191	8a	PCy ₃ -HBF ₄	NEt ₃	CH ₃ CN	36%	14%	
192	8a	PCy ₃ -HBF ₄	NEt ₃	Toluene	0%	0%	

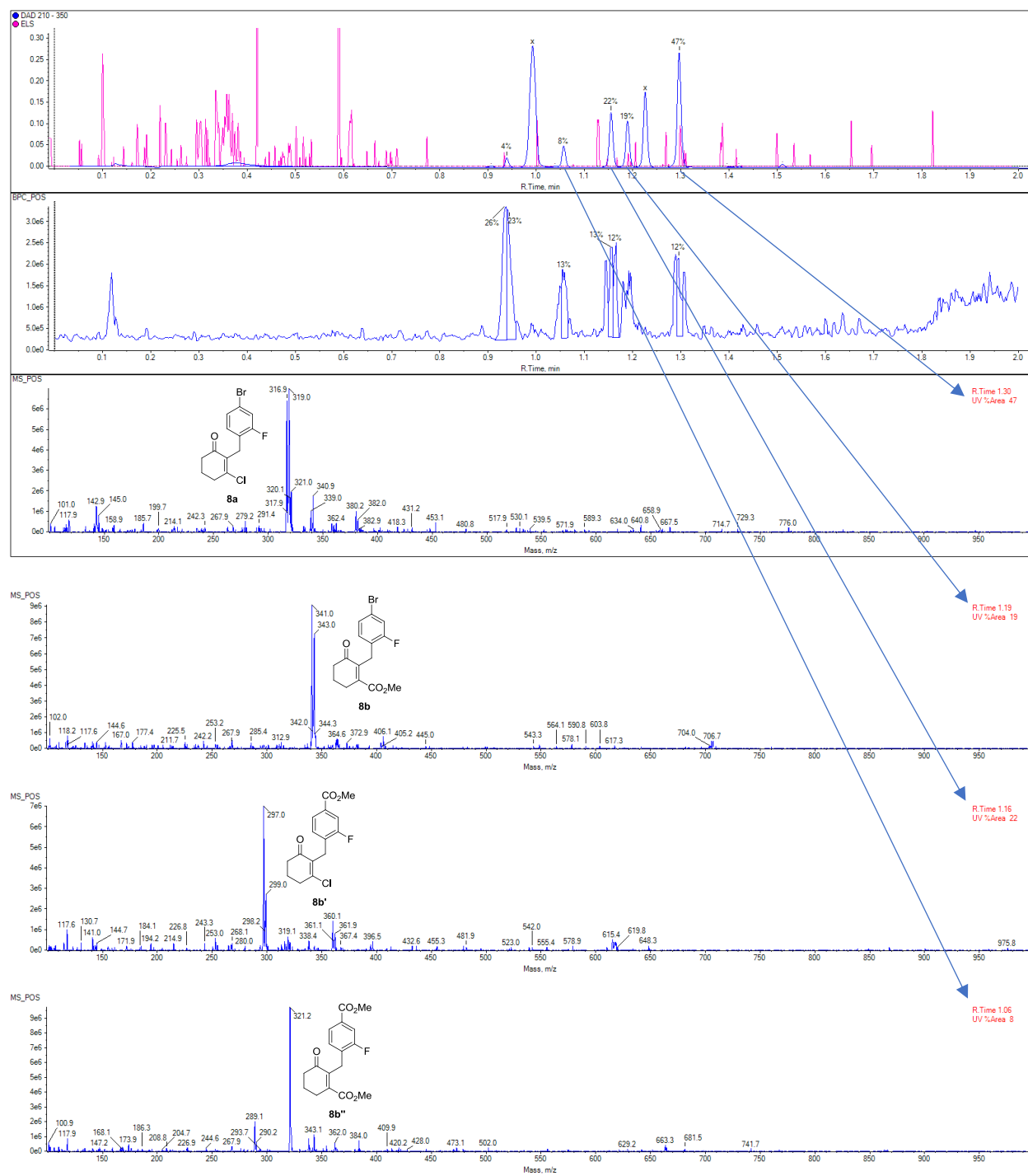


Figure S18: LCMS for Table S1, Entry 178, showing non-selective carbonylation using dppp.

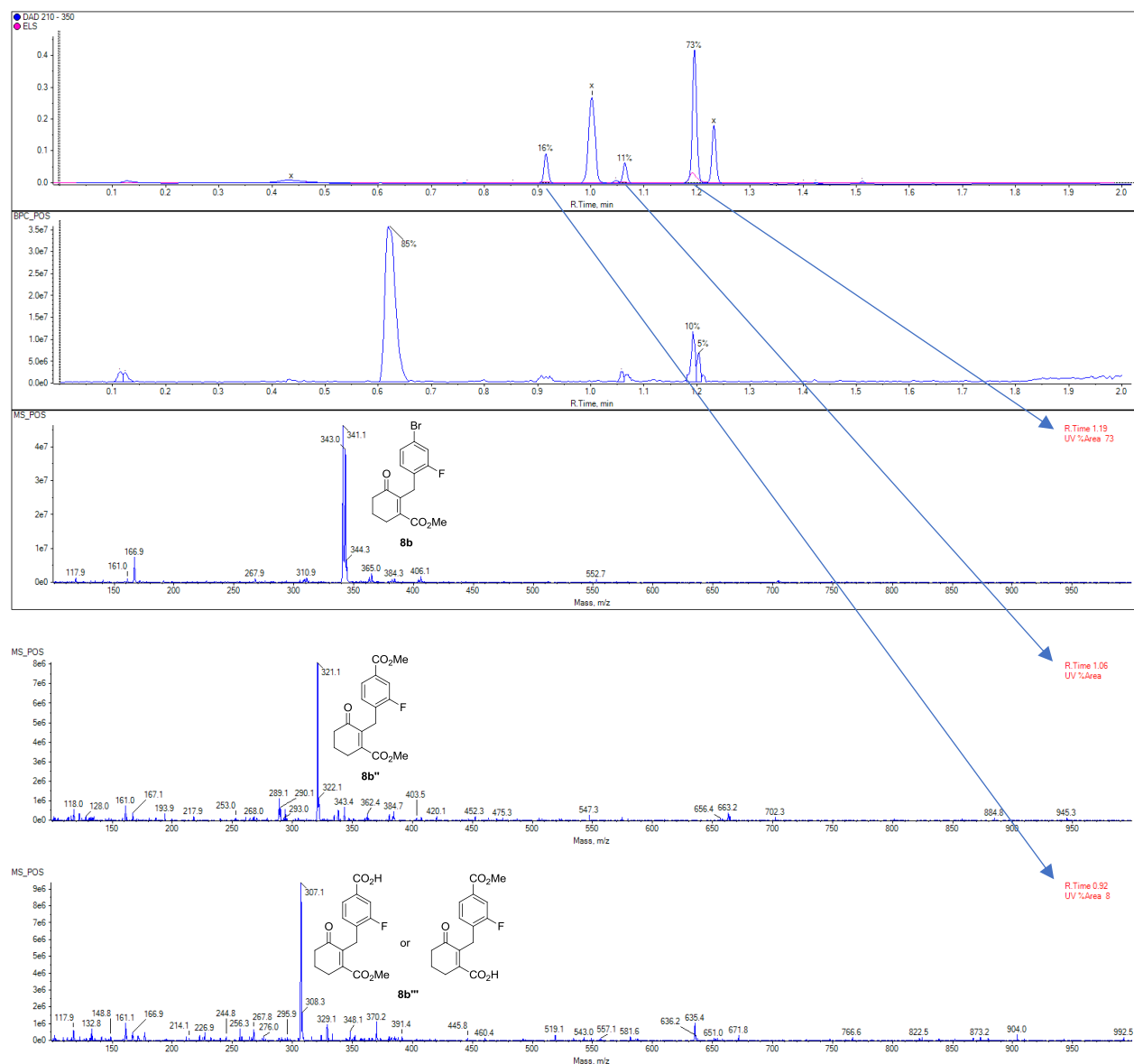
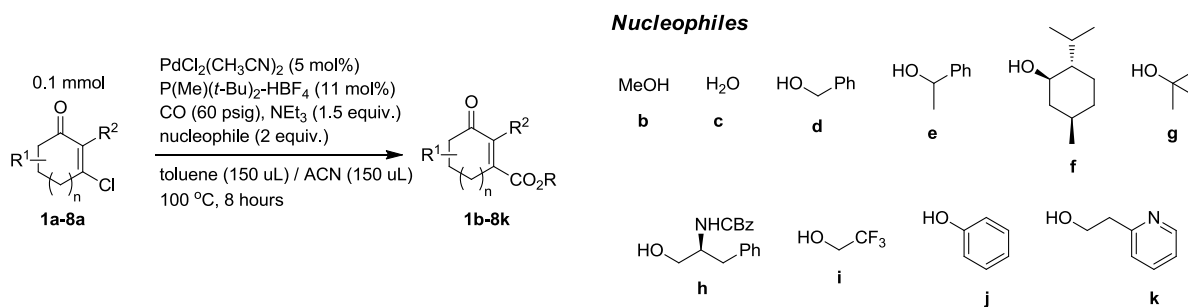


Figure S19: LCMS for Table S1, Entry 182, showing selective carbonylation at Cl using $P(Me)(t-Bu)_2$

Screen 2 (from Figure 2, Main Text):



Each reaction vial was charged with the following materials in this order:

- $\text{PdCl}_2(\text{CH}_3\text{CN})_2$: 1.3 mg, 0.0050 mmol
- $\text{P}(\text{Me})(t\text{-Bu})_2\text{-HBF}_4$: 2.5 mg, 0.010 mmol
- Substrate **1a** through **8a**: 0.100 mmol as a solution in toluene (150 μL) that also contains biphenyl internal standard (3.1 mg, 0.020 mmol)
- Triethylamine: 15.2 mg, 20.9 μL , 0.150 mmol
- Nucleophile **b-k**: 0.200 mmol as a solution in acetonitrile (150 μL), except **h**, which was added as a solid prior to the substrate solution.

Reaction conditions: 100 $^\circ\text{C}$, 60 psig CO, 8 hours.

Determining solution assays (Screen 2): This screen was analysed using LCMS to enable identification of all the desired products and byproducts. To simplify quantification of this screen, mol% values for substrate and product were estimated using area% values from UV absorbance between 210-350 nm (diode array detector) after excluding peaks due to solvent, internal standard, excess nucleophile, or catalyst (as identified by m/z values); this assumes an equal UV absorbance response factor for all components (starting material, product, and byproducts). As for screen 1, select examples were also analyzed by ^1H NMR spectroscopy to determine solution yields versus internal standard (biphenyl). These values are in generally good agreement with the solution yields determined using area%. The major byproducts observed are the product isomer (same m/z , different RT, assigned based on ^1H NMR spectra of select examples as due to alkene isomerization) and the carboxylic acid. All of the results are summarized in Table S2. Note that because not all of these runs have been accurately quantified by calibration against an isolated sample of the product, these results represent a semi-quantitative map of expected reactivity across the eight electrophiles and ten nucleophiles.

For several of the reactions, we observed second component with the same m/z as the desired product. ^1H NMR spectroscopic analysis of many of these reactions revealed that this second species is likely an alkene isomer of the desired product. In Table S2, the area% value for these putative isomers are denoted 'Product Isomer'. This isomer was not definitively identified in every LCMS trace; therefore, the absence of data for 'Product Isomer' in Table S2 should not be interpreted to indicate no isomerization. In the preparative-scale experiments (see Section IV), this isomerization was greatly reduced or eliminated in most cases, likely due to the milder reaction conditions. Our hypothesis is that this isomerization is a competing Pd-catalyzed side pathway, which can be mitigated by lowering reaction temperature and catalyst loading.⁵

Finally, the chemoselectivity for carbonylations with **8a** was assessed by LCMS identification of all ionizing components (see Figures S22-29).

Table S2: Full Set of Results from Screen 2

Entry	Substrate	Nucleophile	% Conv.	Substrate Retention Time (min)	Product Area (%)	Product %Yield (NMR)	Product Retention Time (min)	Product Alkene Isomer Area%	Product Alkene Isomer Retention Time (min)	Carboxylic Acid Area (%)	Carboxylic Acid Retention Time (min)
1	1a	b	100%	0.56	79%	80%	0.53	11%	1.00	5%	0.40
2	1a	c	100%	0.56	83%		0.40			83%	0.40
3	1a	c	91%	0.56	67%		0.40			67%	0.40
4	1a	d	100%	0.56	83%		0.98			4%	0.40
5	1a	e	100%	0.56	72%	74%	1.05	13%	1.11	6%	0.40
6	1a	f	100%	0.56	82%		1.43			7%	0.40
7	1a	f	100%	0.56	80%		1.43			6%	0.40
8	1a	g	100%	0.56	75%		0.92			14%	0.40
9	1a	g	100%	0.56	77%	87%	0.93	7%	0.80	11%	0.40
10	1a	h	100%	0.56	86%		1.16			0%	0.40
11	1a	h	100%	0.56	74%		1.16			6%	0.40
12	1a	i	100%	0.56	58%		0.82			8%	0.40
13	1a	j	100%	0.56	67%	79%	0.91	5%	1.23	7%	0.40
14	1a	k	100%	0.56	53%		0.38			26%	0.40
15	2a	b	93%	0.84	78%		0.77			3%	0.61
16	2a	c	98%	0.84	85%	87%	0.61	11%	1.04	85%	0.61
17	2a	c	85%	0.85	68%		0.61			68%	0.61
18	2a	d	100%	0.85	93%		1.14			5%	0.61
19	2a	e	100%	0.84	82%		1.19			5%	0.61
20	2a	e	100%	0.84	88%	95%	1.20	7%	0.94	4%	0.61
21	2a	f	100%	0.84	84%		1.55			7%	0.61
22	2a	g	100%	0.84	75%		1.12			13%	0.61
23	2a	h	100%	0.84	83%		1.26			6%	0.61
24	2a	h	100%	0.84	86%	53%	1.27	16%	0.92	4%	0.61
25	2a	i	100%	0.84	83%		1.01			5%	0.61
26	2a	j	100%	0.84	75%		1.09			4%	0.61
27	2a	k	100%	0.84	66%		0.50			22%	0.61
28	3a	b	80%	0.78	67%	57%	0.66	10%	0.64	4%	0.42
29	3a	c	94%	0.78	88%		0.42			88%	0.42
30	3a	c	86%	0.78	75%		0.42			75%	0.42
31	3a	d	95%	0.78	79%		1.05			7%	0.42
32	3a	e	100%	0.78	80%	65%	1.12	9%	0.64	10%	0.42
33	3a	f	100%	0.78	82%		1.49			9%	0.42
34	3a	g	79%	0.78	47%		0.99			17%	0.42
35	3a	h	100%	0.78	90%		1.21			5%	0.42
36	3a	i	100%	0.78	81%	57%	0.94	6%	0.94	8%	0.42
37	3a	i	100%	0.78	82%		0.94			6%	0.42
38	3a	j	100%	0.78	84%		1.01			8%	0.42
39	3a	k	100%	0.78	53%		0.43			22%	0.42
40	4a	b	100%	0.88	57%	65%	0.79	3%	1.38	4%	0.59
41	4a	c	100%	0.88	68%		0.59			68%	0.59
42	4a	c	100%	0.88	74%		0.59			74%	0.59
43	4a	d	100%	0.88	77%		1.06			10%	0.59
44	4a	e	100%	0.88	71%	57%	1.12	7%	1.01	11%	0.59
45	4a	f	100%	0.88	76%		1.42			10%	0.59
46	4a	g	96%	0.88	50%		1.03			18%	0.59
47	4a	h	97%	0.88	79%		1.24			7%	0.59
48	4a	i	100%	0.88	75%	57%	0.98	16%	0.92	3%	0.59

49	4a	j	100%	0.88	59%		1.03	31%	0.98	8%	0.59
50	4a	k	100%	0.88	44%		0.53	15%	0.51	30%	0.59
51	5a	b	65%	0.60	56%		0.65			0%	0.38
52	5a	b	42%	0.60	35%		0.56			0%	0.38
53	5a	c	60%	0.60	40%		0.39			40%	0.39
54	5a	c	60%	0.60	43%		0.38			43%	0.39
55	5a	c	74%	0.60	64%		0.39			64%	0.39
56	5a	d	90%	0.60	86%	90%	1.03			0%	0.39
57	5a	d	80%	0.60	73%		1.00			0%	0.39
58	5a	d	86%	0.60	80%	83%	1.00			0%	0.39
59	5a	e	78%	0.60	70%		1.10			4%	0.39
60	5a	e	60%	0.60	56%		1.05			4%	0.39
61	5a	f	74%	0.60	57%		1.46			5%	0.39
62	5a	f	42%	0.60	30%		1.45			5%	0.39
63	5a	g	57%	0.60	38%		0.97			8%	0.39
64	5a	g	52%	0.60	35%		0.94			14%	0.39
65	5a	h	94%	0.60	88%		1.19			0%	0.39
66	5a	h	12%	0.60	0%		1.19			0%	0.39
67	5a	i	98%	0.60	91%		0.89			0%	0.39
68	5a	i	86%	0.60	75%		0.85			0%	0.39
69	5a	j	100%	0.60	92%	93%	0.99			0%	0.39
70	5a	j	96%	0.60	91%		0.92			0%	0.39
71	5a	j	94%	0.60	92%	89%	0.92			0%	0.39
72	5a	k	59%	0.60	52%		0.49			0%	0.39
73	5a	k	39%	0.60	31%		0.38			0%	0.39
74	6a	b	100%	1.05	89%		0.99	7%	0.93	4%	0.85
75	6a	c	100%	1.05	98%	87%	0.86			98%	0.86
76	6a	d	100%	1.05	88%		1.22	6%	1.18	6%	0.84
77	6a	e	100%	1.05	94%		1.27	<1%	1.23	6%	0.83
78	6a	f	100%	1.05	90%	84%	1.56	5%	1.53	5%	0.82
79	6a	g	100%	1.05	84%		1.20	4%	1.17	12%	0.82
80	6a	h	100%	1.05	87%		1.33	6%	1.29	3%	0.85
81	6a	i	100%	1.05	83%		1.13	14%	1.06	3%	0.82
82	6a	j	100%	1.05	88%		1.20	12%	1.13	5%	0.86
83	6a	k	100%	1.05	70%		0.68	5%	0.63	22%	0.83
84	7a	b	100%	1.21	90%		1.16	5%	1.10	0%	1.01
85	7a	c	100%	1.21	97%		1.01			97%	1.01
86	7a	d	100%	1.21	88%		1.36	6%	1.33	0%	1.01
87	7a	e	100%	1.21	90%		1.41	6%	1.38	0%	1.01
88	7a	f	100%	1.21	90%		1.71	6%	1.69	0%	1.01
89	7a	g	100%	1.21	92%		1.36	4%	1.33	0%	1.01
90	7a	h	100%	1.21	87%	89%	1.43	9%	1.40	0%	1.01
91	7a	i	100%	1.21	79%	71%	1.28	16%	1.21	0%	1.01
92	7a	j	100%	1.21	76%		1.34	14%	1.27	0%	1.01
93	7a	k	100%	1.21	89%		0.79	7%	0.75	0%	1.01
94	8a	b	43%	1.24	33%		1.12			0%	0.95
95	8a	c	71%	1.24	66%	66%	0.95			66%	0.95
96	8a	d	72%	1.24	61%		1.35			0%	0.95
97	8a	e	66%	1.24	61%	63%	1.39			5%	0.95
98	8a	f	11%	1.24	11%		1.67			0%	0.95
99	8a	g	24%	1.24	12%		1.35			5%	0.95
100	8a	h	95%	1.24	62%		1.40			0%	0.95
101	8a	i	83%	1.24	74%	62%	1.26			5%	0.95
102	8a	j	88%	1.24	68%		1.32			0%	0.95
103	8a	k	80%	1.24	46%		0.76			23%	0.95

Representative ^1H NMR spectra to illustrate presence of alkene isomer.

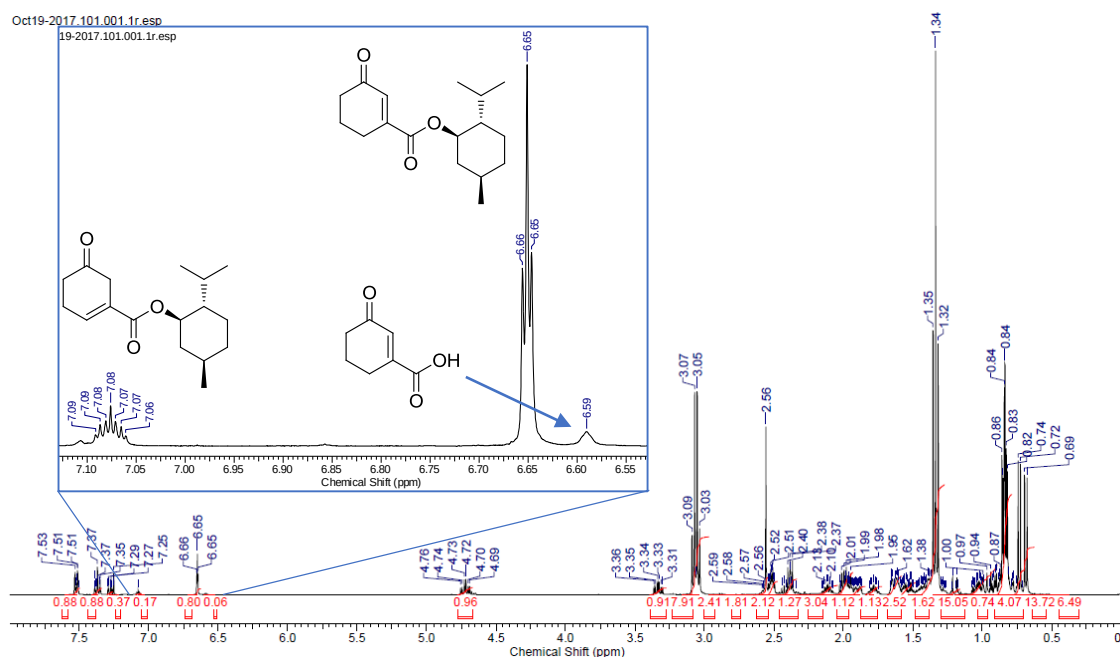


Figure S20: ^1H NMR spectrum of crude reaction mixture from Table S2, Entry 6.

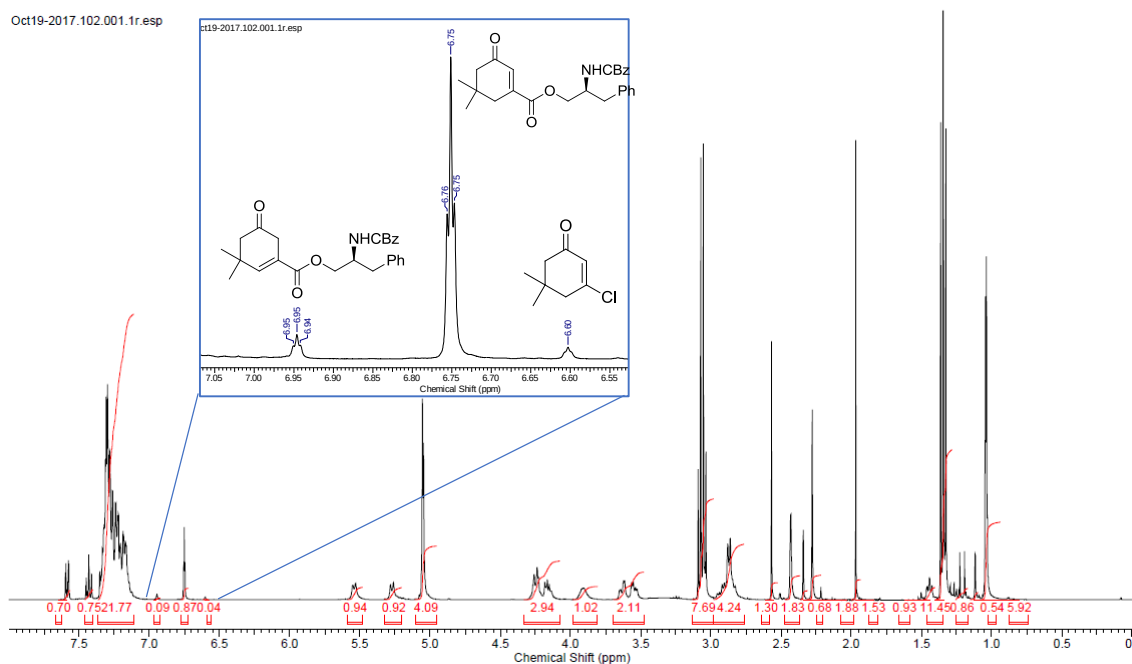
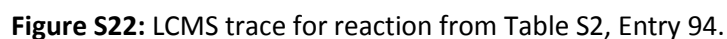


Figure S21: ^1H NMR spectrum of crude reaction mixture from Table S2, Entry 24.

Peaks denoted 'x' in the following traces are either toluene (0.91 min), biphenyl (1.16 min), or alcohol substrates containing a chromophore (BnOH, 1-PhEtOH, PhOH, etc.).



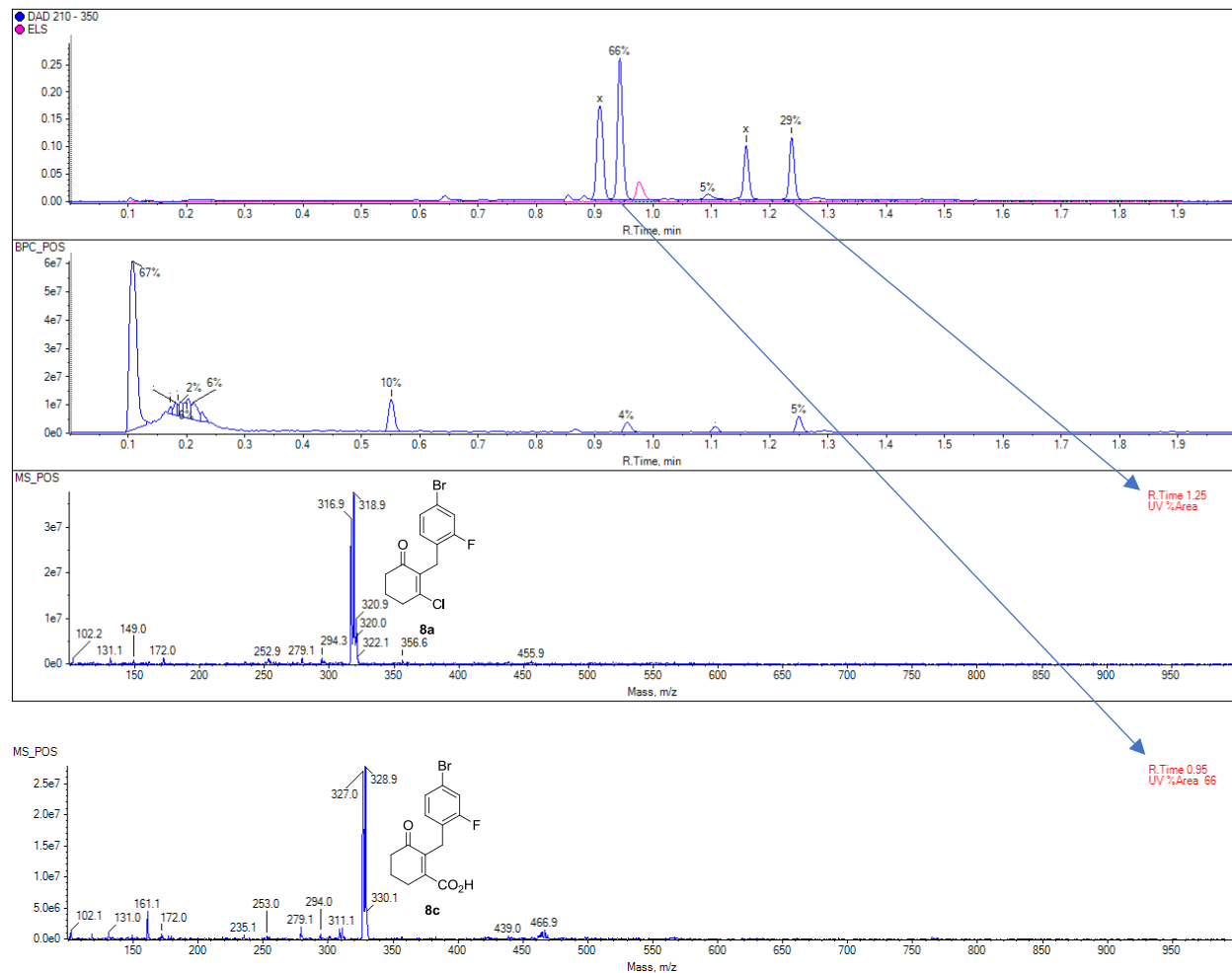


Figure S23: LCMS trace for reaction from Table S2, Entry 95.

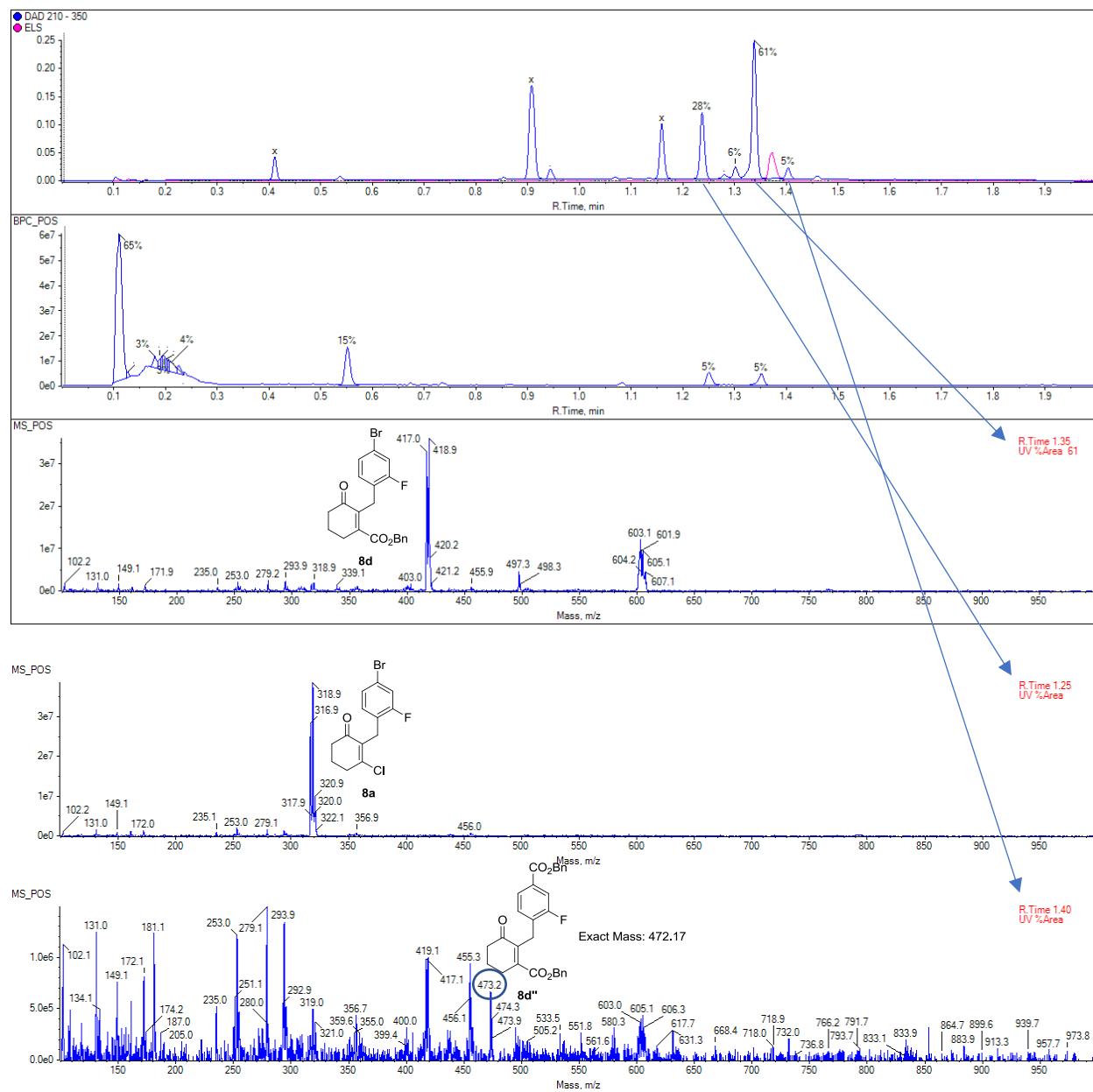


Figure S24: LCMS trace for reaction from Table S2, Entry 96.

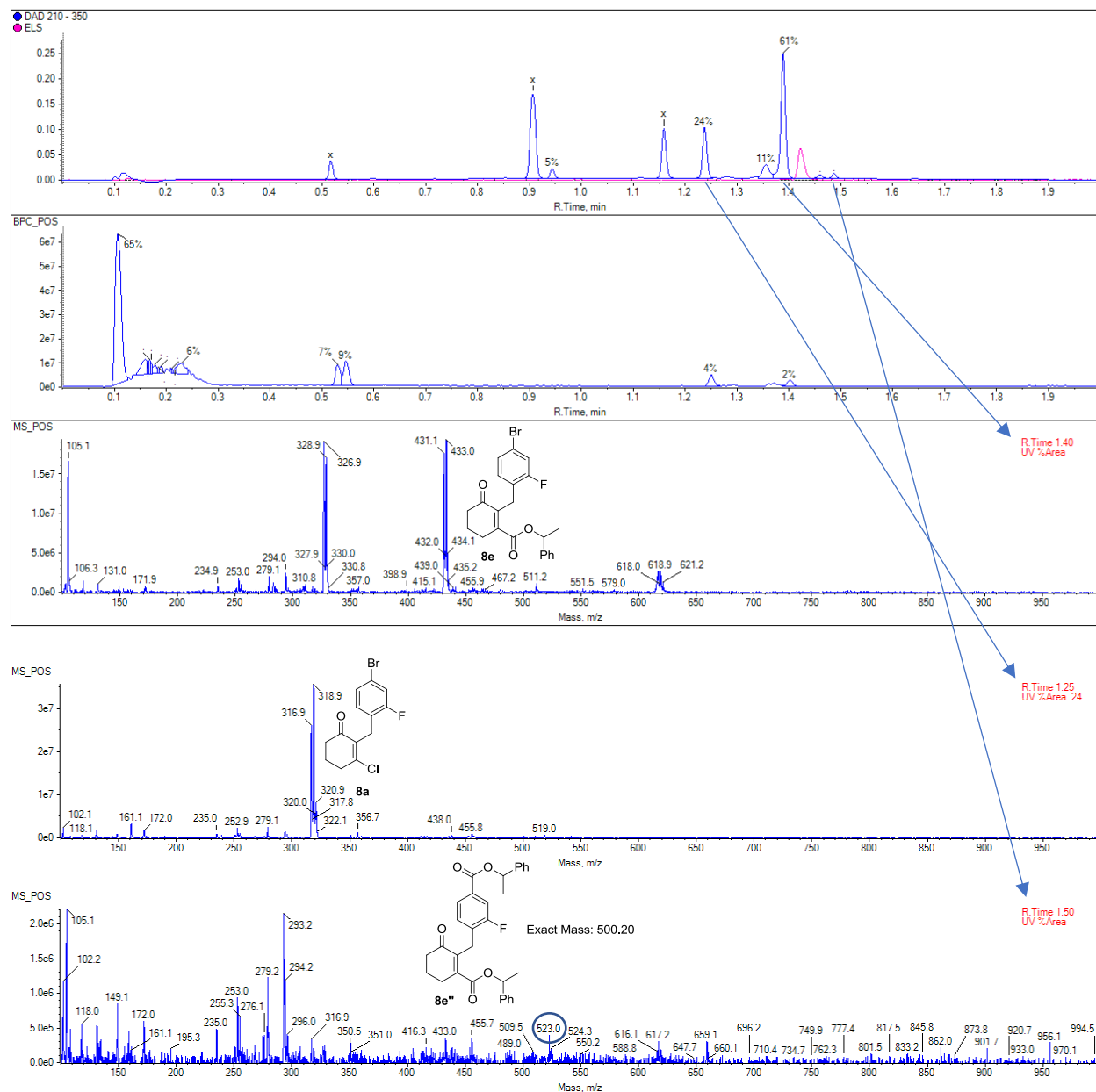


Figure S25: LCMS trace for reaction from Table S2, Entry 97.

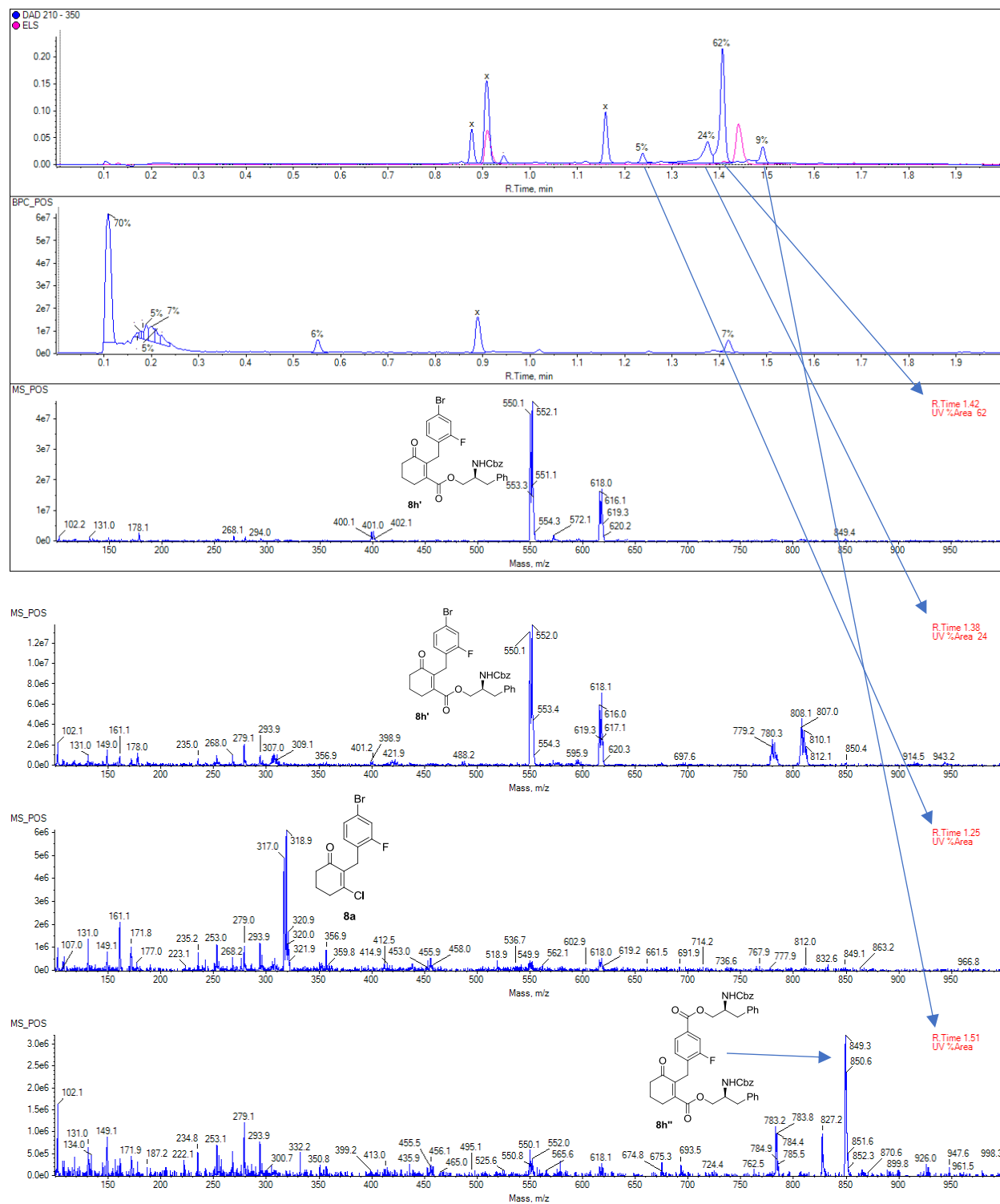


Figure S26: LCMS trace for reaction from Table S2, Entry 100.

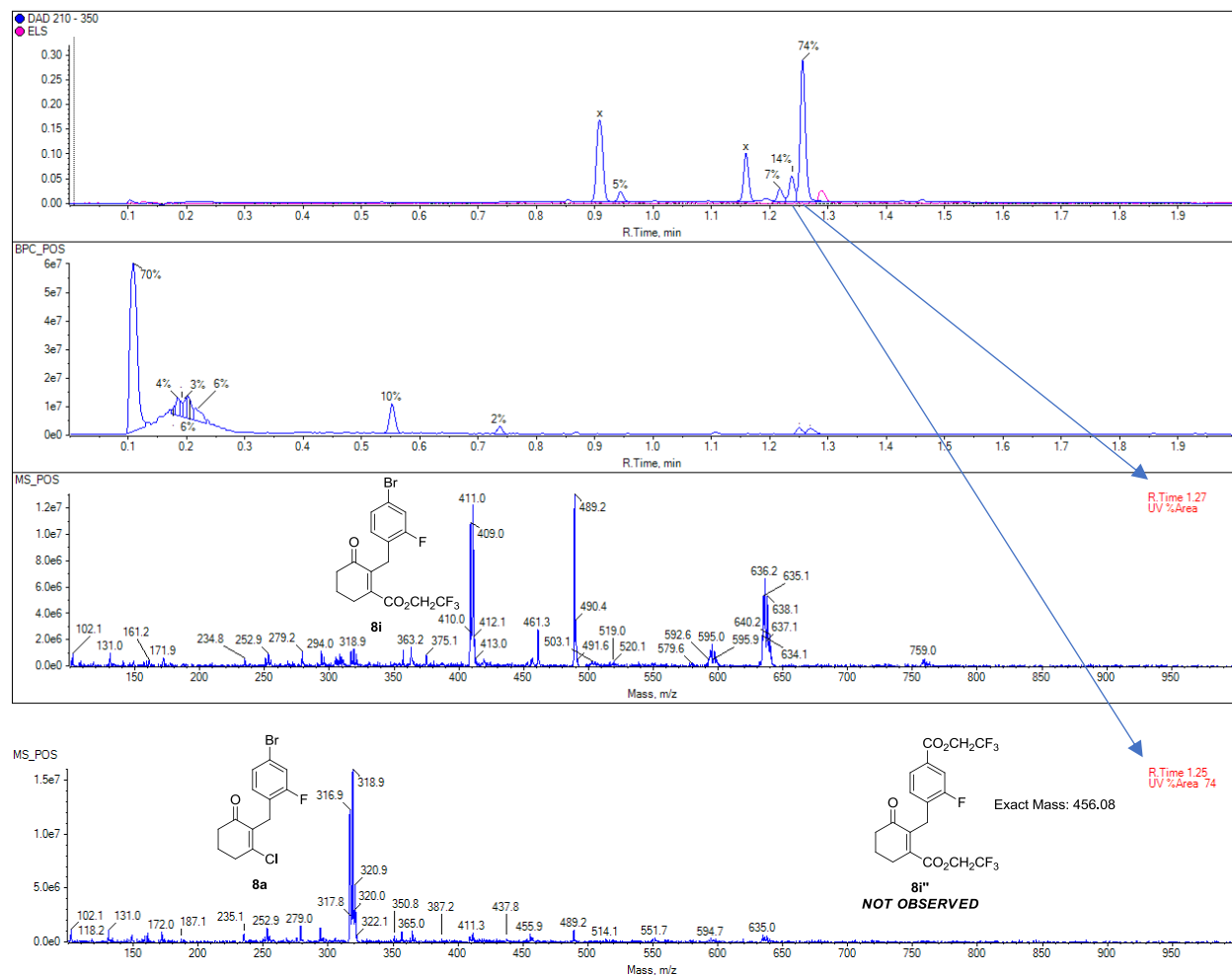


Figure S27: LCMS trace for reaction from Table S2, Entry 101.

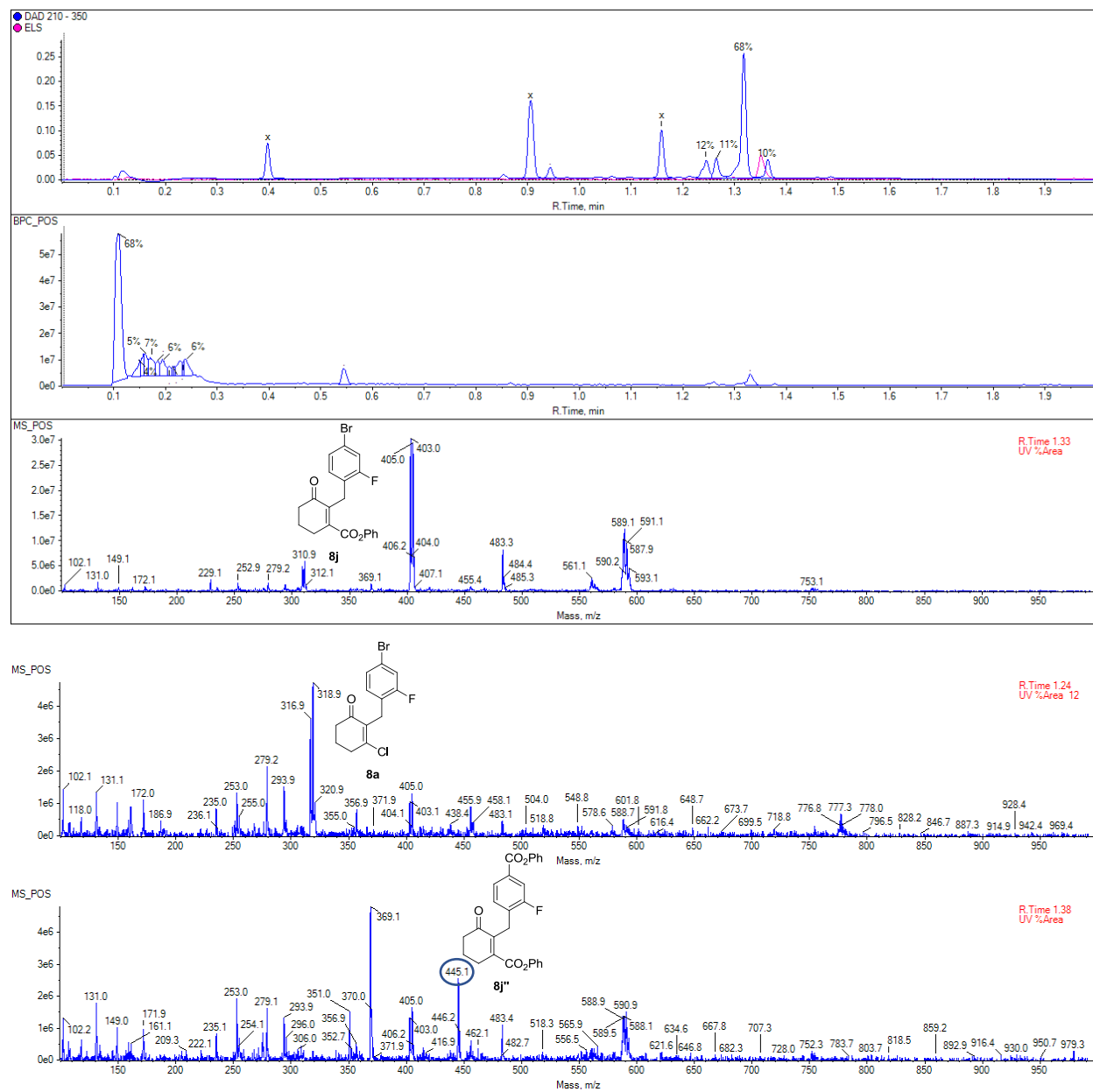


Figure S28: LCMS trace for reaction from Table S2, Entry 102.

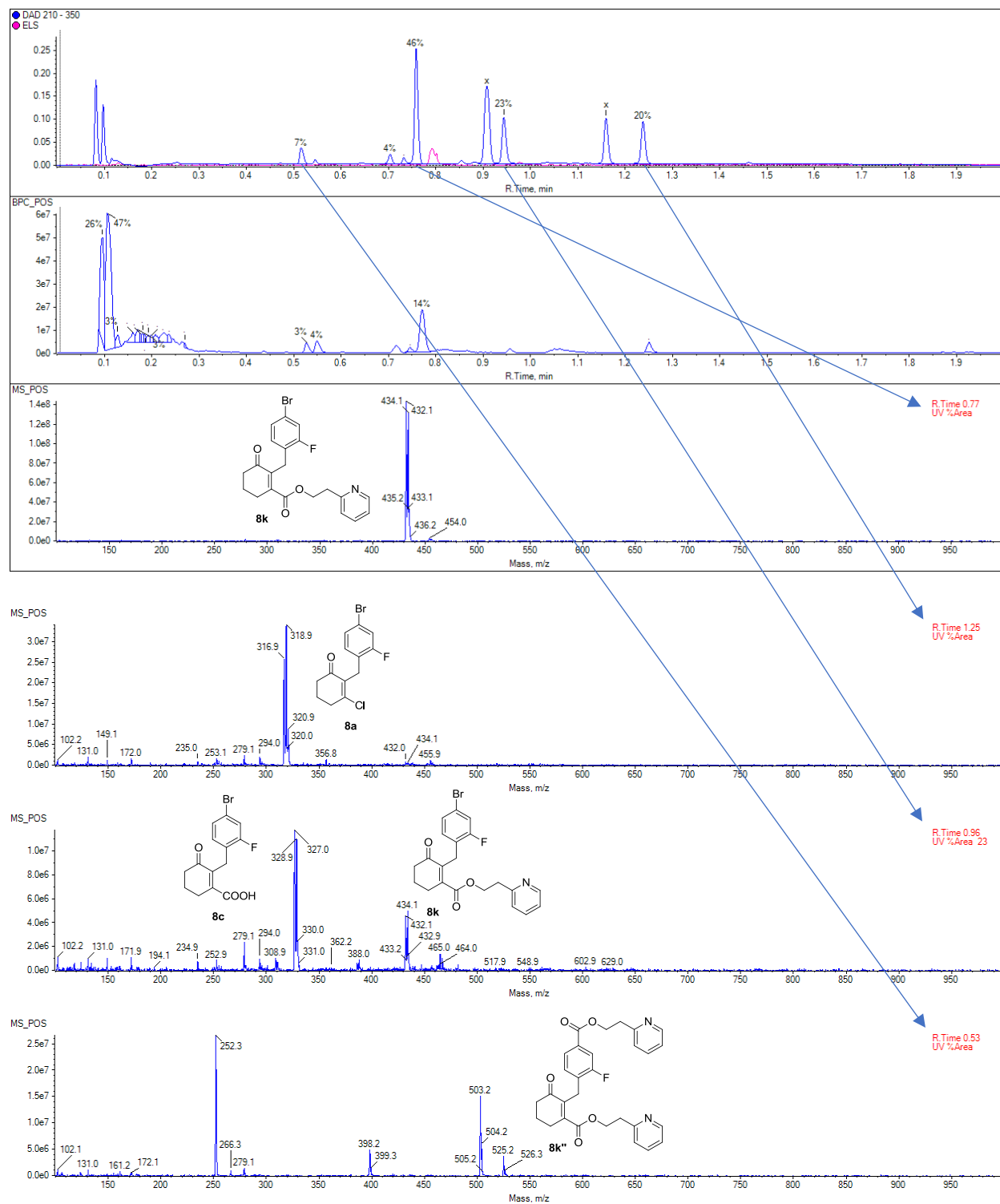
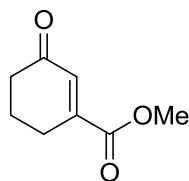


Figure S29: LCMS trace for reaction from Table S2, Entry 103.

III: Preparative-Scale Carbonylations

Characterization of Products

Compounds **1b**,⁶ **1c**,⁷ **1f**,⁸ **1g**,⁹ **3c**,¹⁰ and **5c**¹¹ have been previously reported.



1b

72% (NMR)
66% (isolated)

Material charges: **1a** (1.00 g, 7.66 mmol), PdCl₂(CH₃CN)₂ (39.7 mg, 0.153 mmol), P(Me)(*t*-Bu)₂-HBF₄ (76.0 mg, 0.306 mmol), triethylamine (1.16 g, 1.60 mL, 11.5 mmol), methanol (0.49 g, 0.62 mL, 15.3 mmol), toluene (5.0 mL), acetonitrile (5.0 mL). **1b**: 0.779 g isolated as a pale yellow oil (66% yield). ¹H NMR (400 MHz, CDCl₃) δ ppm 1.99 - 2.13 (m, 2 H) 2.41 - 2.50 (m, 2 H) 2.59 (td, *J* = 6.0, 1.9 Hz, 2 H) 3.83 (s, 3 H) 6.74 (t, *J* = 1.9 Hz, 1 H). ¹³C{¹H} NMR (101 MHz, CDCl₃) δ ppm 22.13, 24.83, 37.68, 52.60, 133.07, 148.76, 166.99, 200.06 (s, 1 C). LRMS (ESI): *m/z* = 155 [M+H]⁺, 196 [M + H + CH₃CN]⁺.

N59767-95.010.001.1r.esp

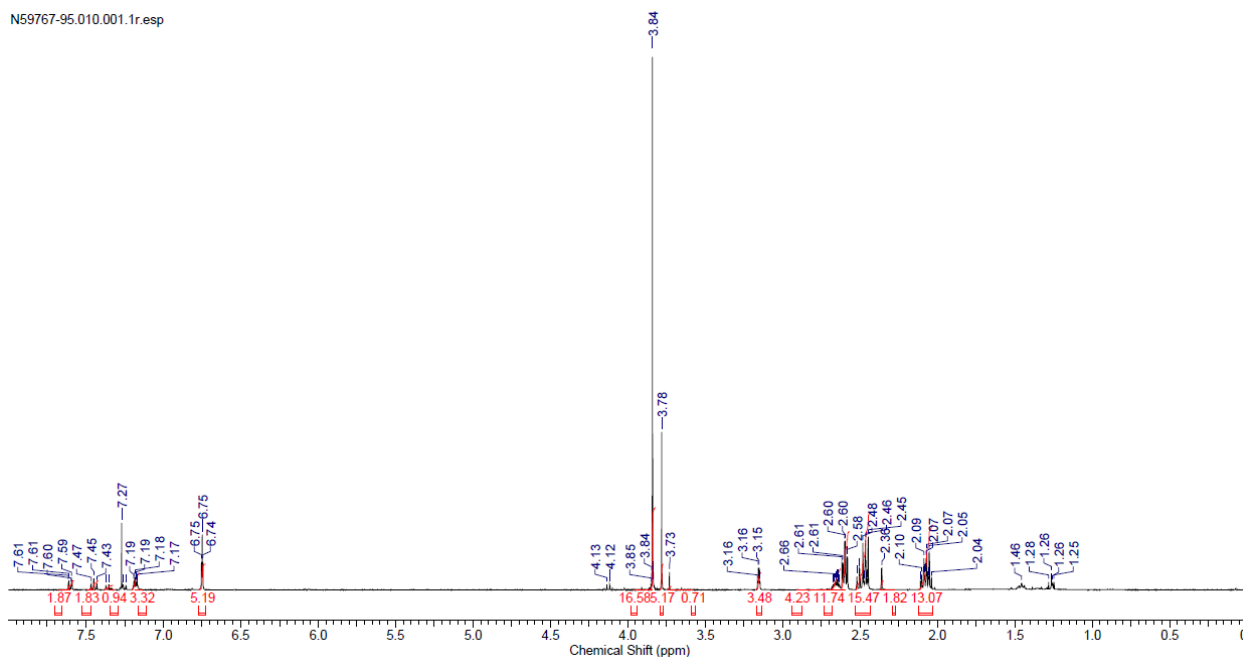


Figure S30: Crude ¹H NMR spectrum of **1b**.

NMR yield determination:

Amount of biphenyl standard added = 0.466 mmol (71.9 mg).

Peak at 7.62 ppm integration set to 0.466 mmol X 4 = 1.86 (signal corresponds to four protons)

Product peak at 3.84 ppm thus corresponds to 16.58 mmol / 3 = 5.53 mmol

NMR yield = 5.53 mmol / 7.66 mmol X 100% = **72%**

N59767-95.011.001.1r.esp

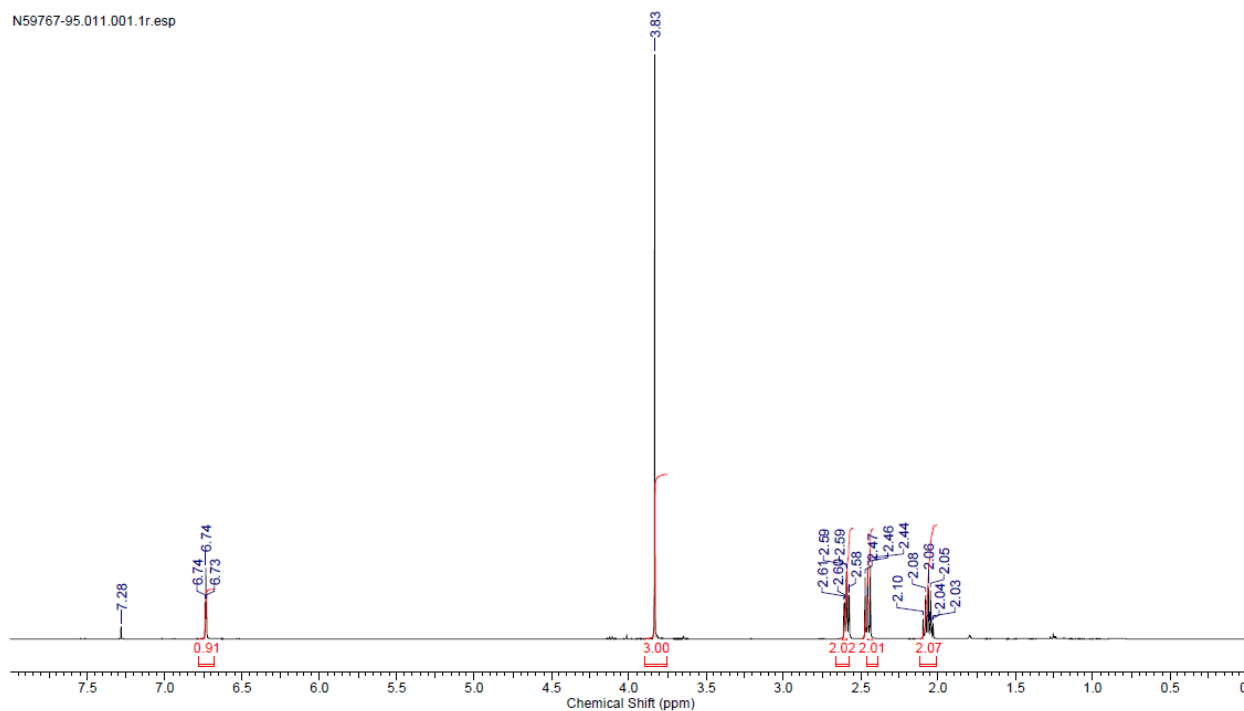


Figure S31: ¹H NMR spectrum of **1b**.

N59767-95.012.001.1r.esp

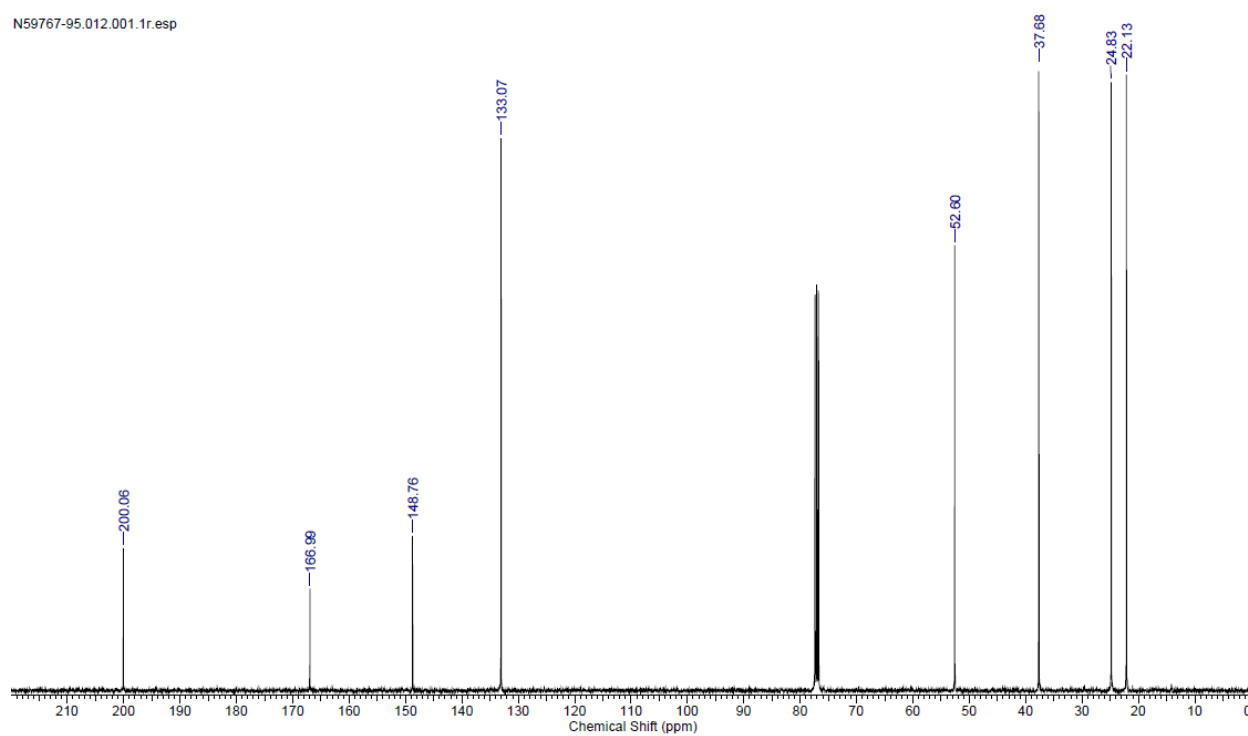


Figure S32: ¹³C{¹H} NMR spectrum of **1b**.

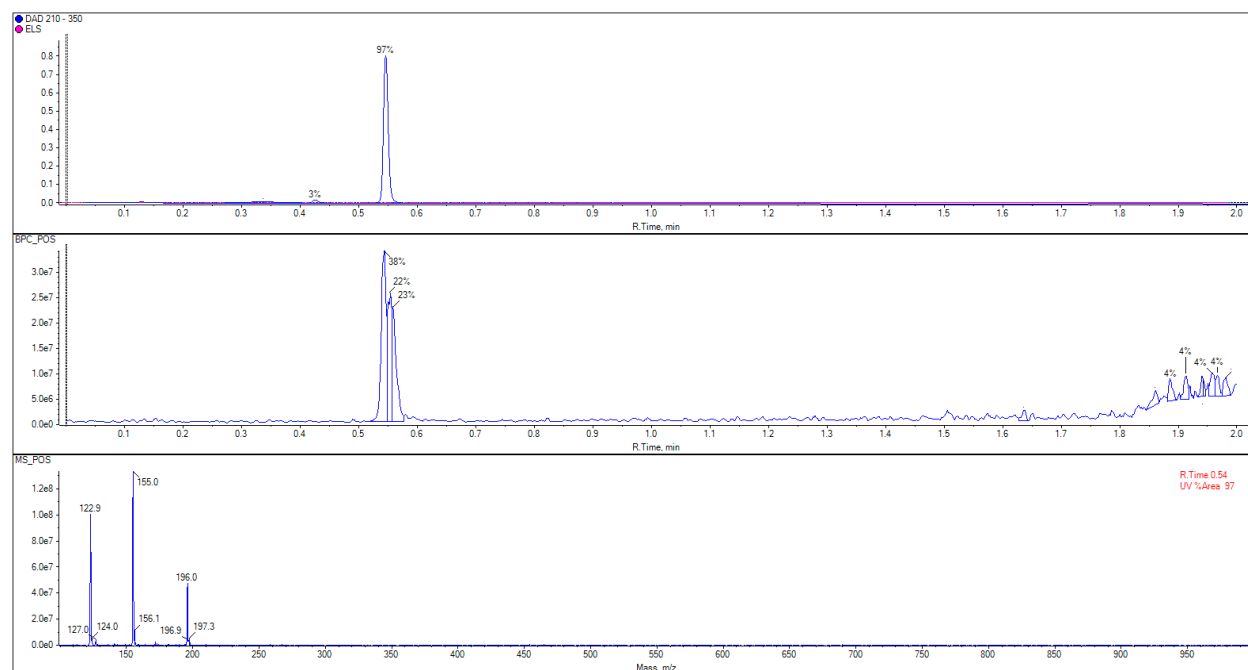
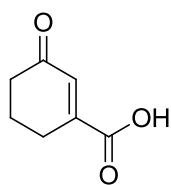


Figure S33: LCMS trace of **1b**.



1c

91% (NMR)
78% (isolated)

Material charges: **1a** (1.00 g, 7.66 mmol), PdCl₂(CH₃CN)₂ (39.7 mg, 0.153 mmol), P(Me)(*t*-Bu)₂-HBF₄ (76.0 mg, 0.306 mmol), triethylamine (1.16 g, 1.60 mL, 11.5 mmol), water (0.28 g, 0.28 mL, 15.3 mmol), toluene (5.0 mL), acetonitrile (5.0 mL). **1c**: 0.837 g isolated as a tan solid (78% yield). ¹H NMR (400 MHz, CD₃OD) δ ppm 2.01 - 2.13 (m, 2 H) 2.41 - 2.52 (m, 2 H) 2.61 (td, *J* = 6.0, 2.0 Hz, 2 H) 6.66 (t, *J* = 1.9 Hz, 1 H). ¹³C{¹H} NMR (101 MHz, CD₃OD) δ ppm 21.91, 24.51, 37.06, 131.71, 150.95, 168.03, 201.30 (s, 1 C). LRMS (ESI): *m/z* = 141 [M+H]⁺, 182 [M + H + CH₃CN]⁺.

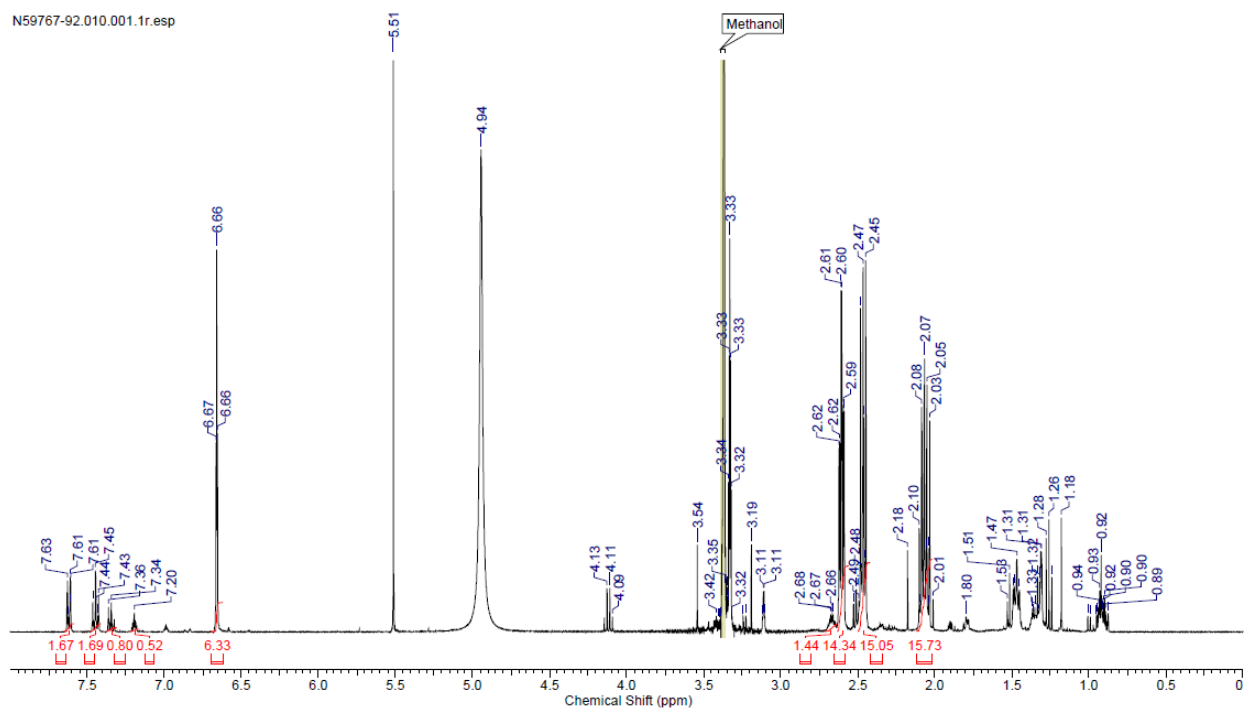


Figure S34: Crude ¹H NMR spectrum of **1c**.

NMR yield determination:

Amount of biphenyl standard added = 0.417 mmol (64.3 mg).

Peak at 7.62 ppm integration set to 0.417 mmol X 4 = 1.67 (signal corresponds to four protons)

Product peak at 6.66 ppm thus corresponds to 6.33 mmol / 0.91 = 6.96 mmol

(0.91 is response factor for signal at 6.66 ppm – see below spectrum for isolated material)

NMR yield = 6.96 mmol / 7.66 mmol X 100% = **91%**

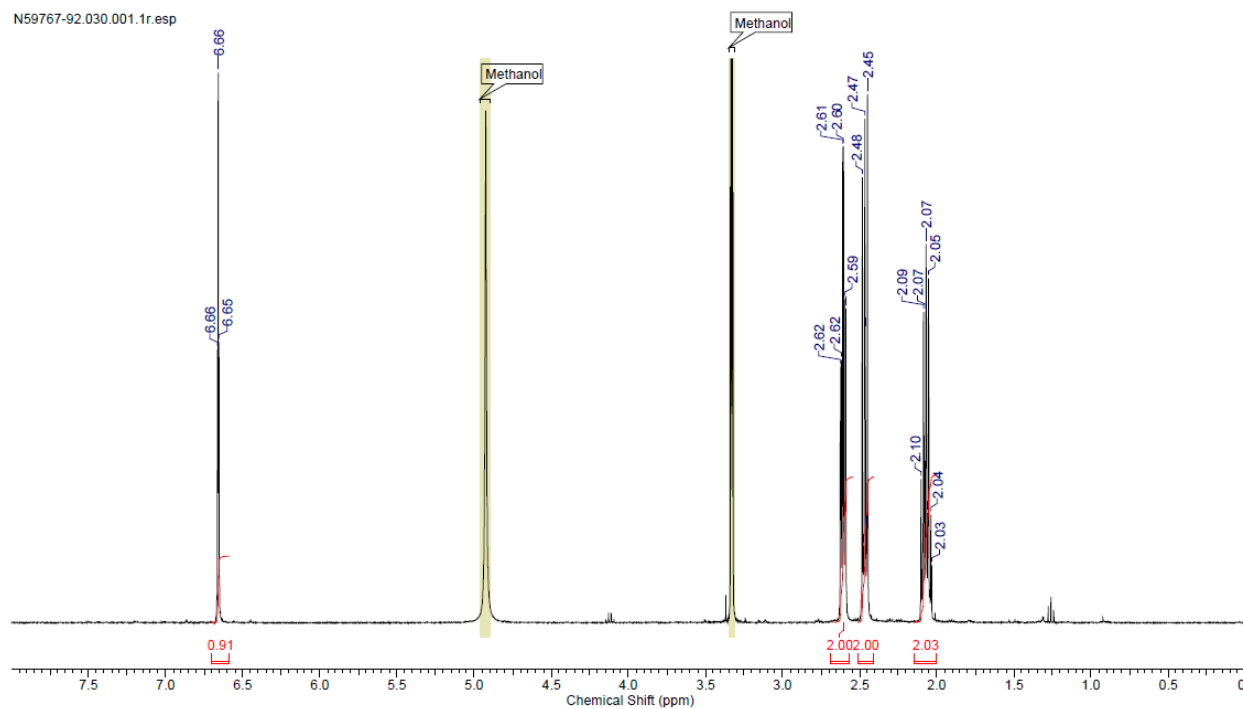


Figure S35: ^1H NMR spectrum of **1c**. Peaks denoted 'methanol' correspond to residual protio solvent from CD_3OD .

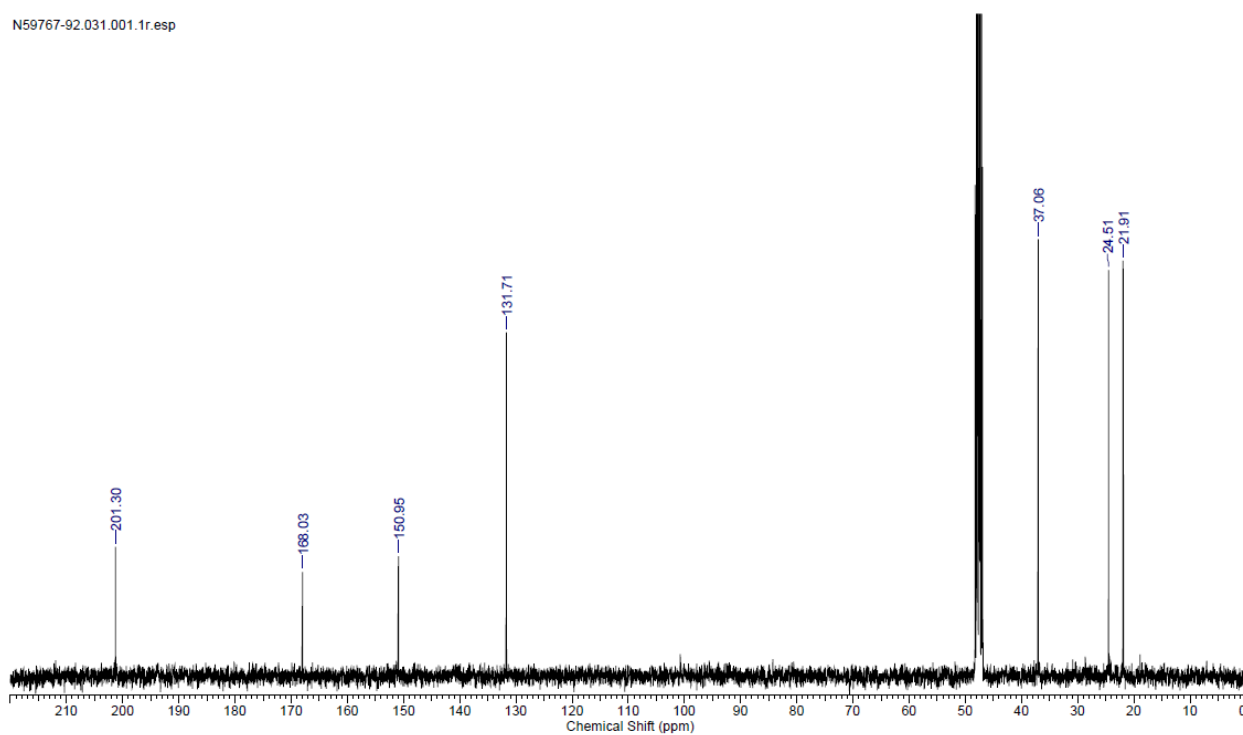


Figure S36: $^{13}\text{C}\{^1\text{H}\}$ NMR spectrum of **1c**.

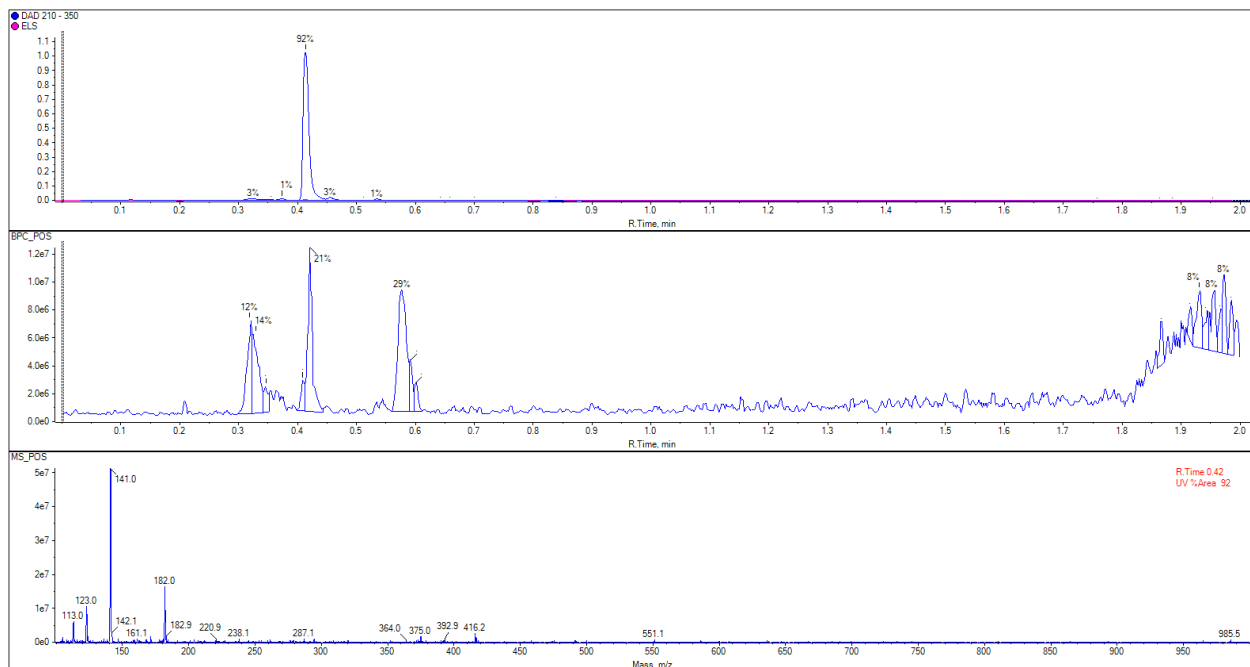
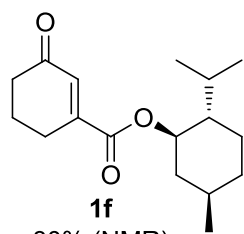


Figure S37: LCMS trace of **1c**.



80% (NMR)
69% (isolated)

Material charges: **1a** (1.00 g, 7.66 mmol), PdCl₂(CH₃CN)₂ (39.7 mg, 0.153 mmol), P(Me)(*t*-Bu)₂-HBF₄ (76.0 mg, 0.306 mmol), triethylamine (1.16 g, 1.60 mL, 11.5 mmol), menthol (2.39 g, 15.3 mmol), toluene (5.0 mL), acetonitrile (5.0 mL). **1f**: 1.47 g isolated as a viscous yellow oil (69% yield). ¹H NMR (400 MHz, CDCl₃) δ ppm 0.76 (d, *J* = 7.0 Hz, 3 H, menthyl-CH₃), 0.90 (d, *J* = 6.7 Hz, 3 H, menthyl-CH(CH₃)₂), 0.92 (d, *J* = 6.7 Hz, 3 H, menthyl-CH(CH₃)₂), 0.96 - 1.16 (m, 2 H), 1.38 - 1.60 (m, 2 H), 1.65 - 1.76 (m, 2 H), 1.86 (td, *J* = 7.0, 2.7 Hz, 1 H), 1.98 - 2.13 (m, 3 H), 2.40 - 2.50 (m, 2 H), 2.59 (tdd, *J* = 6.0, 6.0, 4.0, 1.9 Hz, 2 H, -CH₂-C=O), 4.80 (td, *J* = 10.9, 4.4 Hz, 1 H, -C(O)O-CH-), 6.73 (t, *J* = 1.9 Hz, 1 H, -C=CH-). ¹³C{¹H} NMR (101 MHz, CDCl₃) δ ppm 16.31, 20.76, 21.97, 22.15, 23.38, 24.89, 26.35, 31.39, 34.13, 37.71, 40.67, 47.03, 75.78 (-O-CH-), 132.64 (-C=CH-), 149.63 (-C=CH-), 166.01 (-CO₂R), 200.38 (C=O). LRMS (ESI): *m/z* = 279 [M+H]⁺, 320 [M + Na]⁺.

N59767-73.010.001.1r.esp

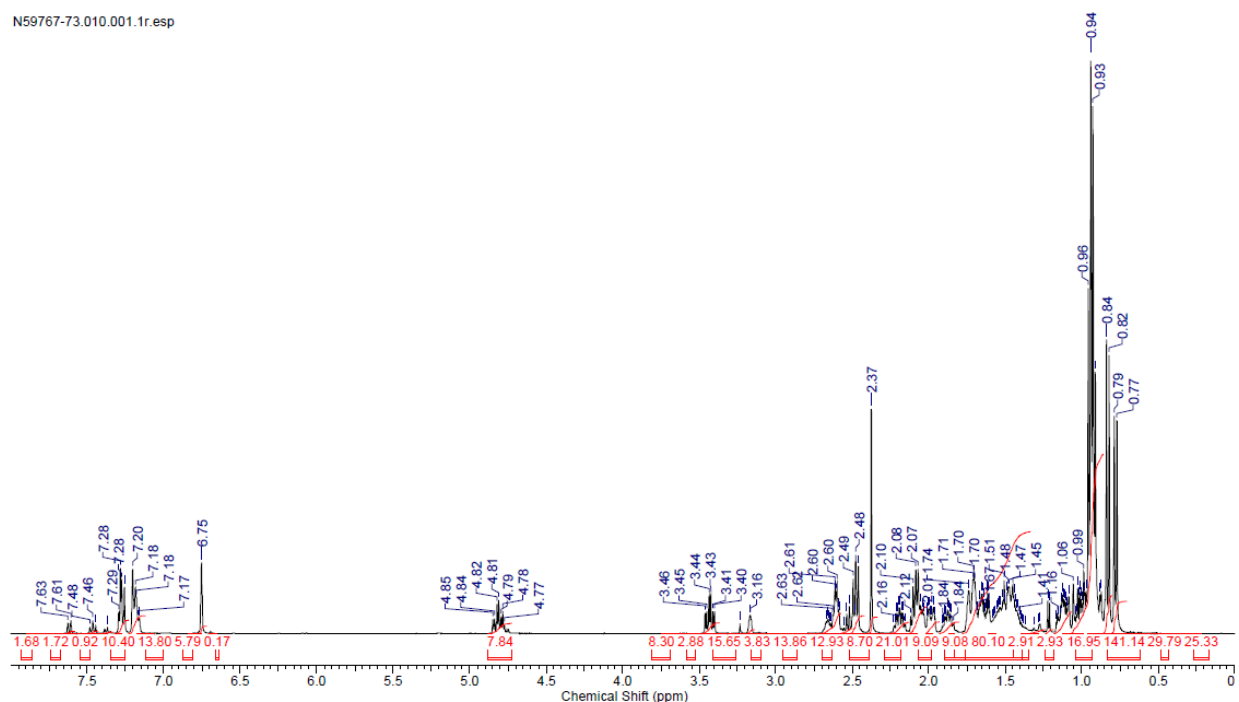


Figure S38: Crude ¹H NMR spectrum of **1f**.

NMR yield determination:

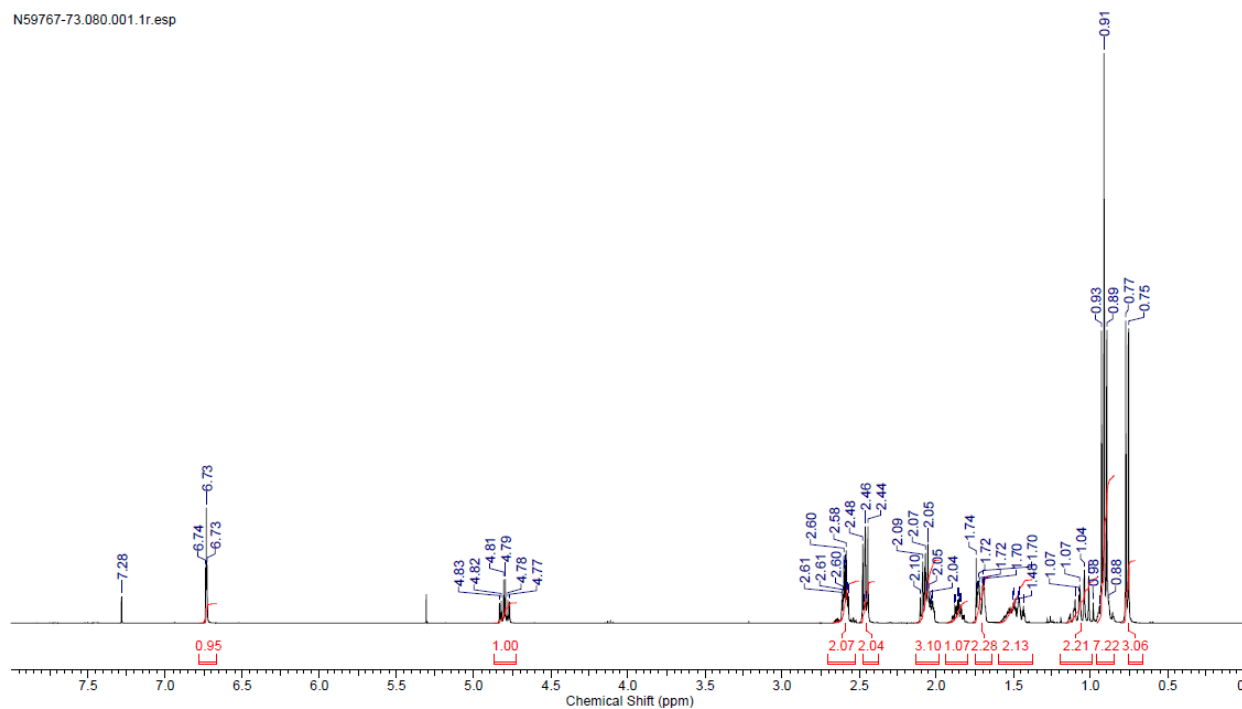
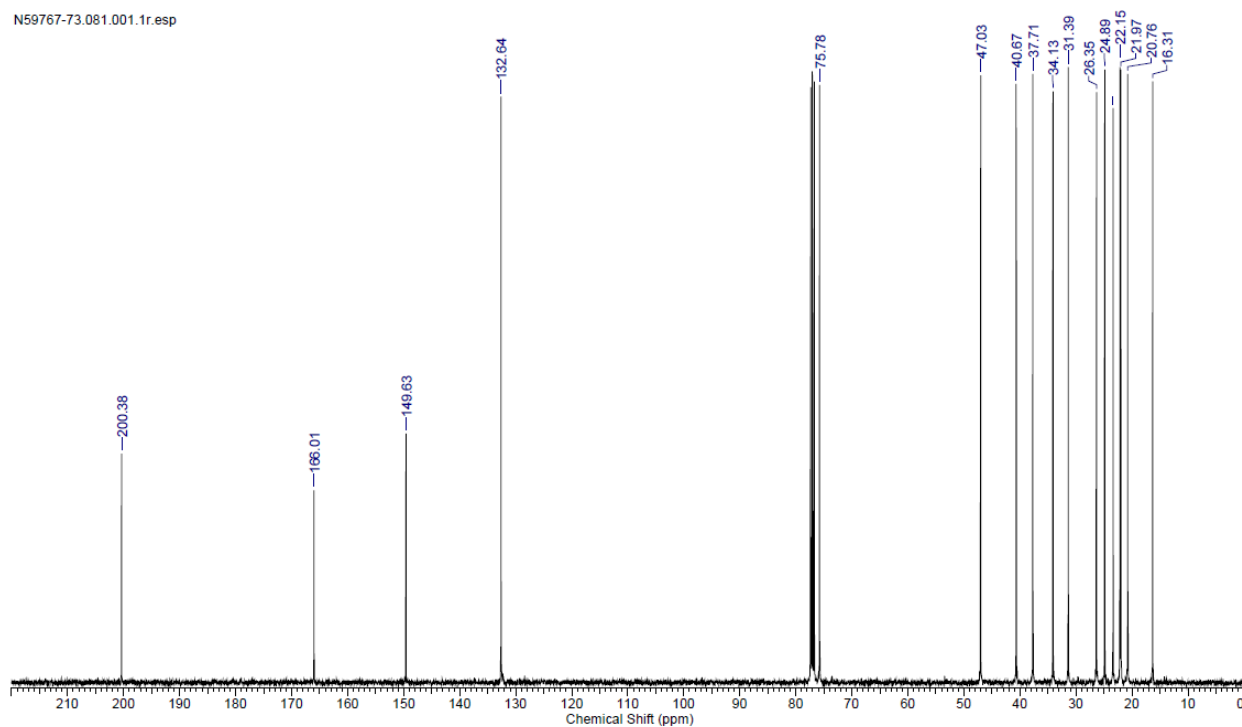
Amount of biphenyl standard added = 0.421 mmol (64.9 mg).

Peak at 7.62 ppm integration set to 0.421 mmol X 4 = 1.68 (signal corresponds to four protons)

Product peak at 6.75 ppm thus corresponds to 5.79 mmol / 0.95 = 6.10 mmol

(0.95 is response factor for vinyl C-H signal – see ¹H NMR spectrum for isolated material)

NMR yield = 6.10 mmol / 7.66 mmol X 100% = **80%**

Figure S39: ¹H NMR spectrum of **1f**.Figure S40: ¹³C{¹H} NMR spectrum of **1f**.

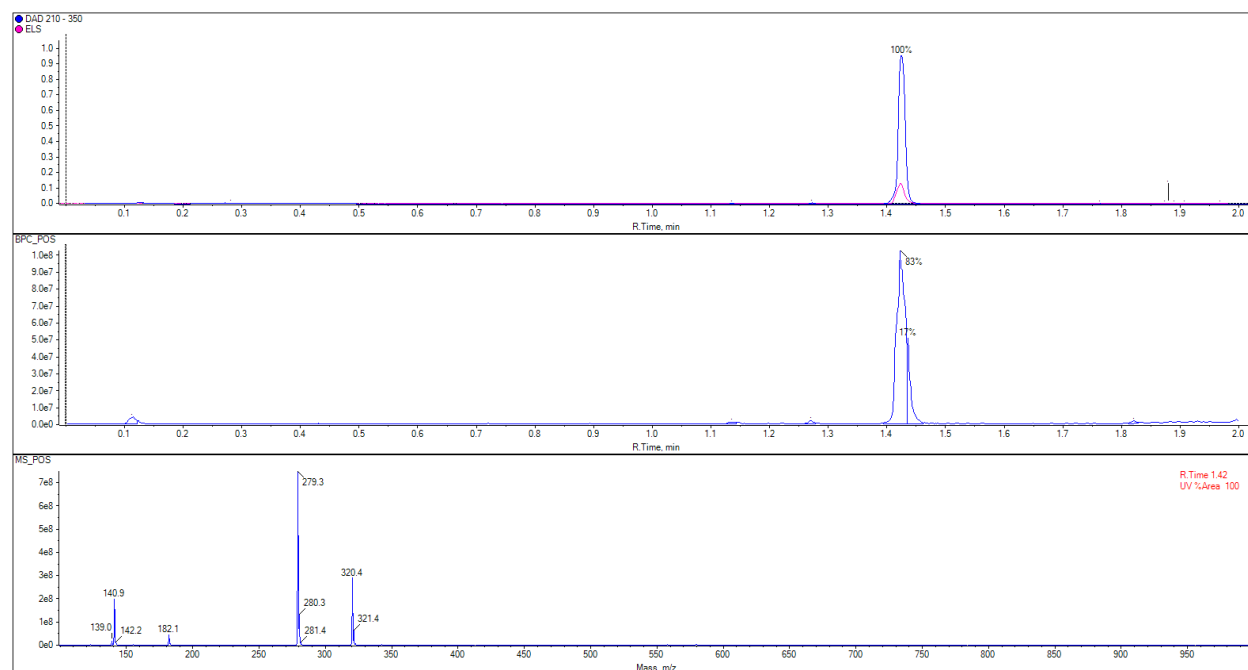
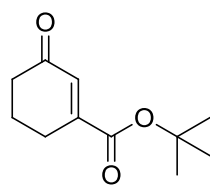


Figure S41: LCMS trace of **1f**.



1g

74% (NMR)
59% (isolated)

Material charges: **1a** (1.00 g, 7.66 mmol), $\text{PdCl}_2(\text{CH}_3\text{CN})_2$ (39.7 mg, 0.153 mmol), $\text{P}(\text{Me})(t\text{-Bu})_2\text{-HBF}_4$ (76.0 mg, 0.306 mmol), triethylamine (1.16 g, 1.60 mL, 11.5 mmol), *tert*-butanol (1.14 g, 1.45 mL, 15.3 mmol), toluene (5.0 mL), acetonitrile (5.0 mL). **1g**: 0.887 g isolated as a pale yellow oil (59% yield). ^1H NMR (400 MHz, CDCl_3) δ ppm 1.52 (s, 9 H, $-\text{C}(\text{CH}_3)_3$), 1.97 - 2.12 (m, 2 H, $-\text{CH}_2-$), 2.40 - 2.49 (m, 2 H, $-\text{CH}_2-\text{C}=\text{C}-$), 2.55 (td, $J = 6.0, 1.9$ Hz, 2 H $-\text{CH}_2-\text{C}=\text{O}$), 6.68 (t, $J = 1.9$ Hz, 1 H $-\text{C}=\text{CH}-$). $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3) δ ppm 22.19 ($-\text{CH}_2-$), 24.82 ($-\text{CH}_2-$), 27.94 ($-\text{OC}(\text{CH}_3)_3$), 37.71 ($-\text{CH}_2-\text{C}=\text{O}$), 82.21 ($-\text{OC}(\text{CH}_3)_3$), 132.33 ($-\text{C}=\text{CH}-$), 150.87 ($-\text{C}=\text{CH}-$), 165.63 ($-\text{CO}_2t\text{Bu}$), 200.64 ($-\text{C}=\text{O}$). LRMS (ESI): $m/z = 197$ $[\text{M}+\text{H}]$, 238 $[\text{M}+\text{H}+\text{CH}_3\text{CN}]^+$.

N59767-74.010.001.1R.ESP

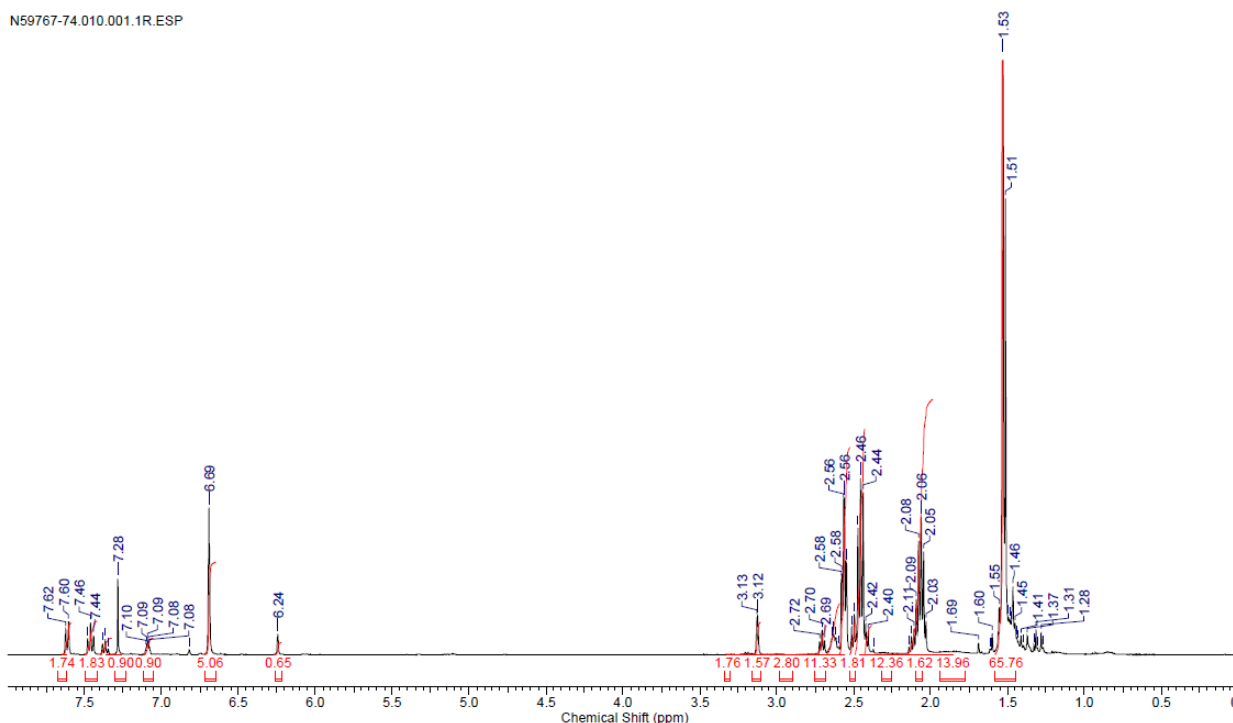


Figure S42: Crude ^1H NMR spectrum of **1g**.

NMR yield determination:

Amount of biphenyl standard added = 0.434 mmol (66.9 mg).

Peak at 7.61 ppm integration set to 0.434 mmol X 4 = 1.74 (signal corresponds to four protons)

Product peak at 6.69 ppm thus corresponds to 5.06 mmol / 0.89 = 5.69 mmol

(0.89 is response factor for vinyl C-H signal – see ^1H NMR spectrum for isolated material)

NMR yield = 5.69 mmol / 7.66 mmol X 100% = **74%**

NMRz.140.001.1r.esp

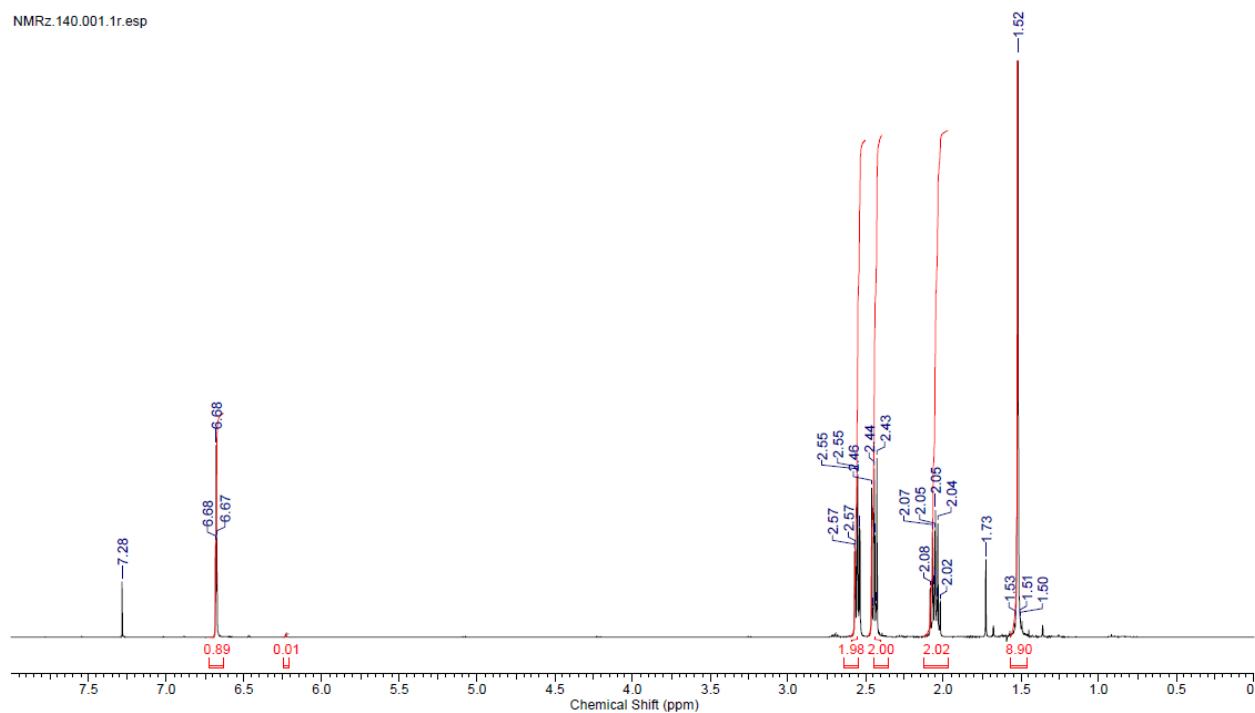


Figure S43: ¹H NMR spectrum of **1g**.

NMRz.141.001.1r.esp

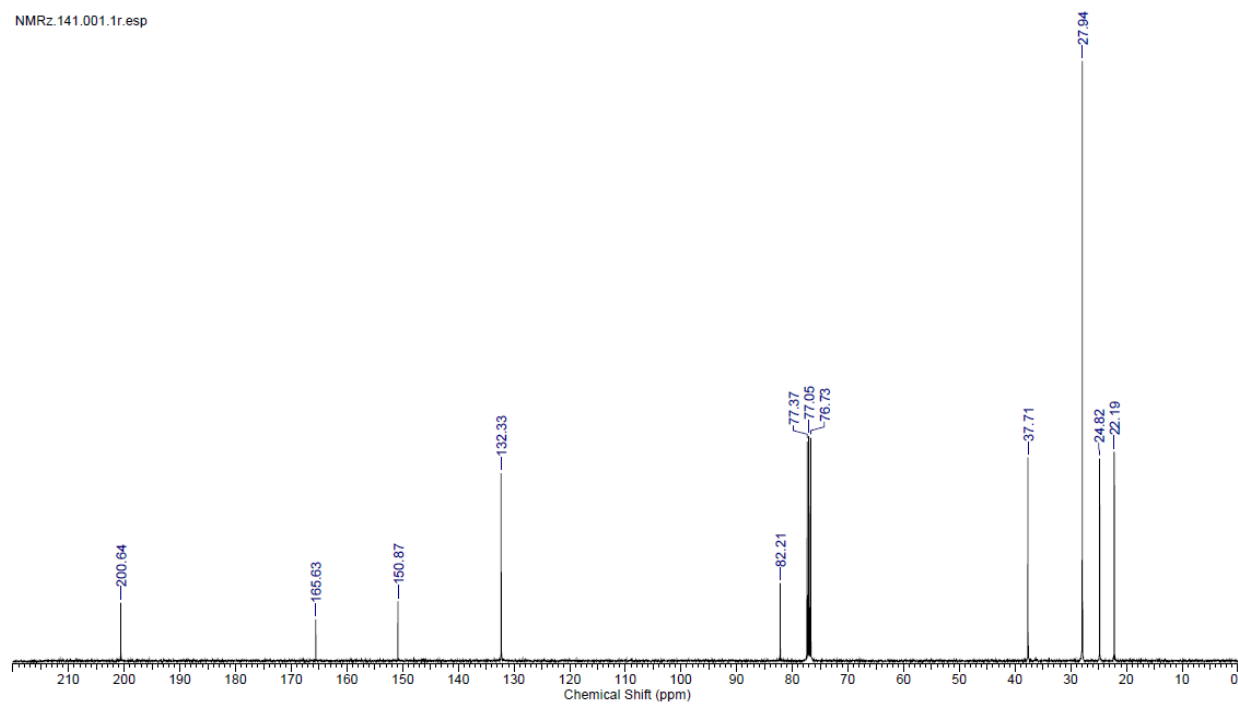


Figure S44: ¹³C{¹H} NMR spectrum of **1g**.

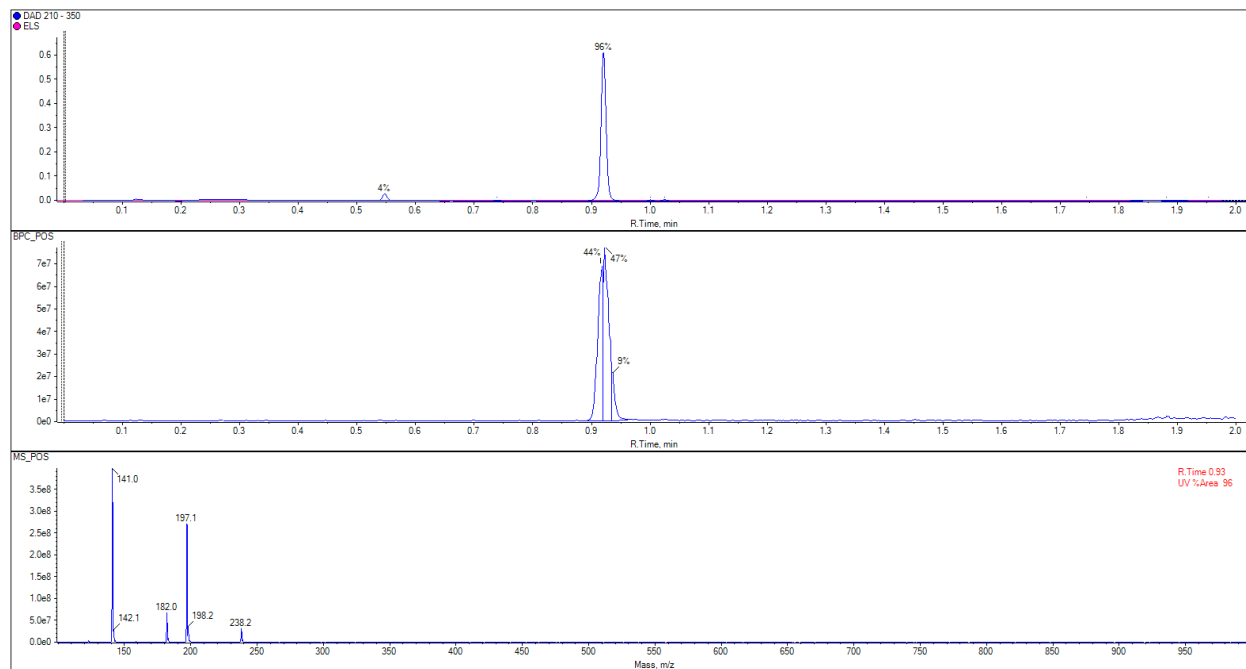
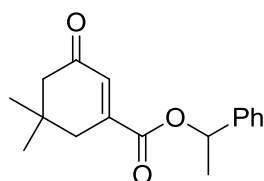


Figure S45: LCMS trace of 1g.



2e

83% (NMR)
73% (isolated)

Material charges: **2a** (1.00 g, 6.30 mmol), PdCl₂(CH₃CN)₂ (32.7 mg, 0.126 mmol), P(Me)(*t*-Bu)₂-HBF₄ (62.6 mg, 0.252 mmol), triethylamine (0.957 g, 1.32 mL, 11.5 mmol), 1-phenylethanol (1.54 g, 12.6 mmol), toluene (5.0 mL), acetonitrile (5.0 mL). **2e**: 1.25 g isolated as a yellow oil (73% yield). ¹H NMR (400 MHz, CDCl₃) δ ppm 1.07 (s, 3 H) 1.09 (s, 3 H) 1.63 (d, *J*=6.55 Hz, 3 H) 2.32 (s, 2 H) 2.50 (d, *J*=1.86 Hz, 2 H) 6.01 (q, *J*=6.55 Hz, 1 H) 6.84 (t, *J*=1.91 Hz, 1 H) 7.30 - 7.37 (m, 1 H) 7.37 - 7.42 (m, 3 H). ¹³C{¹H} NMR (101 MHz, CDCl₃) δ ppm 22.28, 28.15, 28.17, 33.51, 38.72, 51.44, 73.90, 126.08, 128.21, 128.66, 132.15, 141.02, 147.11, 165.84, 200.62. LRMS (ESI): *m/z* = 273 [M+H]⁺, 317 [M+H+CH₃CN]⁺.

N59767-81.010.001.1r.esp

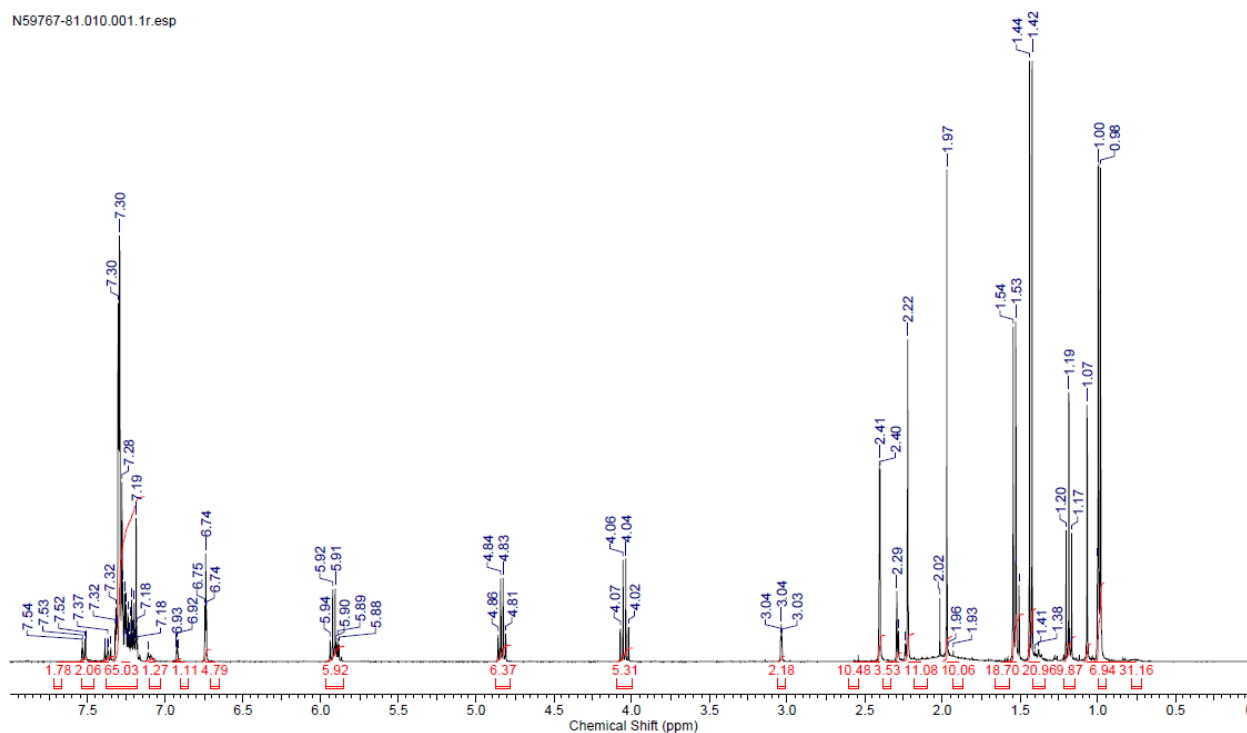


Figure S46: Crude ¹H NMR spectrum of **2e**.

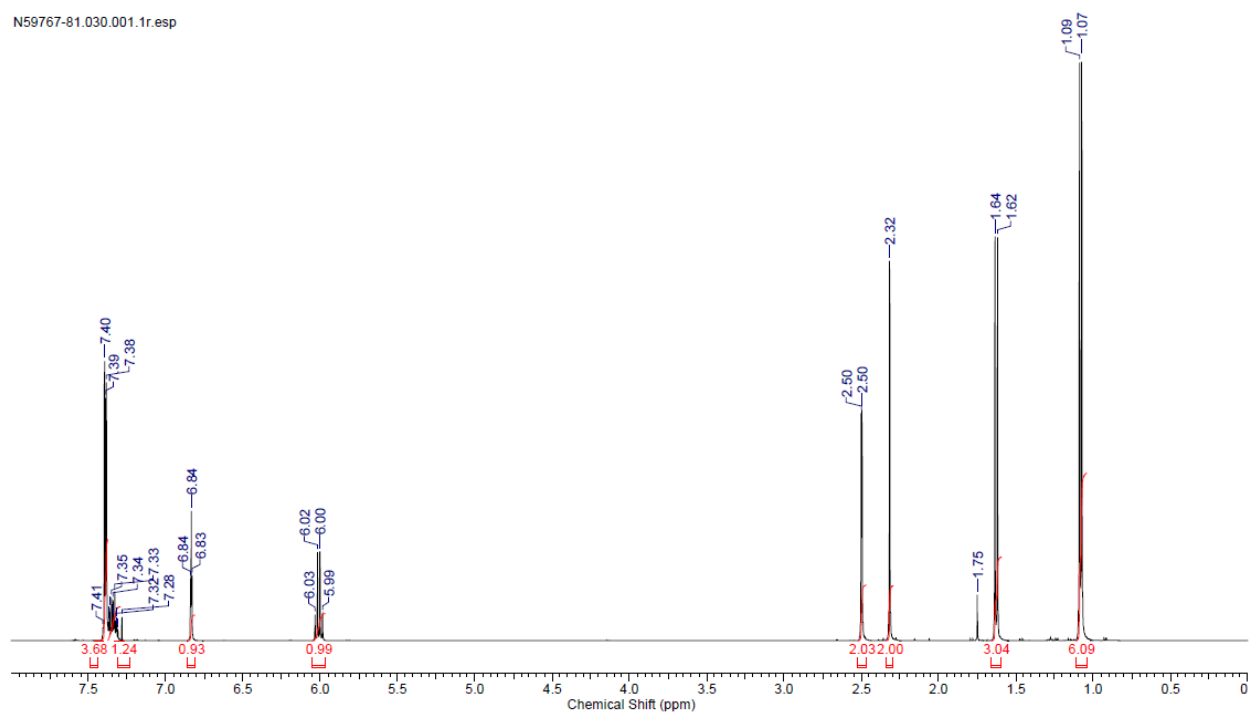
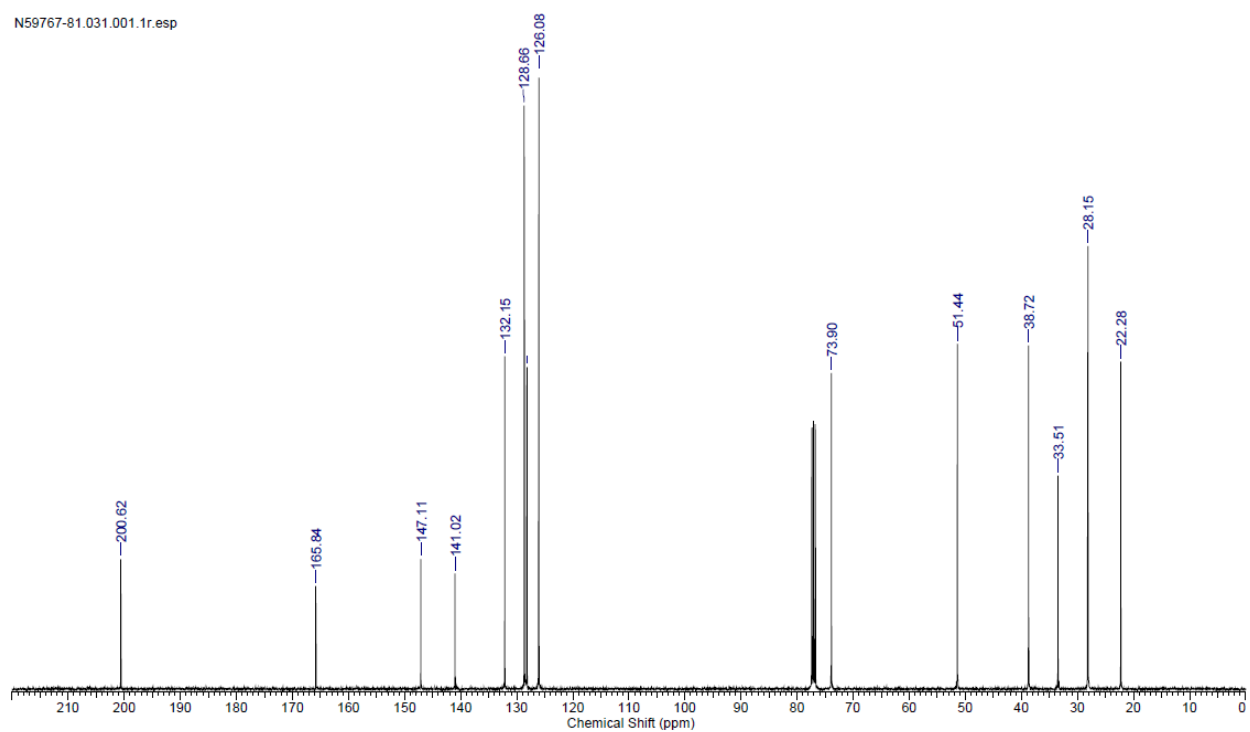
NMR yield determination:

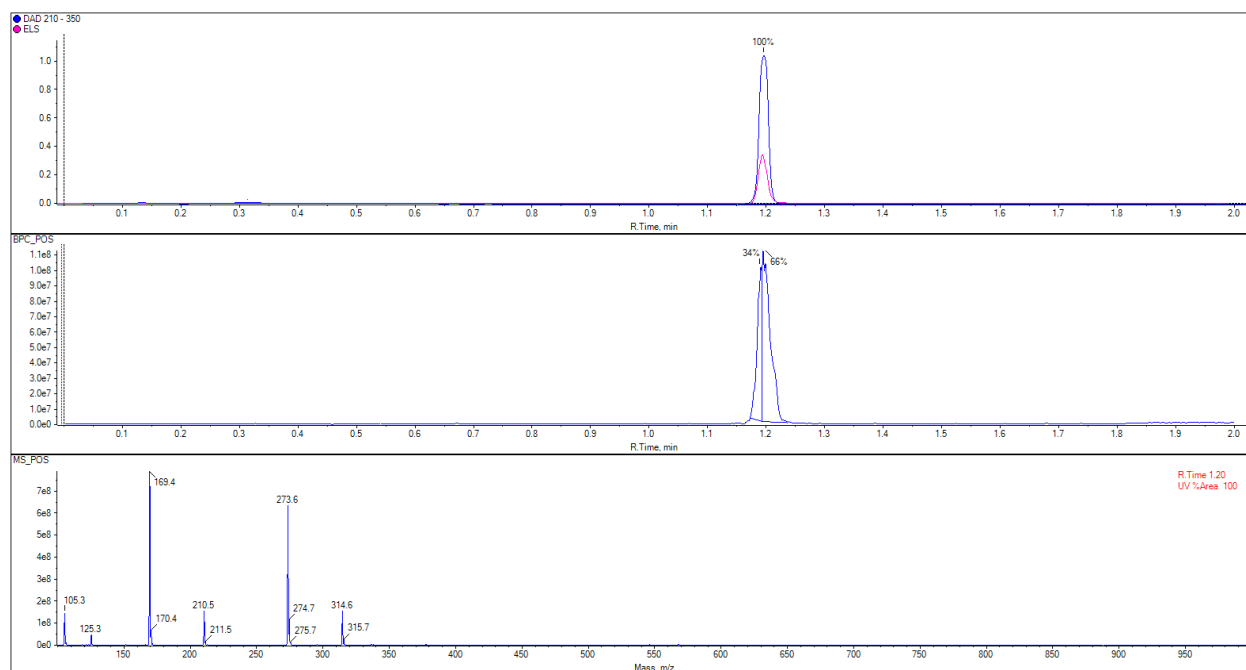
Amount of biphenyl standard added = 0.445 mmol (68.6 mg).

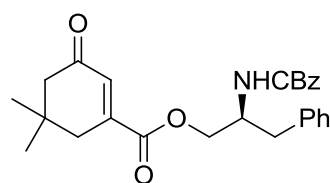
Peak at 7.54 ppm integration set to 0.445 mmol X 4 = 1.78 (signal corresponds to four protons)

Product peak at 2.41 ppm thus corresponds to 10.48 mmol / 2 = 5.24 mmol

NMR yield = 5.24 mmol / 6.30 mmol X 100% = **83%**

Figure S47: ¹H NMR spectrum of 2e.Figure S48: ¹³C{¹H} NMR spectrum of 2e.





2h

77% (NMR)
71% (isolated)

Material charges: **2a** (1.00 g, 6.30 mmol), PdCl₂(CH₃CN)₂ (32.7 mg, 0.126 mmol), P(Me)(*t*-Bu)₂-HBF₄ (62.6 mg, 0.252 mmol), triethylamine (0.957 g, 1.32 mL, 11.5 mmol), *N*-CBz-L-phenylalaninol (2.16 g, 7.57 mmol), toluene (5.0 mL), acetonitrile (5.0 mL). **2h**: 1.87 g isolated as a yellow oil (71% isolated). ¹H NMR (400 MHz, CDCl₃) δ ppm 1.09 (2 x s, 3 H) 2.33 (s, 2 H) 2.47 (d, *J*=1.50 Hz, 2 H) 2.88 (dd, *J*=13.50, 7.00 Hz, 1 H) 2.96 (dd, *J*=14.00, 5.97 Hz, 1 H) 4.14 - 4.23 (m, 1 H) 4.23 - 4.35 (m, 2 H) 4.93 (d, *J*=8.22 Hz, 1 H) 5.10 (s, 2 H) 6.77 (t, *J*=1.91 Hz, 1 H) 7.20 (d, *J*=7.14 Hz, 2 H) 7.23 - 7.42 (m, 8 H). ¹³C{¹H} NMR (101 MHz, CDCl₃) δ ppm 28.11, 28.16, 33.51, 37.87, 38.71, 51.09, 51.41, 66.13, 66.91, 126.98, 128.14, 128.59, 128.79, 129.20, 132.44, 136.23, 136.54, 146.29, 155.69, 166.41, 200.38. LRMS (ESI): *m/z* = 436 [M+H]⁺.

N61569-20.010.001.1r.esp

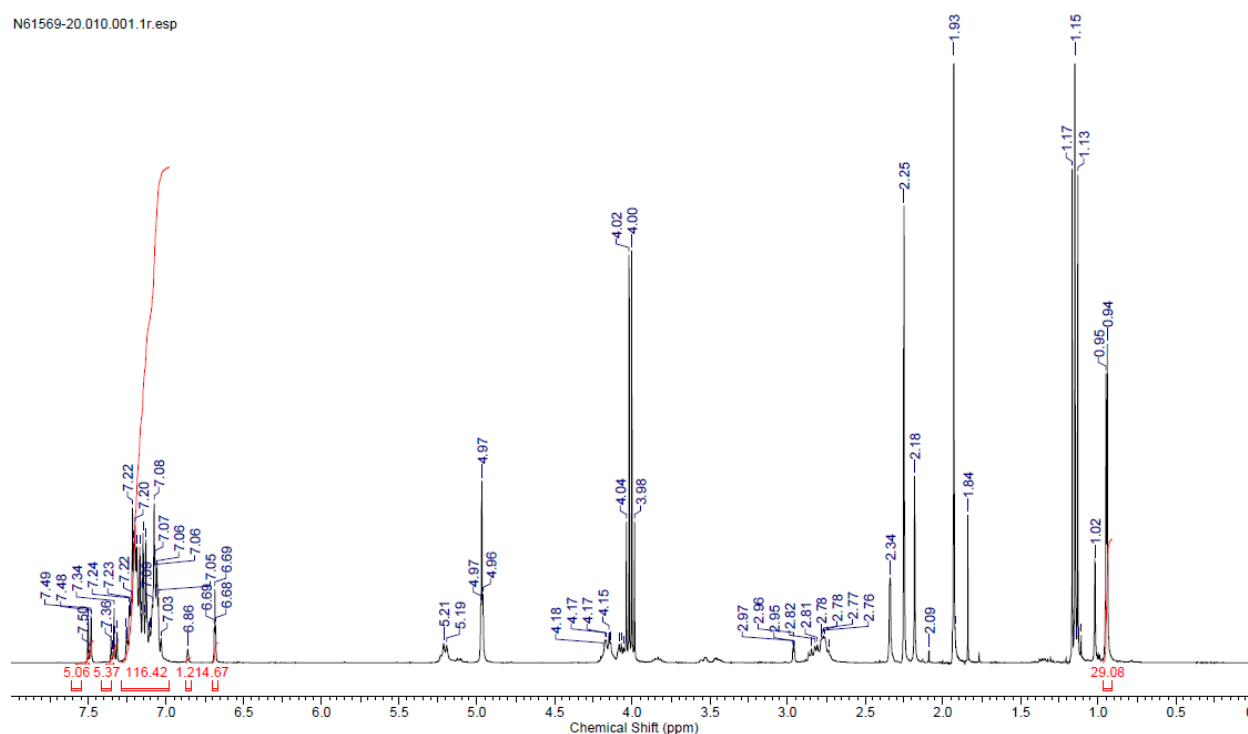


Figure S50: Crude ¹H NMR spectrum of **2h**.

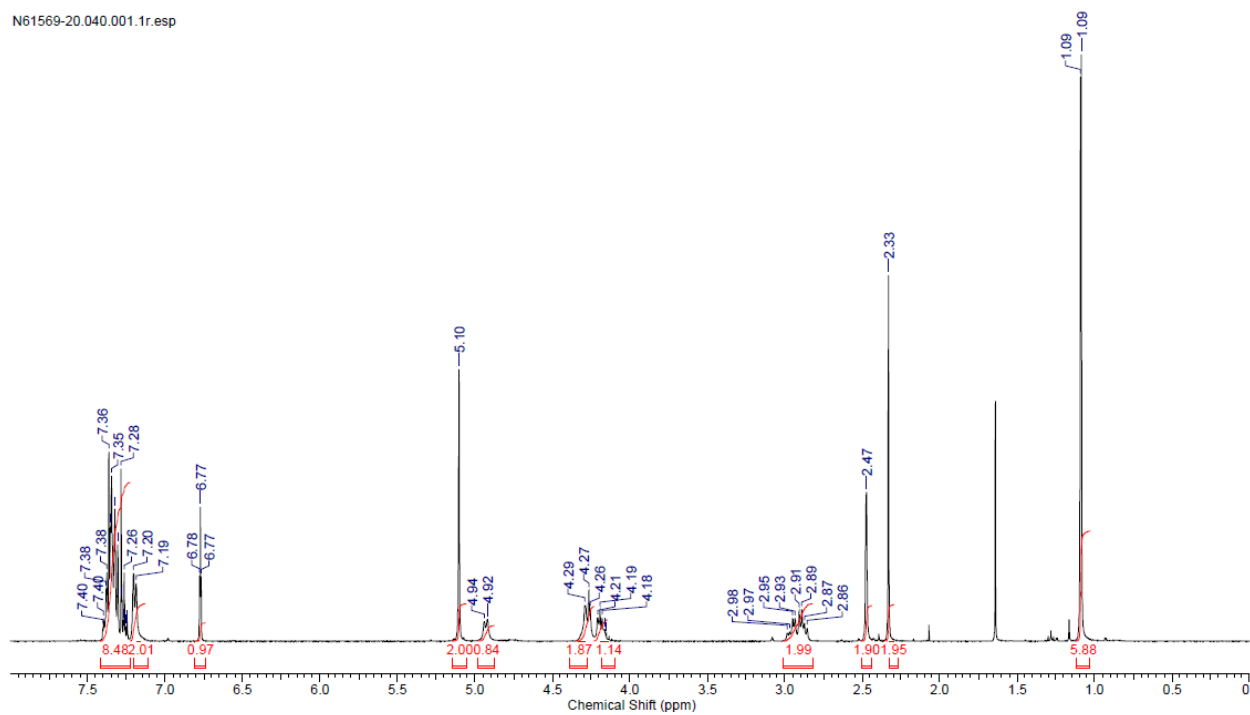
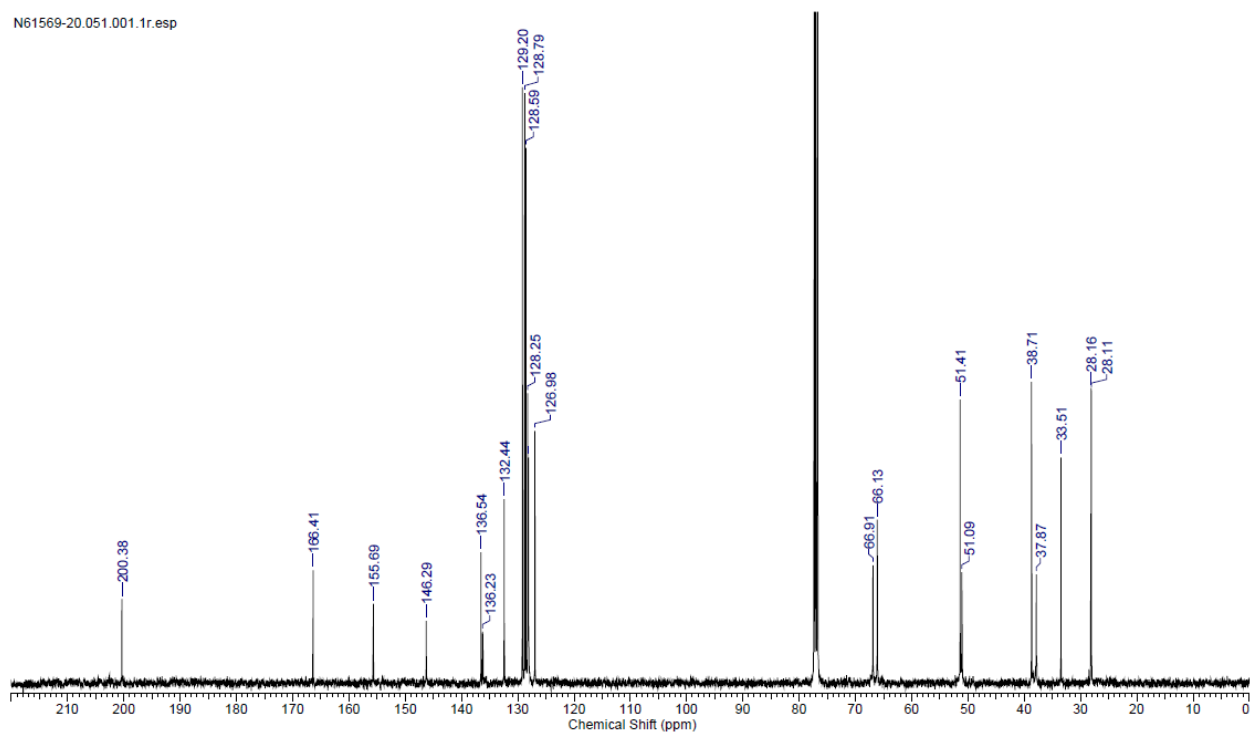
NMR yield determination:

Amount of biphenyl standard added = 1.265 mmol (195.1 mg).

Peak at 7.50 ppm integration set to 1.265 mmol X 4 = 5.06 (signal corresponds to four protons)

Product peak at 0.95 ppm thus corresponds to 29.08 mmol / 6 = 4.85 mmol

NMR yield = 4.85 mmol / 6.30 mmol X 100% = **77%**

Figure S51: ¹H NMR spectrum of **2h**.Figure S52: ¹³C{¹H} NMR spectrum of **2h**.

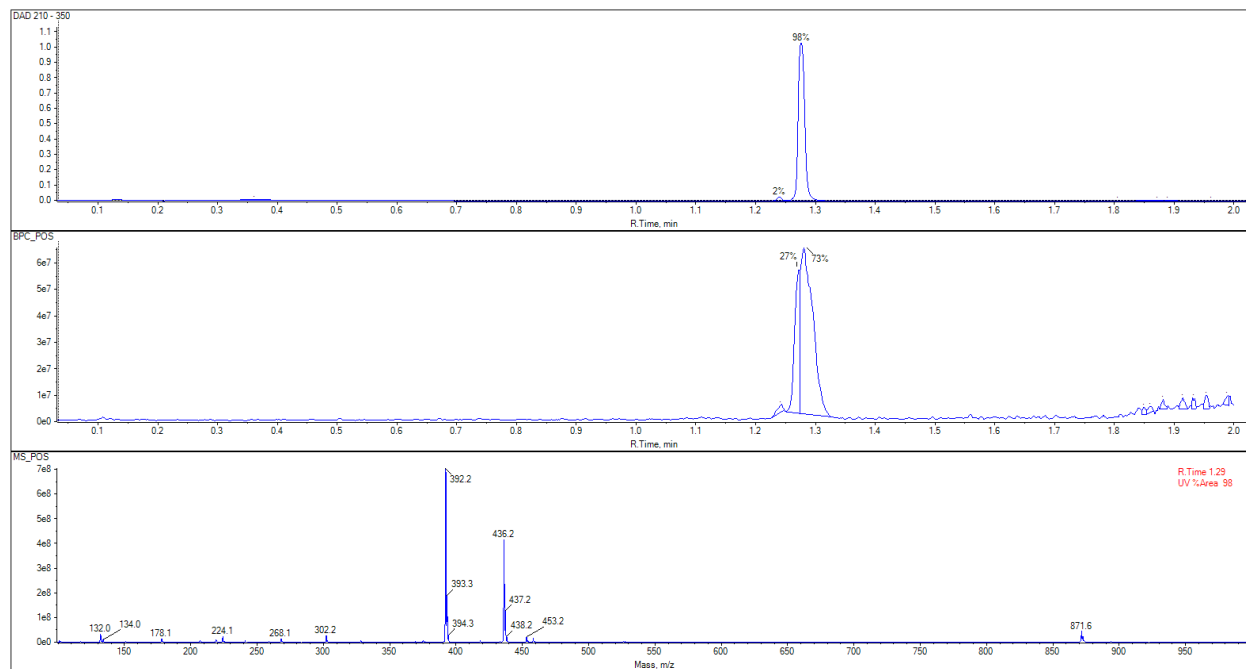
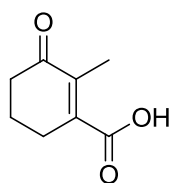


Figure S53: LCMS trace of 2h.



3c

97% (NMR)
87% (isolated)

Material charges: **3a** (1.00 g, 6.92 mmol), PdCl₂(CH₃CN)₂ (35.9 mg, 0.138 mmol), P(Me)(*t*-Bu)₂-HBF₄ (68.6 mg, 0.277 mmol), triethylamine (1.05 g, 1.45 mL, 10.4 mmol), water (0.25 g, 0.25 mL, 13.8 mmol), toluene (5.0 mL), acetonitrile (5.0 mL). **3c**: 0.928 g isolated as a pale yellow solid (87% yield). ¹H NMR (400 MHz, CD₃OD) δ ppm 1.91 (t, *J* = 2.0 Hz, 3 H) 2.00 - 2.08 (m, 2 H) 2.45 - 2.51 (m, 2 H) 2.61 (tq, *J* = 6.0, 2.0 Hz, 2 H). ¹³C{¹H} NMR (101 MHz, CD₃OD) δ ppm 11.32, 22.00, 27.02, 37.29, 134.78, 146.65, 170.28, 200.37. LRMS (ESI): *m/z* = 155 [M+H]⁺, 196 [M+H+CH₃CN]⁺.

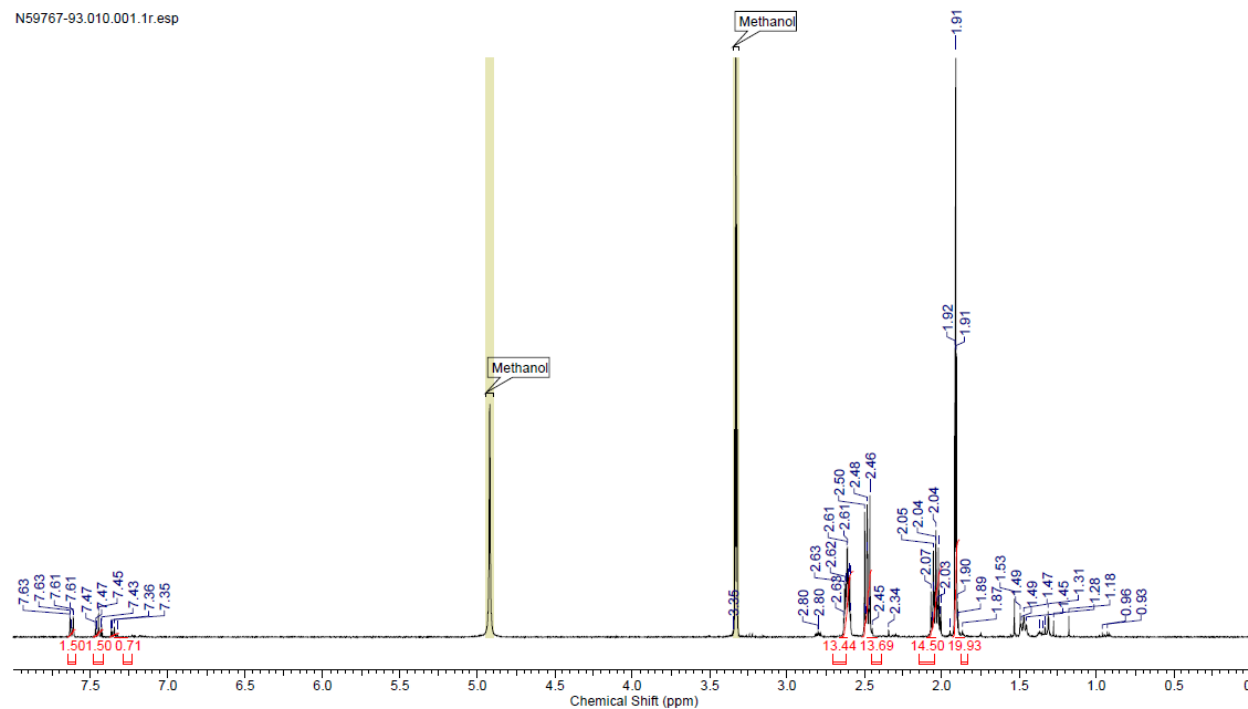


Figure S54: Crude ¹H NMR spectrum of **3c**.

NMR yield determination:

Amount of biphenyl standard added = 0.375 mmol (57.9 mg).

Peak at 7.54 ppm integration set to 0.375 mmol X 4 = 1.50 (signal corresponds to four protons)

Product peak at 2.61 ppm thus corresponds to 13.44 mmol / 2 = 6.72 mmol

NMR yield = 6.72 mmol / 6.92 mmol X 100% = **97%**

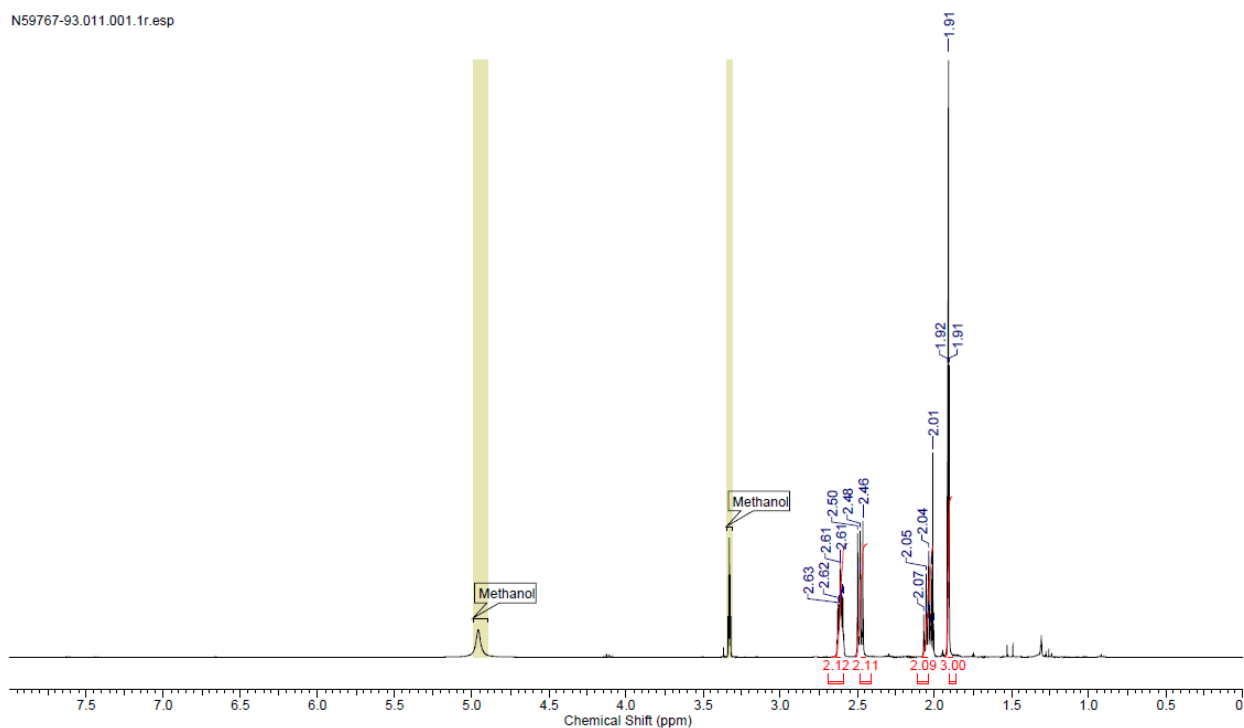


Figure S55: ^1H NMR spectrum of **3c**. Peaks denoted 'methanol' correspond to residual protio solvent from CD_3OD .

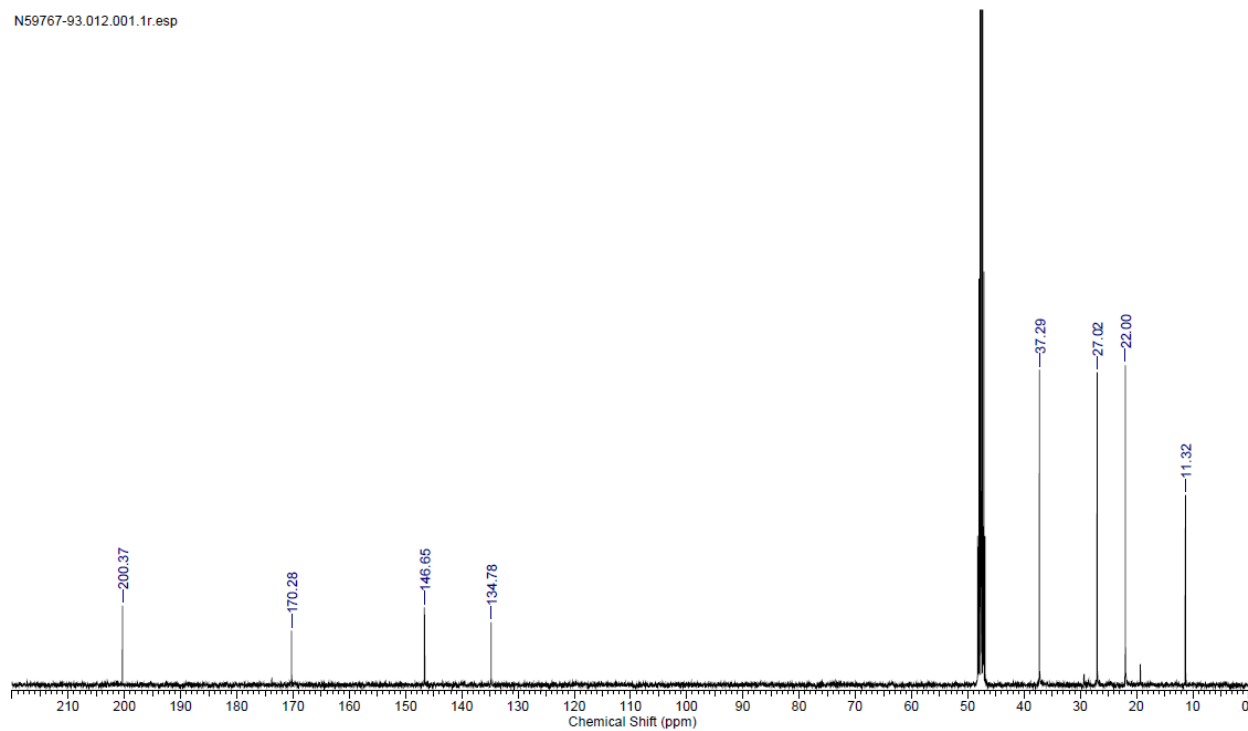


Figure S56: $^{13}\text{C}\{^1\text{H}\}$ NMR spectrum of **3c**.

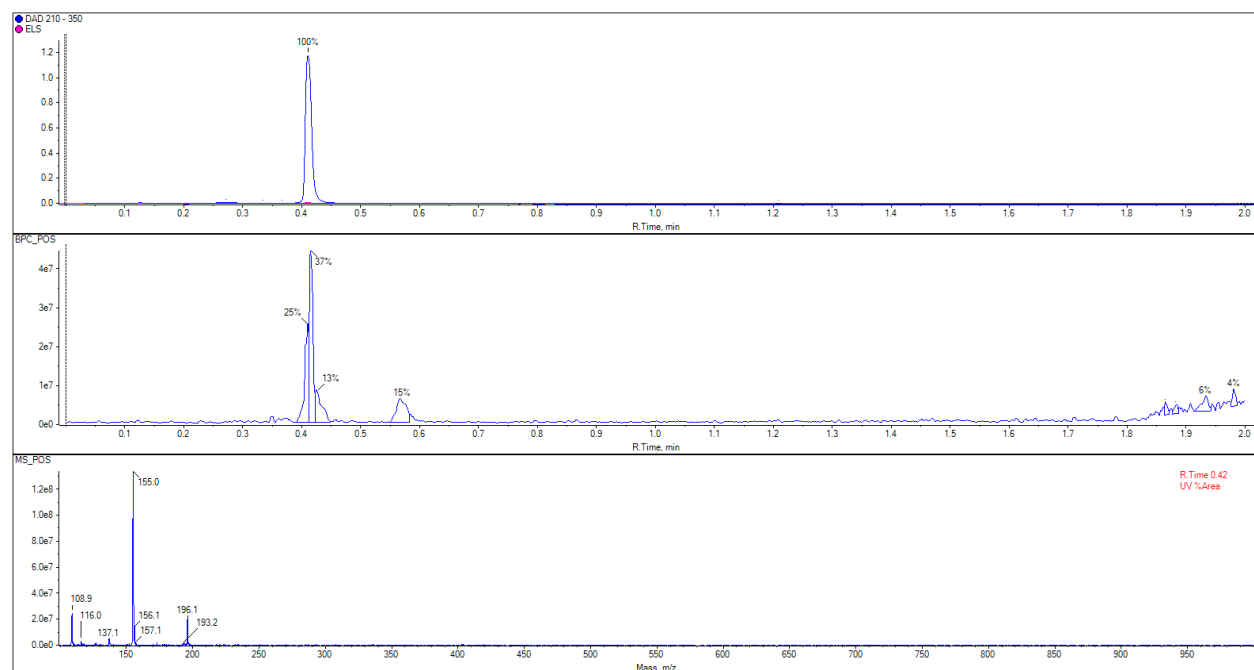
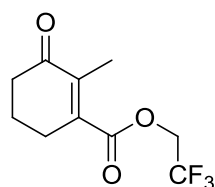


Figure S57: LCMS trace of **3c**.



3i

75% (NMR)
69% (isolated)

Material charges: **3a** (1.00 g, 6.92 mmol), PdCl₂(CH₃CN)₂ (35.9 mg, 0.138 mmol), P(Me)(*t*-Bu)₂-HBF₄ (68.6 mg, 0.277 mmol), triethylamine (1.05 g, 1.45 mL, 10.4 mmol), 2,2,2-trifluoroethanol (1.38 g, 1.00 mL, 13.8 mmol), toluene (5.0 mL), acetonitrile (5.0 mL). **3i**: 1.13 g isolated as a yellow oil (69% yield). ¹H NMR (400 MHz, CDCl₃) δ ppm 2.02 (t, *J* = 2.1 Hz, 3 H, C=C-CH₃), 2.03 - 2.12 (m, 2 H), 2.48 - 2.57 (m, 2 H), 2.60 - 2.68 (m, 2 H), 4.63 (q, *J* = 8.3 Hz, 2 H, -OCH₂CF₃). ¹³C{¹H} NMR (101 MHz, CDCl₃) δ ppm 12.49, 21.88, 26.96, 37.60, 60.42 (q, *J* = 36.8 Hz, -OCH₂CF₃), 122.80 (q, *J* = 276.9 Hz, -OCH₂CF₃), 139.50 (-C=C-CH₃), 141.75 (-C=C-CO₂CH₂CF₃), 166.33 (-CO₂CH₂CF₃), 198.74 (C=O). LRMS (ESI): *m/z* = 237 [M+H]⁺, 278 [M+H+CH₃CN]⁺.

N59767-77.010.001.1r.esp

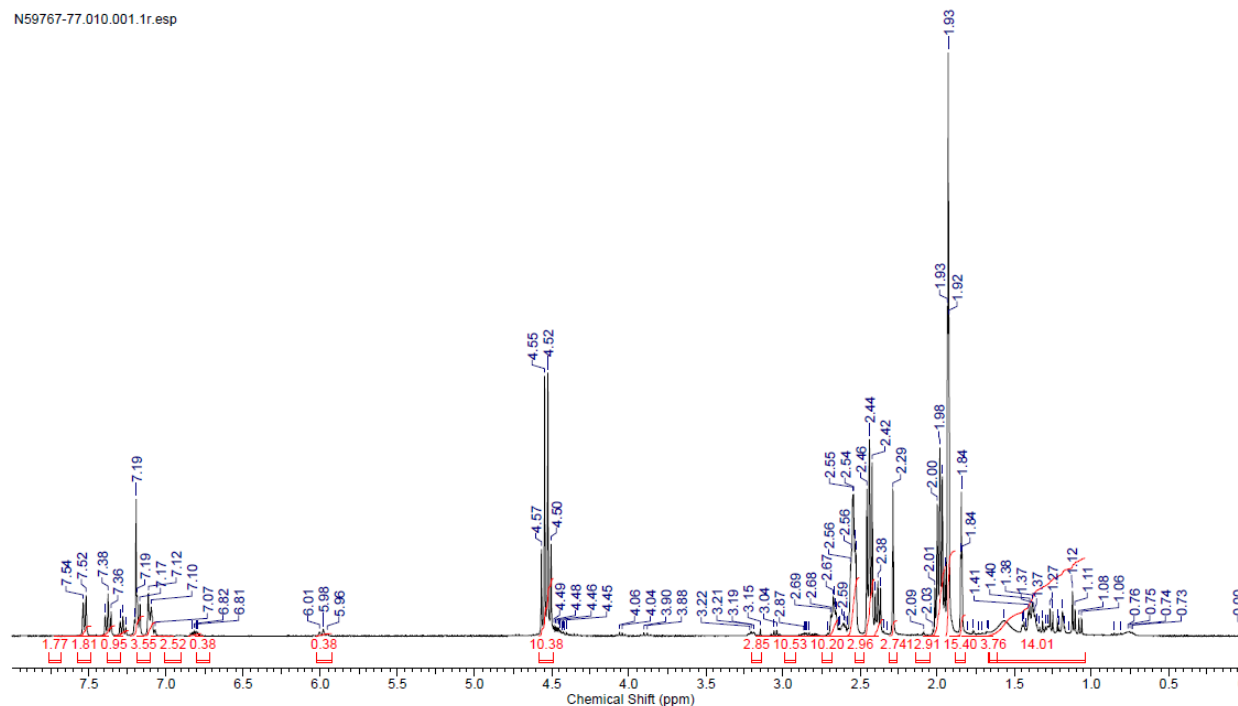


Figure S58: Crude ¹H NMR spectrum of **3i**.

NMR yield determination:

Amount of biphenyl standard added = 0.443 mmol (68.3 mg).

Peak at 7.62 ppm integration set to 0.446 mmol X 4 = 1.77 (signal corresponds to four protons)

Product peak at 4.53 ppm thus corresponds to 10.38 mmol / 2 = 5.19 mmol

NMR yield = 5.19 mmol / 6.92 mmol X 100% = **75%**

N61569-18.010.001.1r.esp

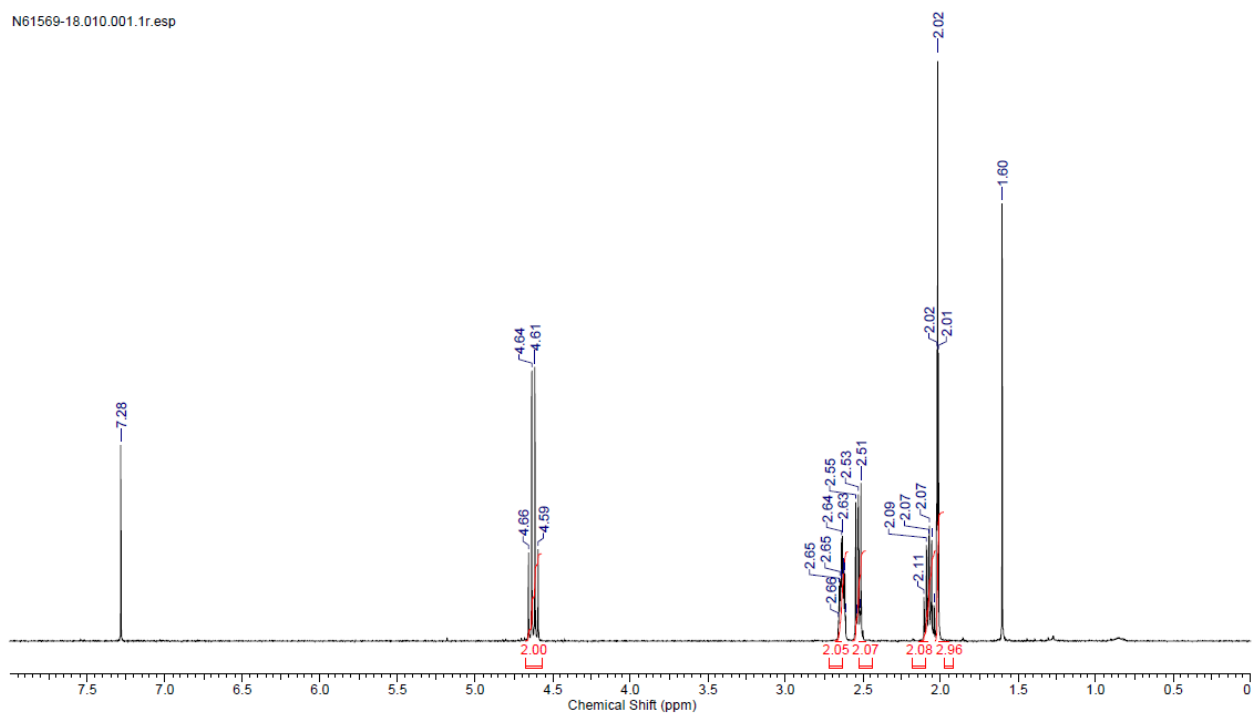


Figure S59: ¹H NMR spectrum of **3i**.

N61569-18.022.001.1r.esp

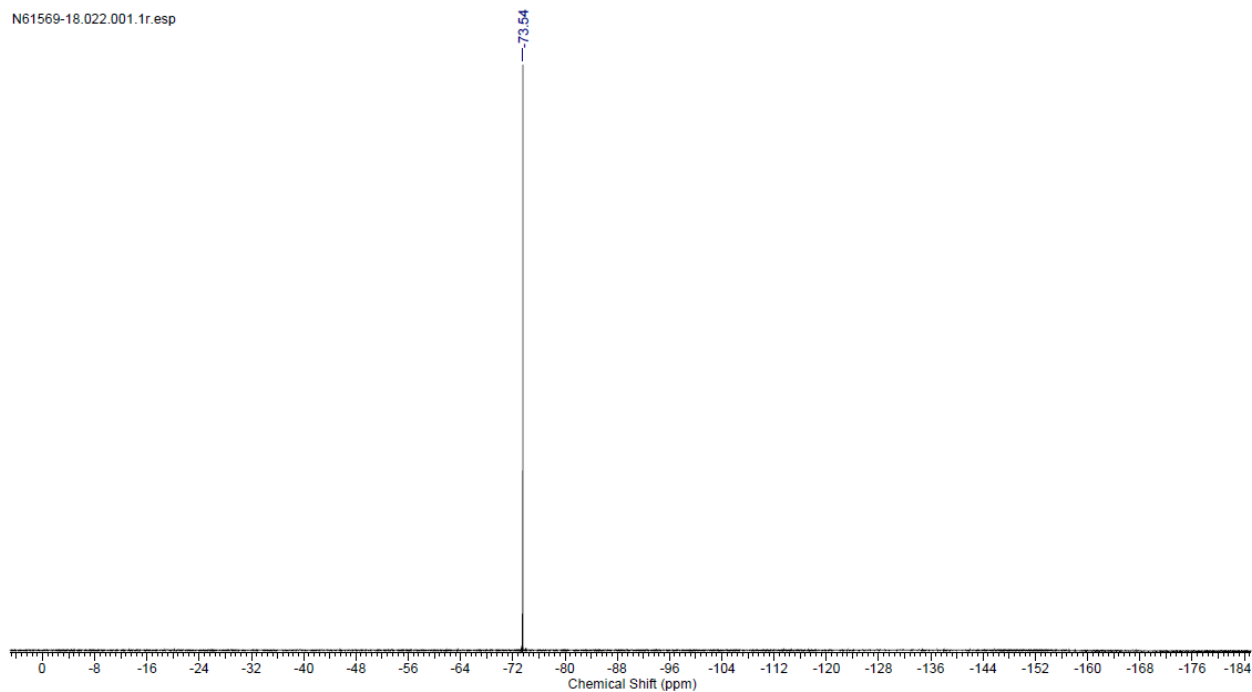
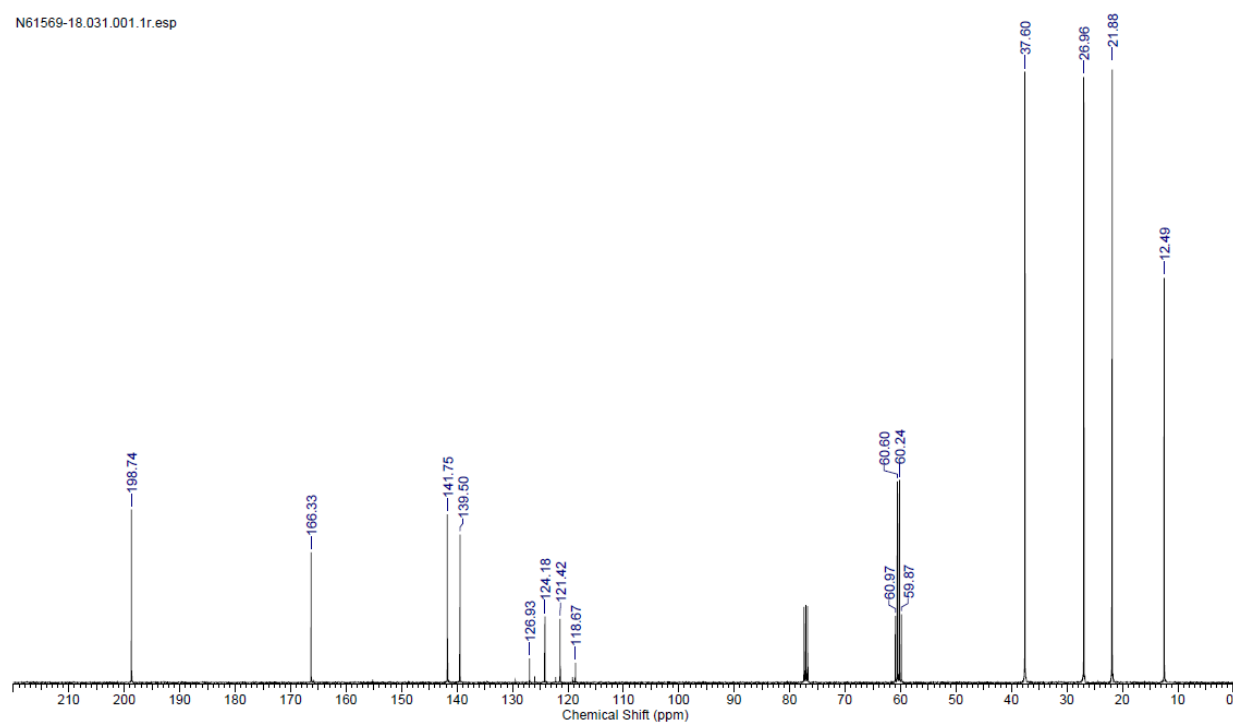
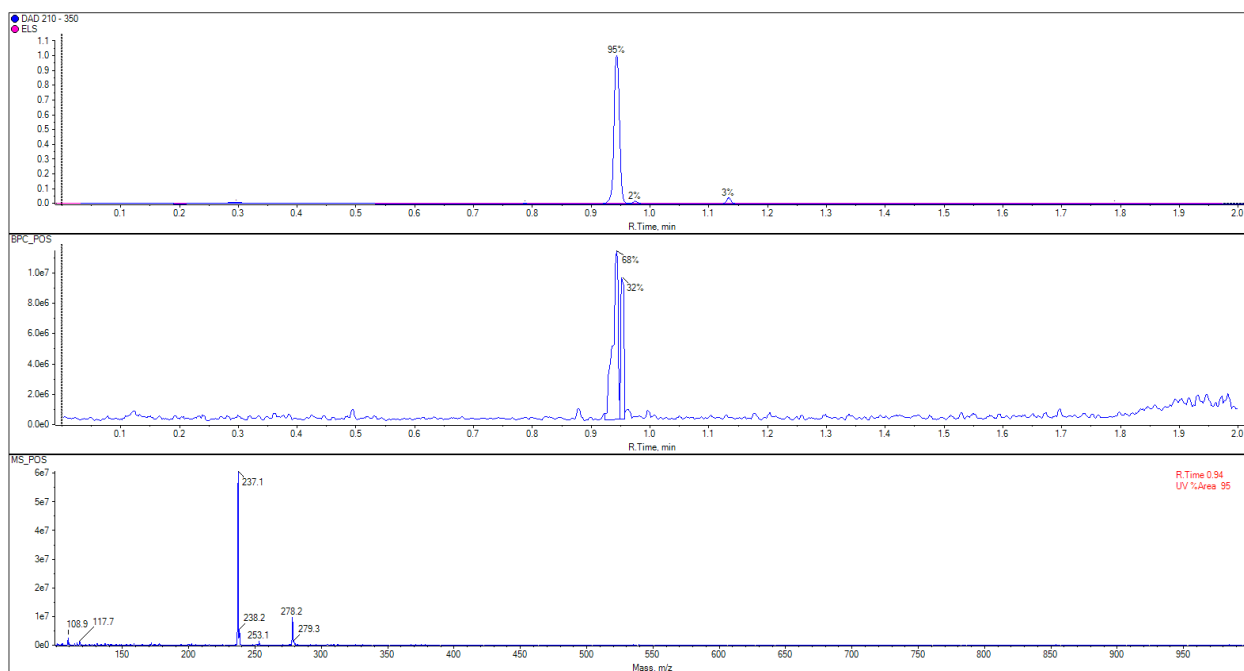
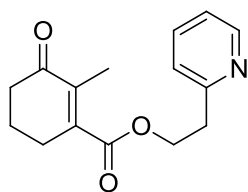


Figure S60: ¹⁹F NMR spectrum of **3i**.

Figure S61: $^{13}\text{C}\{^1\text{H}\}$ NMR spectrum of **3i**.Figure S62: LCMS trace of **3i**.



3k

62% (NMR)
47% (isolated)

Material charges: **3a** (1.00 g, 6.92 mmol), $\text{PdCl}_2(\text{CH}_3\text{CN})_2$ (35.9 mg, 0.138 mmol), $\text{P}(\text{Me})(t\text{-Bu})_2\text{-HBF}_4$ (68.6 mg, 0.277 mmol), triethylamine (1.05 g, 1.45 mL, 10.4 mmol), 2-(2-pyridyl)ethanol (1.70 g, 1.56 mL, 13.8 mmol), toluene (5.0 mL), acetonitrile (5.0 mL).

Work-up, isolation, and purification: This compound was isolated using a modification to the general procedure. The crude reaction mixture was diluted with TBME (5 mL), ethyl acetate (5 mL), brine (8 mL), and 2 M HCl (4 mL). The phases were mixed and separated; at this point, the aqueous phase was observed to be yellow. Analysis of the organic and aqueous phases by LCMS revealed considerable product in the aqueous layer. The aqueous phase was basified using sat. NaHCO_3 , and extracted with ethyl acetate (3 x 10 mL). The combined organic extracts were dried over MgSO_4 , filtered, and the solvent removed. A solution yield by ^1H NMR spectroscopy was performed on this crude material. At this point, selective extractions were chosen to purify this compound, rather than attempt column chromatography. The major impurities observed by LCMS were unreacted starting materials (both **3a** and 2-(2-pyridyl)ethanol) and the carboxylic acid **3c**, along with a small amount of 2-vinylpyridine (resulting from dehydration of the alcohol). The crude residue was redissolved in TBME (10 mL), which resulted in the precipitation of a white solid (**3c**). The solid **3c** was removed by filtration through a small plug of Celite. The TBME layer (extract 1) was extracted with a 1:1 mixture of 2 M HCl and brine (2 x 20 mL) to separate the product from unreacted **3a**. The aqueous phase was then basified with sat. NaHCO_3 to a pH $\sim$ 6, and extracted with TBME (10 mL, extract 2). LCMS analysis of the TBME layer indicated no product. The aqueous phase was then basified with 1 M NaOH to pH $\sim$ 9, and extracted with TBME (10 mL, extract 3). LCMS analysis revealed partitioning of the desired product into the organic layer, while the pyridine-containing byproducts remained almost completely in the aqueous layer. A final extraction of the aqueous with TBME (10 mL, extract 4) was conducted, but LCMS revealed almost no product. Extract 3 was washed with water (3 x 15 mL), brine (1 x 15 mL), and dried over MgSO_4 . After filtration and solvent removal, **3k** was isolated as a pale yellow oil (0.843 g, 47% yield).

3k: ^1H NMR (400 MHz, CDCl_3) δ ppm 1.81 (t, J = 2.0 Hz, 3 H, $\text{C}=\text{C}-\text{CH}_3$), 1.93 - 2.04 (m, 2 H, $-\text{CH}_2-$), 2.41 - 2.46 (m, 2 H, $-\text{CH}_2-\text{C}=\text{C}$), 2.46 - 2.53 (m, 2 H, $-\text{CH}_2-\text{C}=\text{O}$), 3.19 (t, J = 6.7 Hz, 2 H, $-\text{OCH}_2\text{CH}_2\text{Py}$), 4.64 (t, J = 6.7 Hz, 2 H, $-\text{OCH}_2\text{CH}_2\text{Py}$), 7.17 (ddd, J = 7.6, 4.9, 1.1 Hz, 1 H, $\text{Py}-\text{H}^2$), 7.20 (d, J = 7.7 Hz, 1 H, $\text{Py}-\text{H}^4$), 7.63 (td, J = 7.7, 1.9 Hz, 1 H, $\text{Py}-\text{H}^3$), 8.56 (ddd, J = 5.0, 2.0, 1.0 Hz, 1 H, $\text{Py}-\text{H}^1$). $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3) δ ppm 12.56, 22.15, 27.26, 37.19, 37.78, 64.31, 121.79, 123.46, 136.47, 136.96, 144.38, 149.57, 157.63, 168.39 ($-\text{CO}_2\text{R}$), 199.52 ($\text{C}=\text{O}$). LRMS (ESI): m/z = 260 $[\text{M}+\text{H}]^+$.

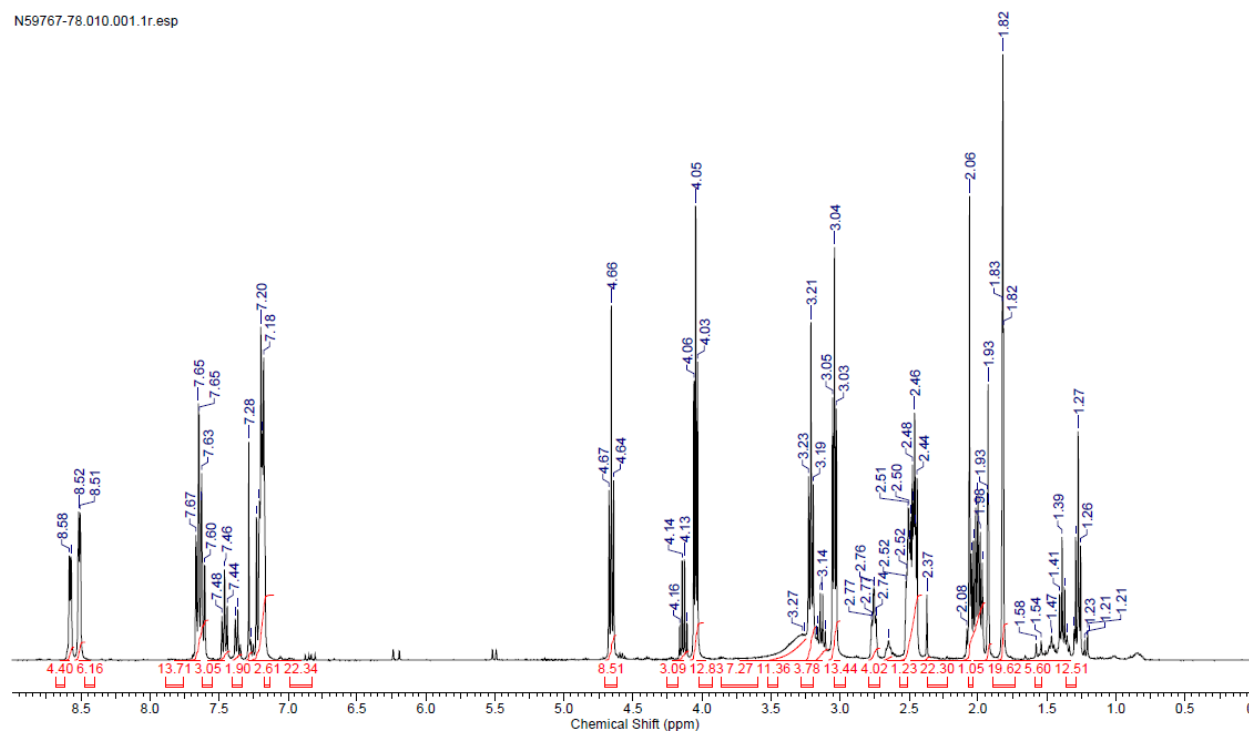


Figure S63: Crude ^1H NMR spectrum of **3k**.

NMR yield determination:

Amount of biphenyl standard added = 0.763 mmol (117.6 mg).

Peak at 7.47 ppm integration set to 0.763 mmol $\times$ 4 = 3.05 (signal corresponds to four protons)

Product peak at 4.66 ppm thus corresponds to 8.51 mmol / 2 = 4.26 mmol

NMR yield = 4.26 mmol / 6.92 mmol $\times$ 100% = **62%**

N59767-78.030.001.1r.esp

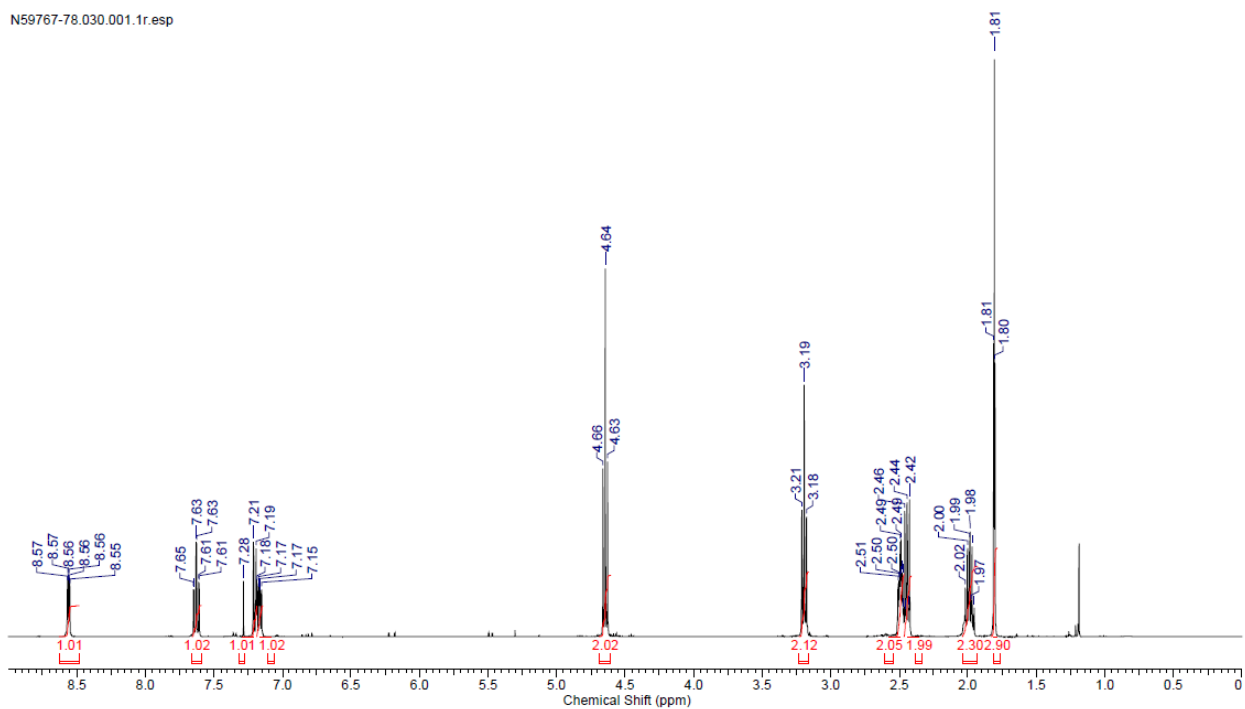


Figure S64: ¹H NMR spectrum of 3k.

N59767-78.031.001.1r.esp

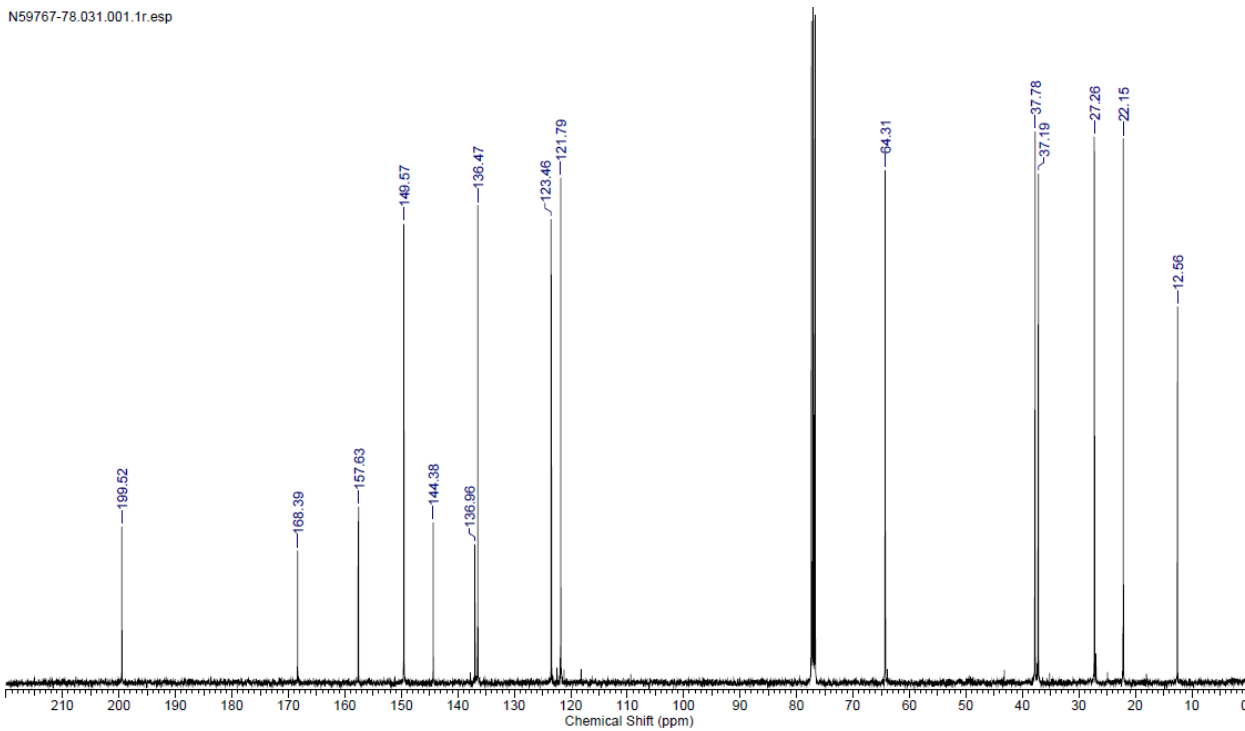


Figure S65: ¹³C{¹H} NMR spectrum of 3k.

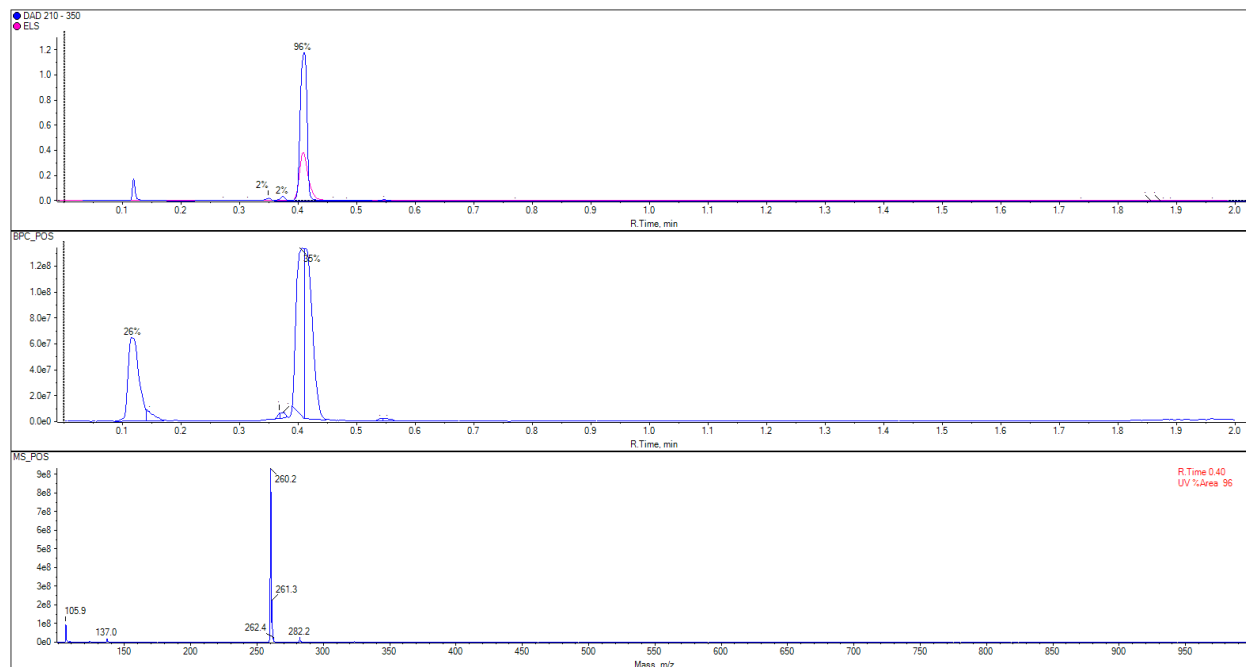
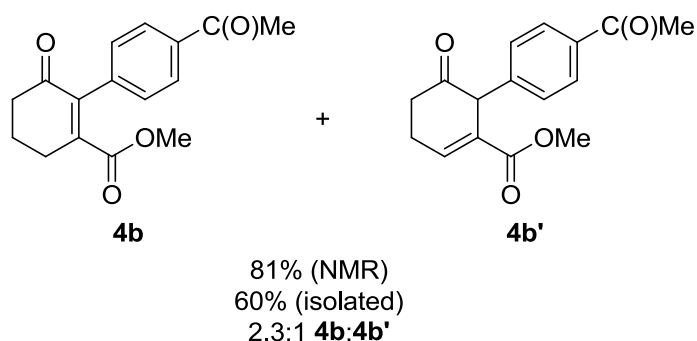


Figure S66: LCMS trace of **3k**.



Material charges: **4a** (0.900 g, 3.62 mmol), PdCl₂(CH₃CN)₂ (19.0 mg, 0.072 mmol), P(Me)(*t*-Bu)₂-HBF₄ (36.0 mg, 0.145 mmol), triethylamine (0.549 g, 0.76 mL, 5.43 mmol), methanol (0.232 g, 0.29 mL, 7.24 mmol), toluene (5.0 mL), acetonitrile (5.0 mL). Compound isolated as a yellow oil (0.589 g, 60% yield) as a mixture of two alkene isomers (2.3:1 **4b:4b'** as judged by ¹H NMR spectroscopy).

¹H NMR (400 MHz, CDCl₃). **4b**: Major alkene isomer: δ ppm 2.10 (quin, *J*=6.38 Hz, 2 H) 2.50 (s, 3 H) 2.51 - 2.56 (m, 2 H) 2.67 (t, *J*=6.02 Hz, 2 H) 3.41 (s, 3 H) 7.10 - 7.15 (m, 2 H) 7.86 (s, 2 H). **4b'**: Minor alkene isomer: δ ppm 2.27 (m, 1 H) 2.47 (s, 3 H) 2.57 - 2.64 (m, 1 H) 2.71 - 2.82 (m, 1 H) 3.54 (s, 3 H) 4.43 (s, 1 H) 7.29 (d, *J*=8.22 Hz, 2 H) 7.33 - 7.37 (m, 1 H) 7.80 - 7.83 (m, 2 H).

¹³C{¹H} NMR (101 MHz, CDCl₃) δ ppm 22.03 (**4b**), 25.57 (**4b'**), 26.56 (**4b+4b'**, ArC(O)CH₃), 27.58 (**4b**), 34.25 (**4b'**), 38.01 (**4b**), 51.94 (**4b'**, -CO₂CH₃), 52.07 (**4b**, -CO₂CH₃), 54.96 (**4b'**), 127.71 (**4b**), 127.86 (**4b'**), 128.79 (**4b'**), 129.33 (**4b**), 130.44 (**4b'**), 136.10 (**4b'**), 136.25 (**4b**), 138.79 (**4b**), 139.63 (**4b'**), 140.62 (**4b**), 142.81 (**4b'**), 148.13 (**4b**), 165.49 (**4b'**), 168.32 (**4b**), 197.38 (**4b**), 197.44 (**4b'**, Ar-C(O)Me), 197.60 (**4b**), 206.43 (**4b'**, -CH₂(C=O)-CHAr-).
 LRMS (ESI): *m/z* = 273 [M+H]⁺.

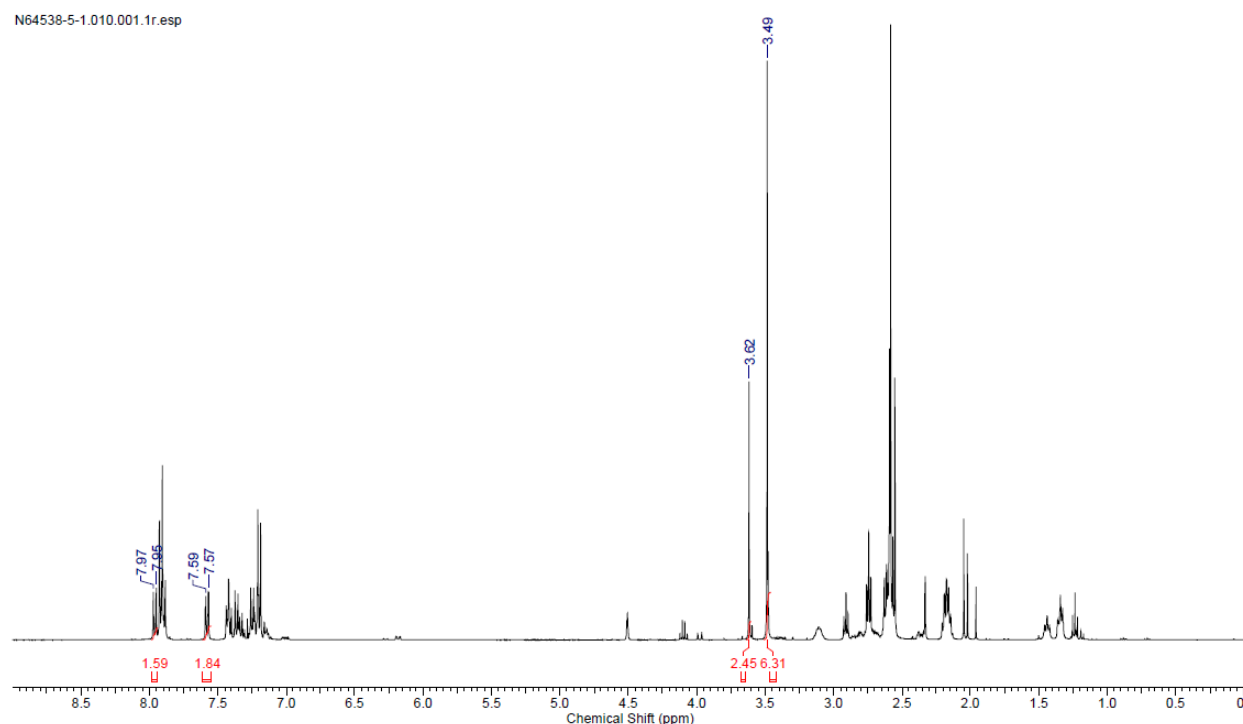


Figure S67: Crude ¹H NMR spectrum of **4b/4b'**.

NMR yield determination:

Amount of biphenyl standard added = 0.460 mmol (71.0 mg).

Peak at 7.47 ppm integration set to 0.460 mmol X 4 = 1.84 (signal corresponds to four protons)

Product peak (**4b**) at 3.49 ppm thus corresponds to 6.31 mmol / 3 = 2.10 mmol

Product isomer peak (**4b'**) at 3.62 ppm thus corresponds to 2.45 mmol / 3 = 0.817 mmol

NMR yield (**4b**) = 2.10 mmol / 3.62 mmol X 100% = **58%**

NMR yield (**4b'**) = 0.817 mmol / 3.62 mmol X 100% = **23%**

Total NMR yield of **4b** + **4b'** = **81%**

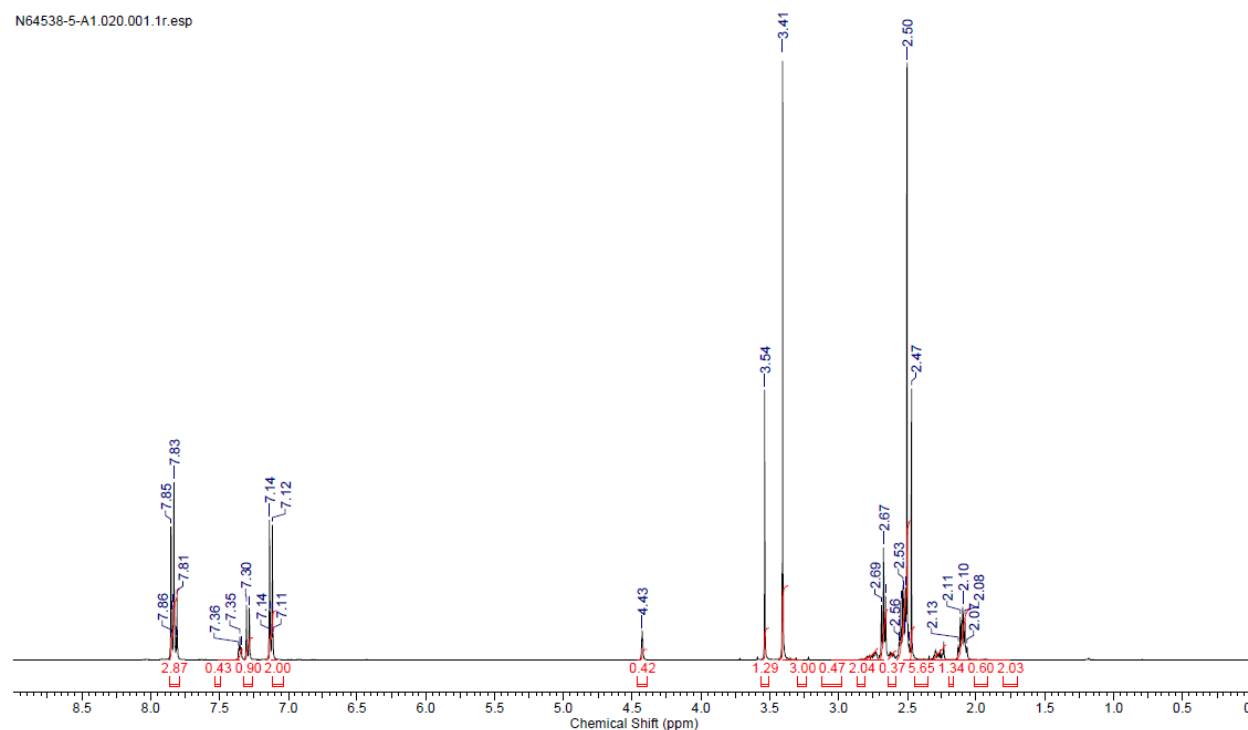
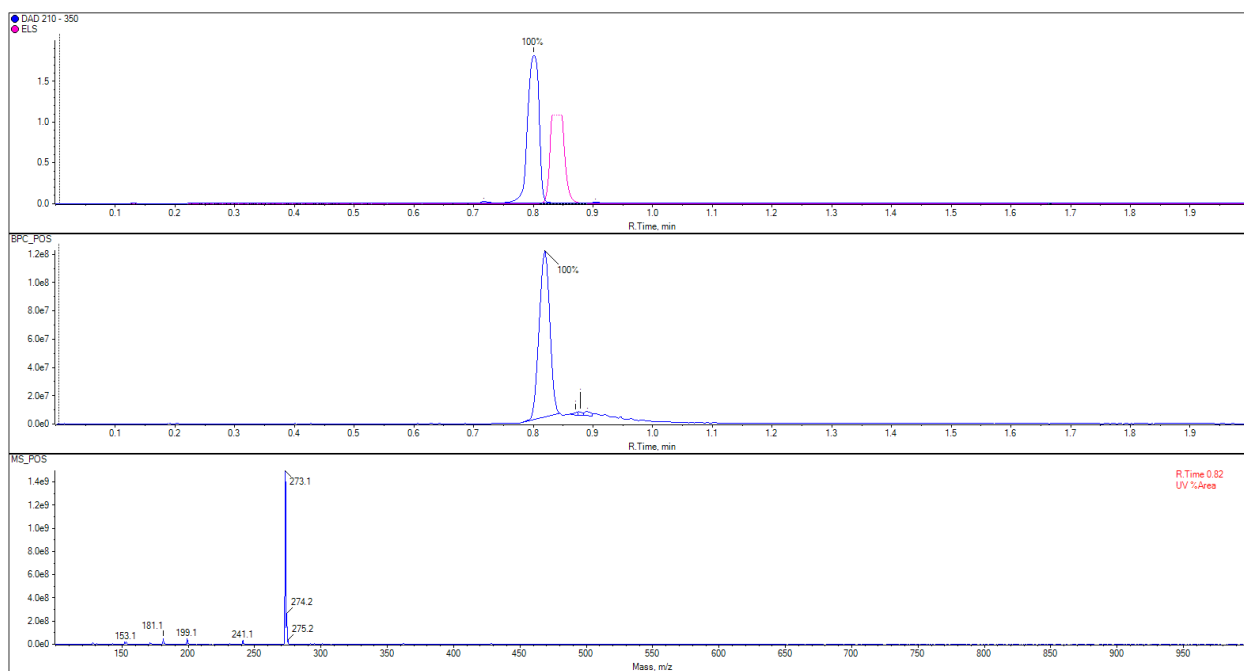
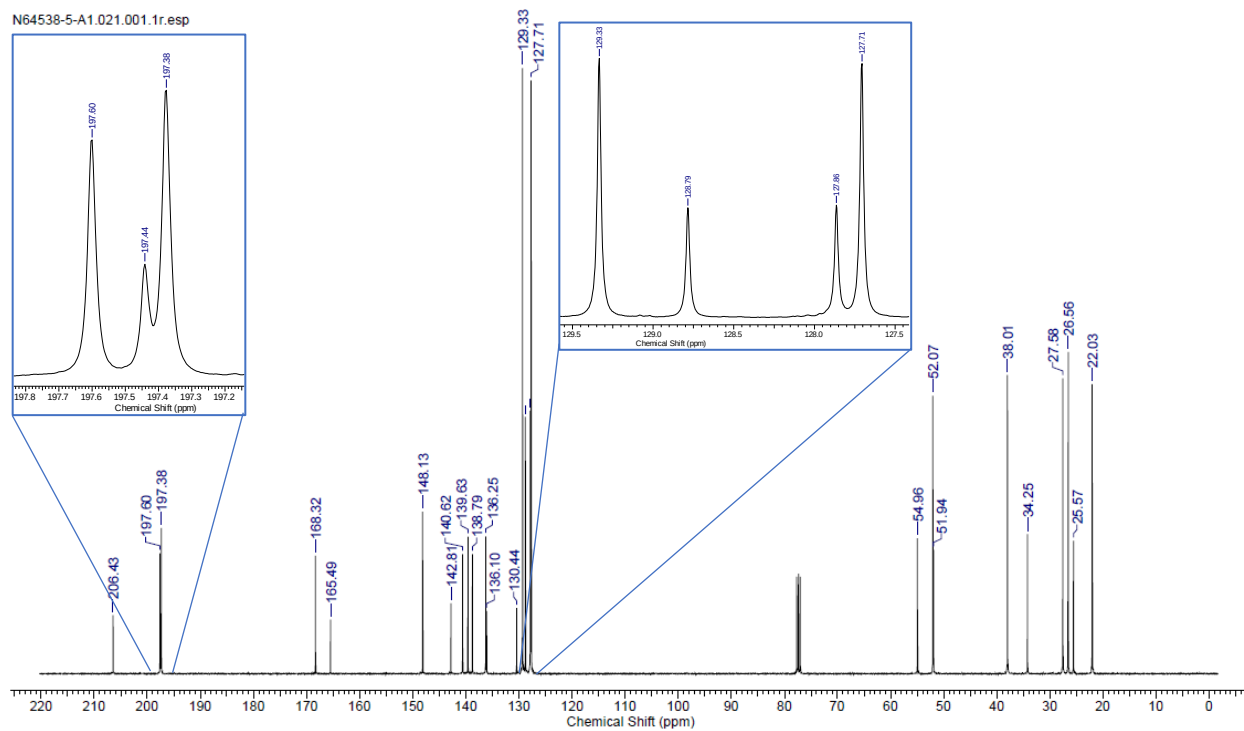
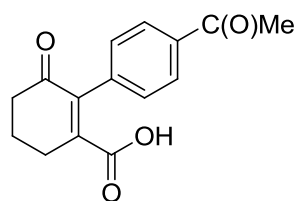


Figure S68: ¹H NMR spectrum of **4b/4b'**.





4c

88% (isolated)
(NMR yield n.d.)

Material charges: **4a** (0.900 g, 3.62 mmol), $\text{PdCl}_2(\text{CH}_3\text{CN})_2$ (19.0 mg, 0.072 mmol), $\text{P}(\text{Me})(t\text{-Bu})_2\text{-HBF}_4$ (36.0 mg, 0.145 mmol), triethylamine (0.549 g, 0.76 mL, 5.43 mmol), water (0.130 g, 0.130 mL, 7.24 mmol), toluene (5.0 mL), acetonitrile (5.0 mL). **4c**: 0.826 g isolated as a tan solid (88% yield). ^1H NMR (400 MHz, CD_3OD) δ ppm 2.11 - 2.22 (m, 2 H) 2.55 - 2.65 (m, 2 H) 2.59 (s, 3 H) 2.78 (t, $J=6.02$ Hz, 2 H) 7.25 - 7.29 (m, 2 H) 7.91 - 7.96 (m, 2 H). $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CD_3OD) δ ppm 21.92, 25.46, 27.42, 37.63, 127.42, 129.59, 136.08, 137.17, 140.21, 150.42, 169.80, 198.52, 198.97. LRMS (ESI): m/z = 259 $[\text{M}+\text{H}]^+$.

Biphenyl was omitted from this preparation; therefore, no NMR yield was determined.

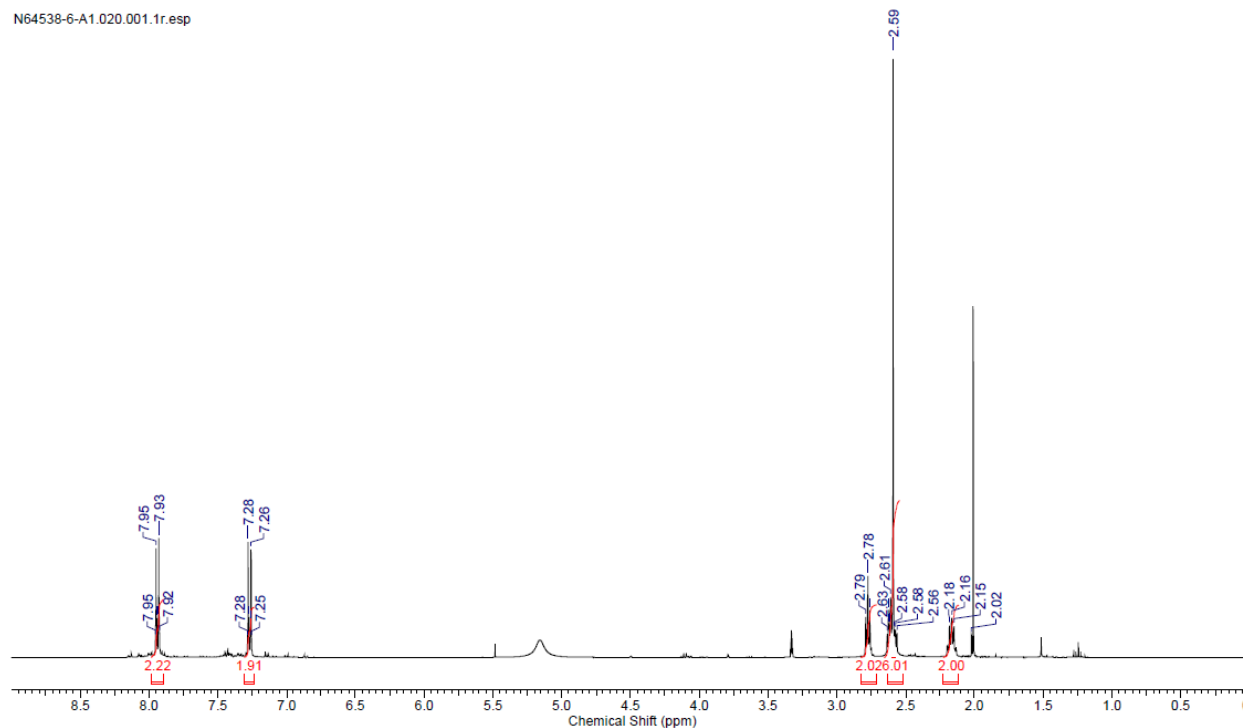


Figure S71: ^1H NMR spectrum of **4c**.

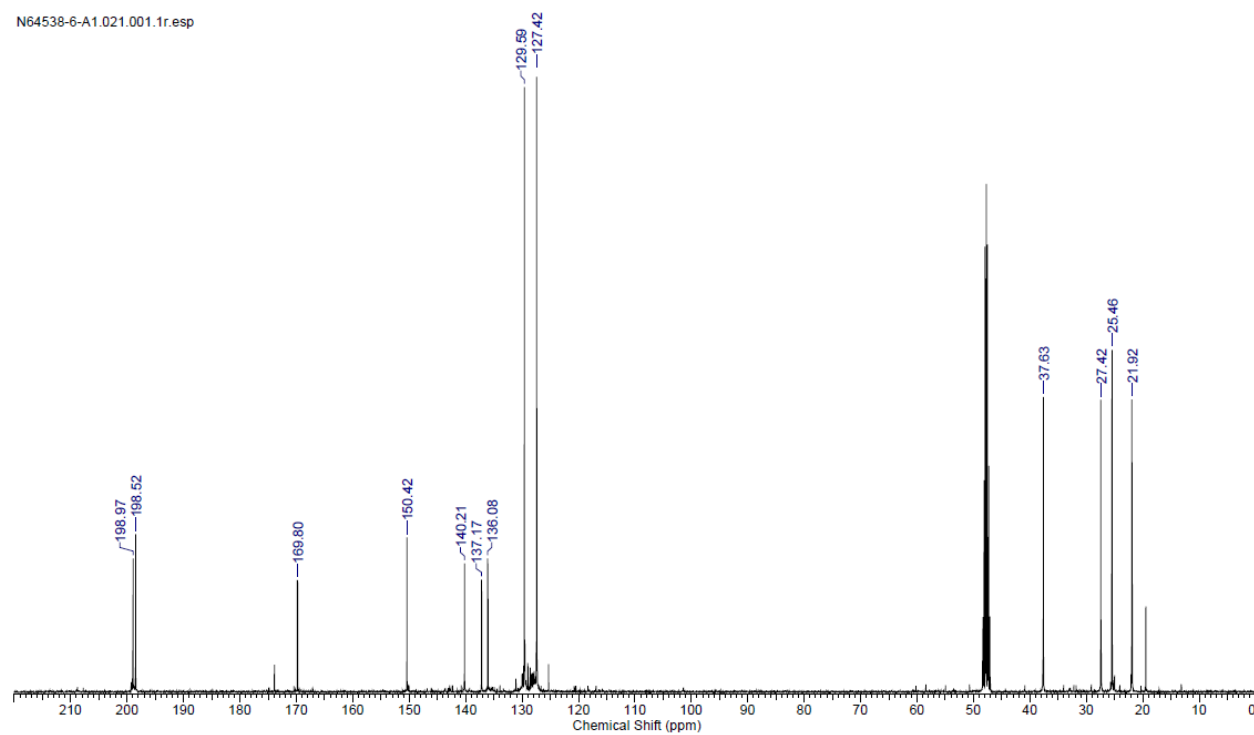


Figure S72: $^{13}\text{C}\{^1\text{H}\}$ NMR spectrum of **4c**.

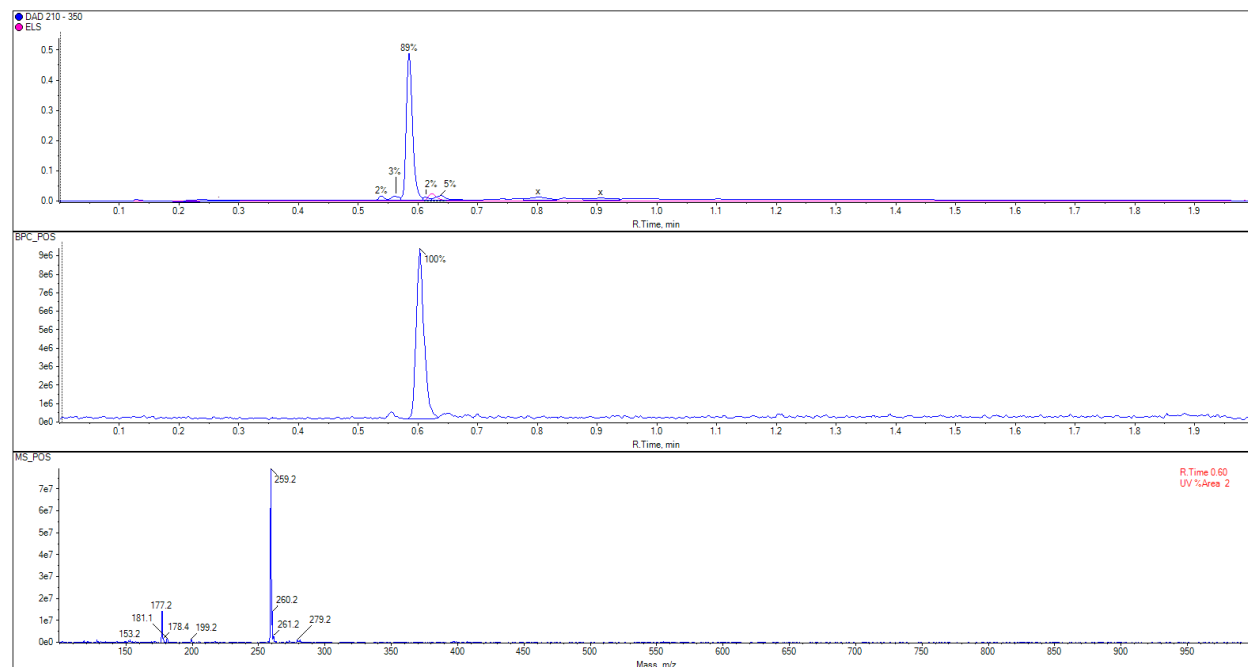
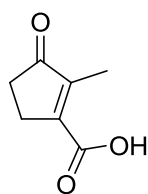


Figure S73: LCMS trace of **4c**.



5c

65% (NMR)
45% (isolated)

Material charges: **5a** (1.00 g, 7.66 mmol), $\text{PdCl}_2(\text{CH}_3\text{CN})_2$ (39.7 mg, 0.153 mmol), $\text{P}(\text{Me})(t\text{-Bu})_2\text{-HBF}_4$ (76.0 mg, 0.306 mmol), triethylamine (1.16 g, 1.60 mL, 11.5 mmol), benzyl alcohol (1.66 g, 1.59 mL, 15.3 mmol), toluene (5.0 mL), acetonitrile (5.0 mL). **5c**: 0.483 g isolated as a tan solid (45% yield). ^1H NMR (400 MHz, CD_3OD) δ ppm 2.01 (t, $J = 2.4$ Hz, 3 H) 2.46 - 2.51 (m, 2 H) 2.74 - 2.80 (m, 2 H). $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CD_3OD) δ ppm 8.36, 26.27, 33.37, 145.84, 156.24, 166.97, 210.98. LRMS (ESI): $m/z = 141$ $[\text{M}+\text{H}]^+$.

N59767-94.010.001.1r.esp

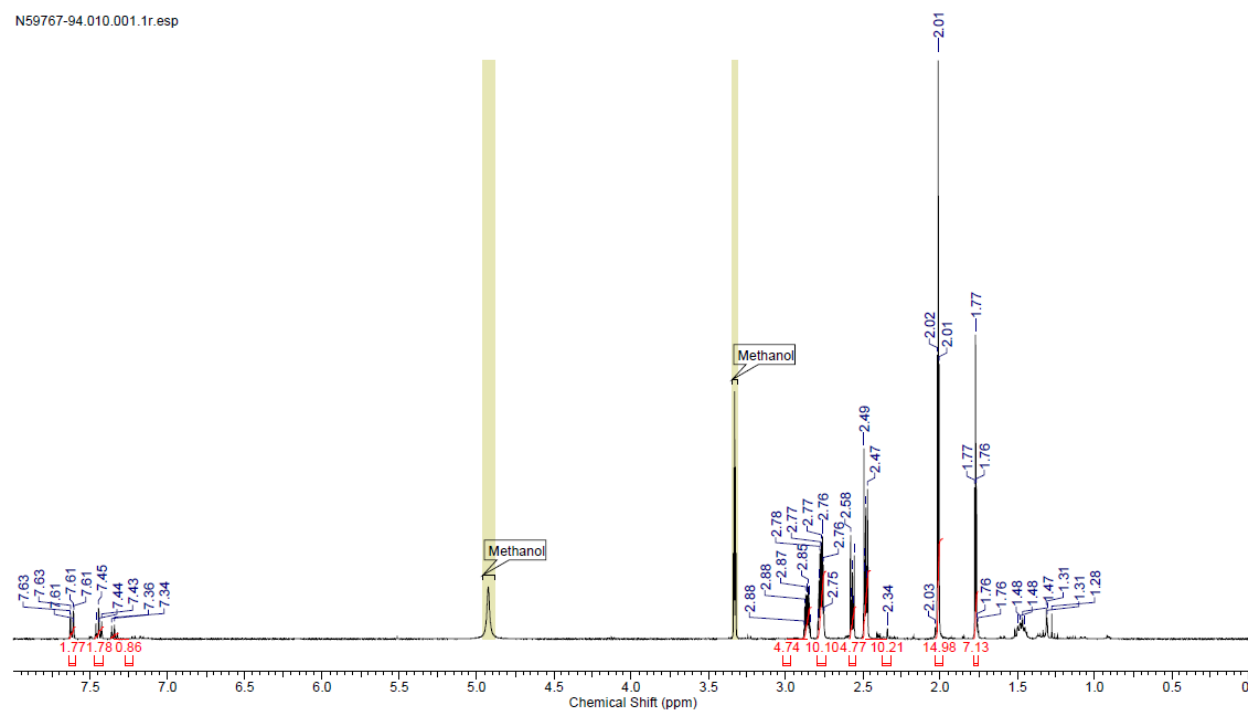


Figure S74: Crude ^1H NMR spectrum of **5c**.

NMR yield determination:

Amount of biphenyl standard added = 0.444 mmol (68.5 mg).

Peak at 7.62 ppm integration set to 0.444 mmol $\times 4 = 1.78$ (signal corresponds to four protons)

Product peak at 2.01 ppm thus corresponds to $14.98 \text{ mmol} / 3 = 4.99 \text{ mmol}$

NMR yield = $4.99 \text{ mmol} / 7.66 \text{ mmol} \times 100\% = 65\%$

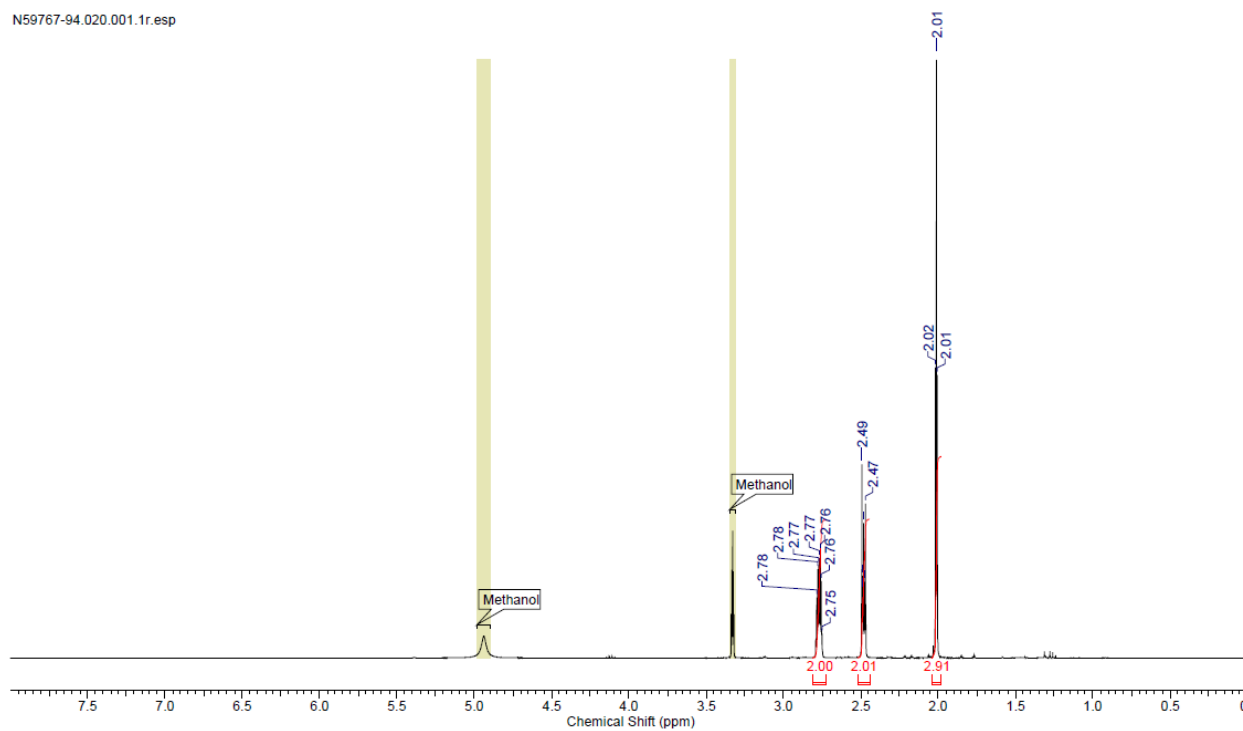


Figure S75: ^1H NMR spectrum of **5c**. Peaks denoted 'methanol' correspond to residual protio solvent from CD_3OD .

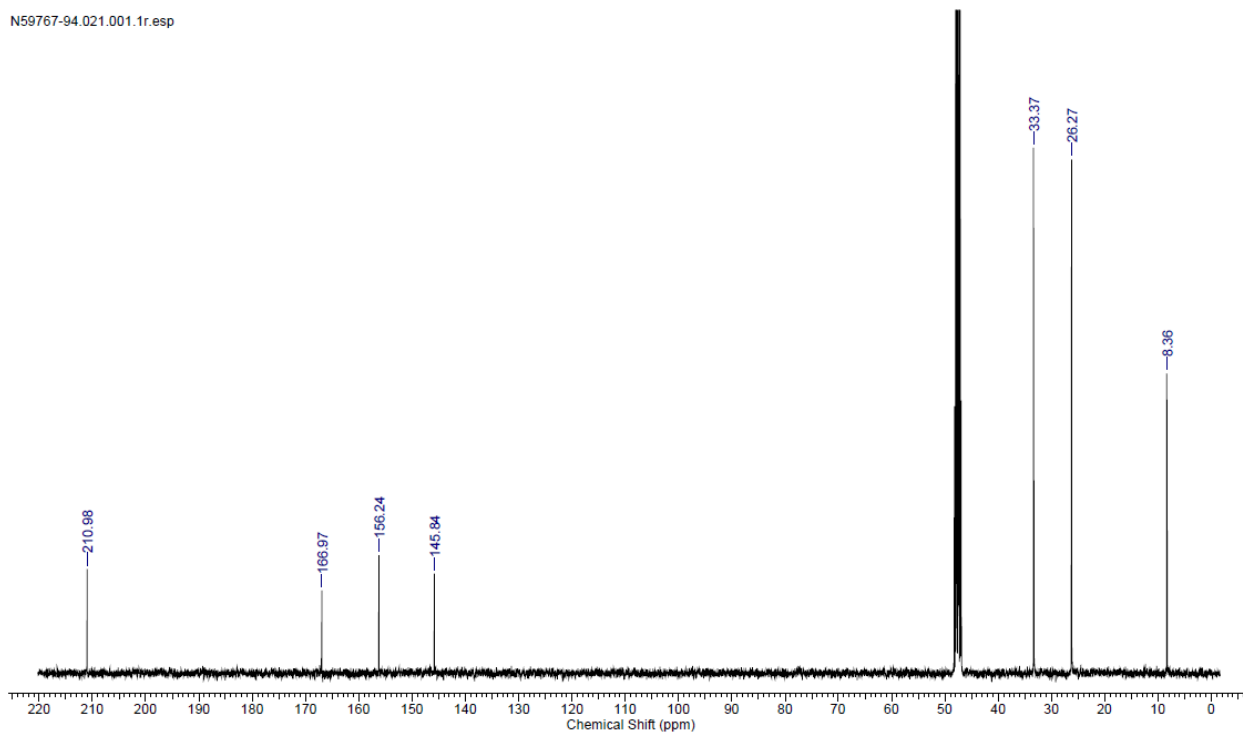


Figure S76: $^{13}\text{C}\{^1\text{H}\}$ NMR spectrum of **5c**.

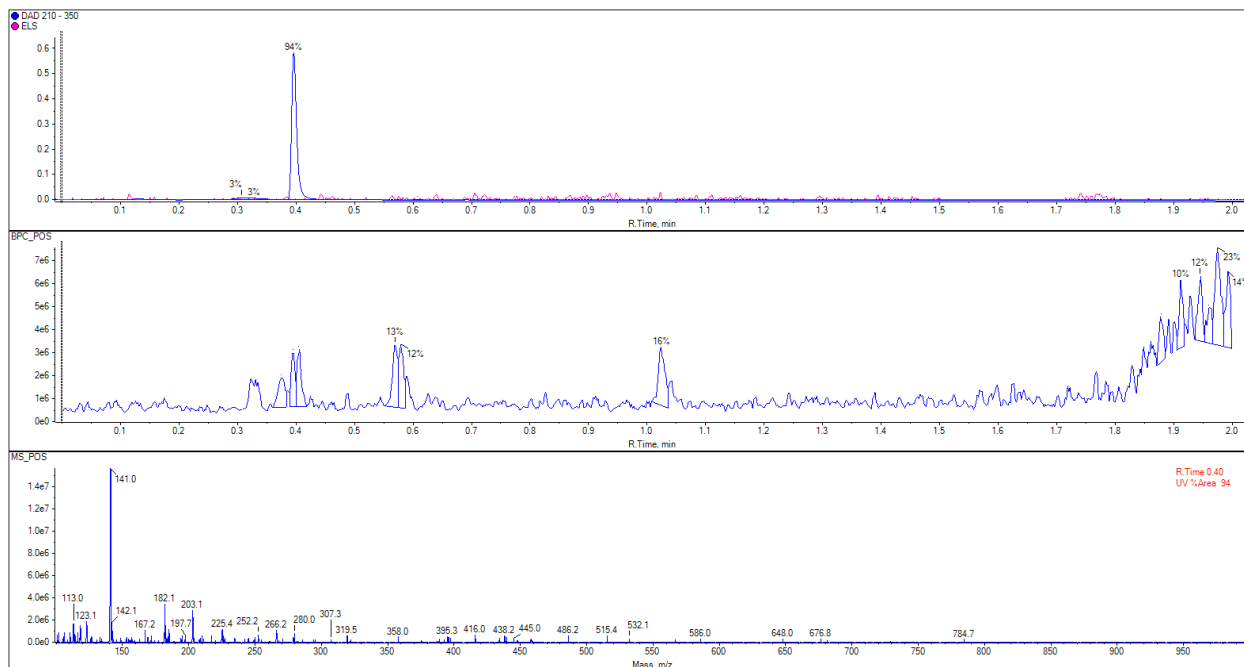
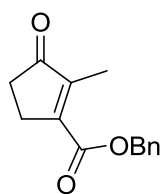


Figure S77: LCMS trace of **5c**.



5d

78% (NMR)
71% (isolated)

Material charges: **5a** (1.00 g, 7.66 mmol), PdCl₂(CH₃CN)₂ (39.7 mg, 0.153 mmol), P(Me)(*t*-Bu)₂-HBF₄ (76.0 mg, 0.306 mmol), triethylamine (1.16 g, 1.60 mL, 11.5 mmol), benzyl alcohol (1.66 g, 1.59 mL, 15.3 mmol), toluene (5.0 mL), acetonitrile (5.0 mL). **5d**: 1.25 g isolated as a white solid (71% yield). ¹H NMR (400 MHz, CDCl₃) δ ppm 2.07 (t, *J* = 2.4 Hz, 3 H, C=C-CH₃), 2.44 - 2.54 (m, 2 H, -CH₂-C=C), 2.73 - 2.86 (m, 2 H, -CH₂-C=O), 5.32 (s, 2 H, -OCH₂Ph), 7.31 - 7.50 (m, 5 H, Ph-*H* x 5). ¹³C{¹H} NMR (101 MHz, CDCl₃) δ ppm 9.94, 26.45, 33.86, 66.92, 128.31, 128.52, 128.71, 135.36, 147.73, 154.14, 165.31 (CO₂Bn), 209.74 (C=O). LRMS (ESI): *m/z* = 231 [M+H]⁺, 272 [M+H+CH₃CN]⁺.

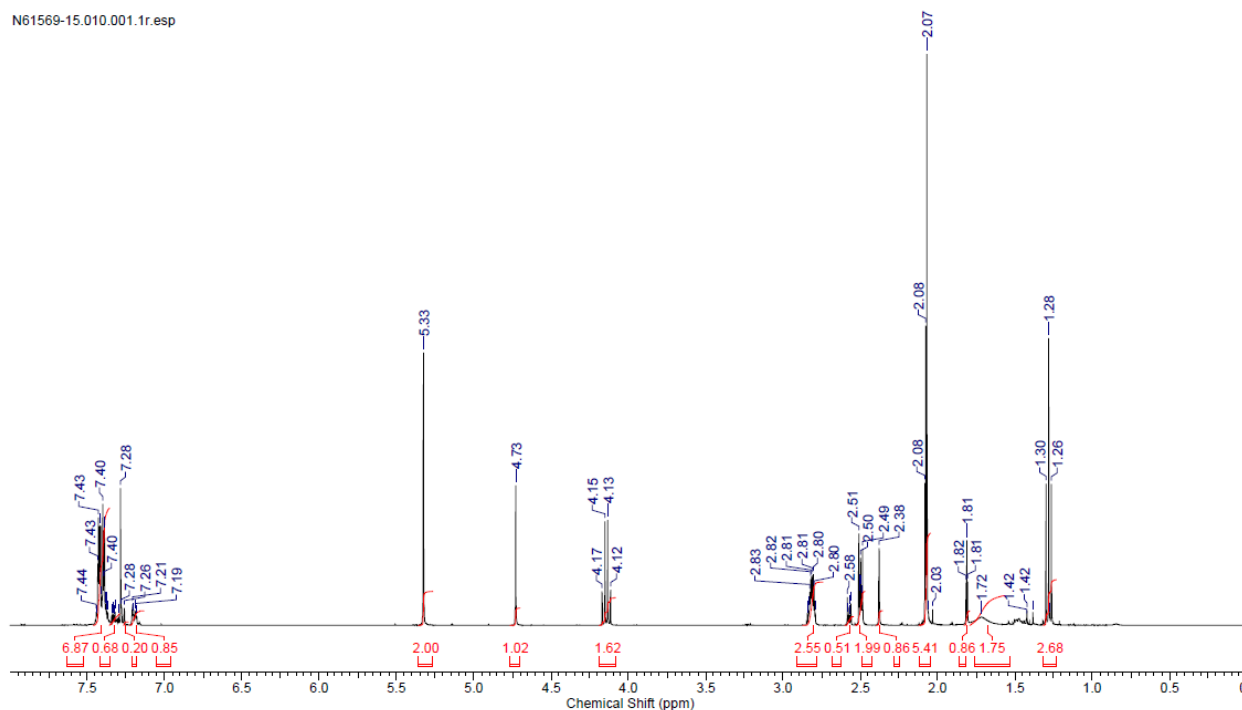


Figure S78: Crude ¹H NMR spectrum of **5d**.

NMR yield determination:

Biphenyl was omitted from this preparation. Therefore, NMR yield was approximated using the total integration of the signal at 2.81 ppm (which is comprised of coincident peaks for starting material and product).

$$\text{NMR yield} = 2.0 / 2.55 \times 100\% = \mathbf{78\%}$$

LCMS analysis of the crude product mixture reveals only starting material **5a** (0.71 min) and desired product **5d** (1.04 min), along with small peaks corresponding to benzyl alcohol (0.59 min) and a Pd-complex with an m/z and isotope pattern consistent with an oxidative addition complex (0.86 min). Peaks denoted 'x' are either present in blanks (0.49 min, 0.53 min) or toluene from the reaction solution (1.03 min). We are therefore confident in the 78% solution yield determined by ^1H NMR spectroscopy.

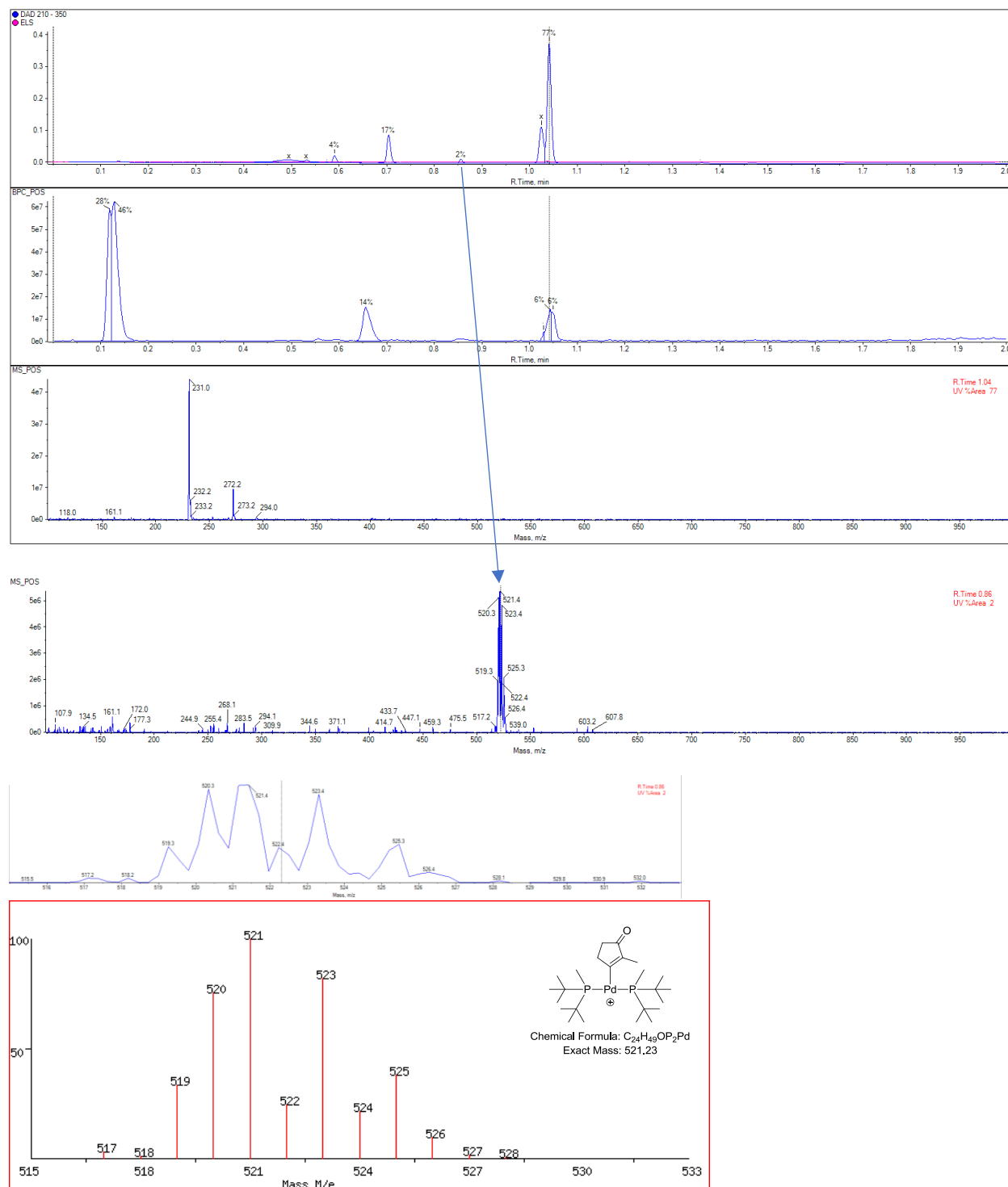
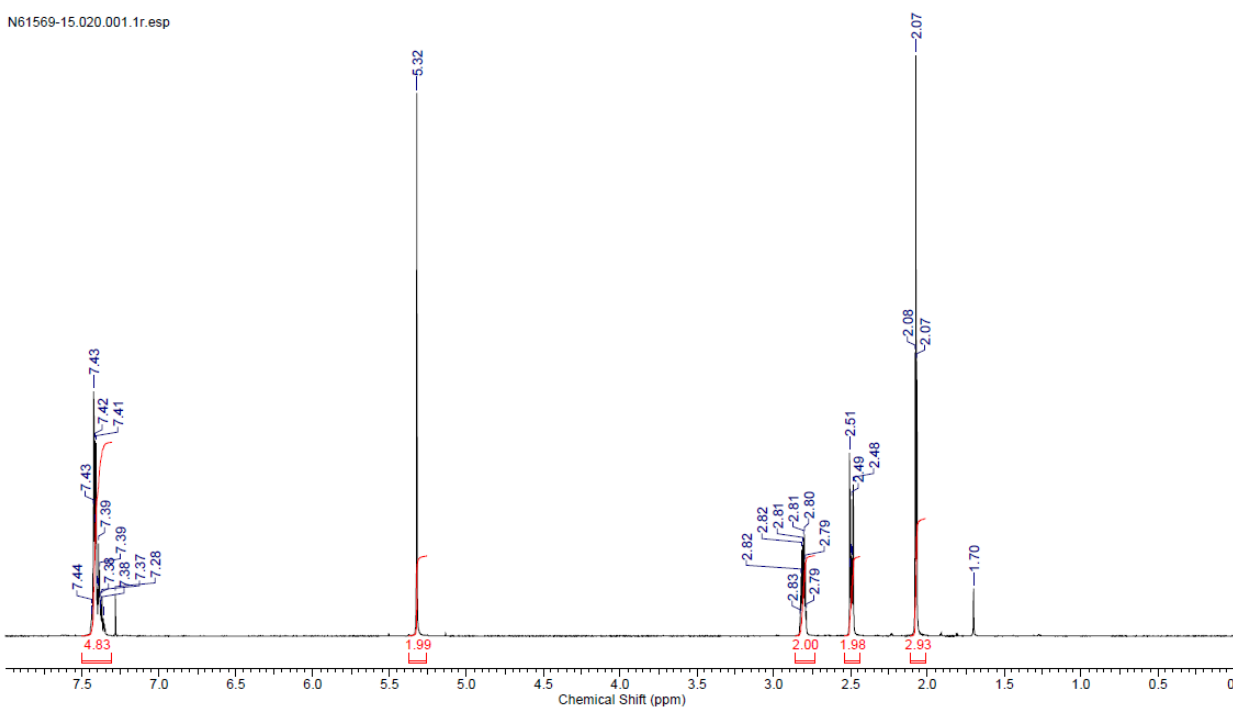
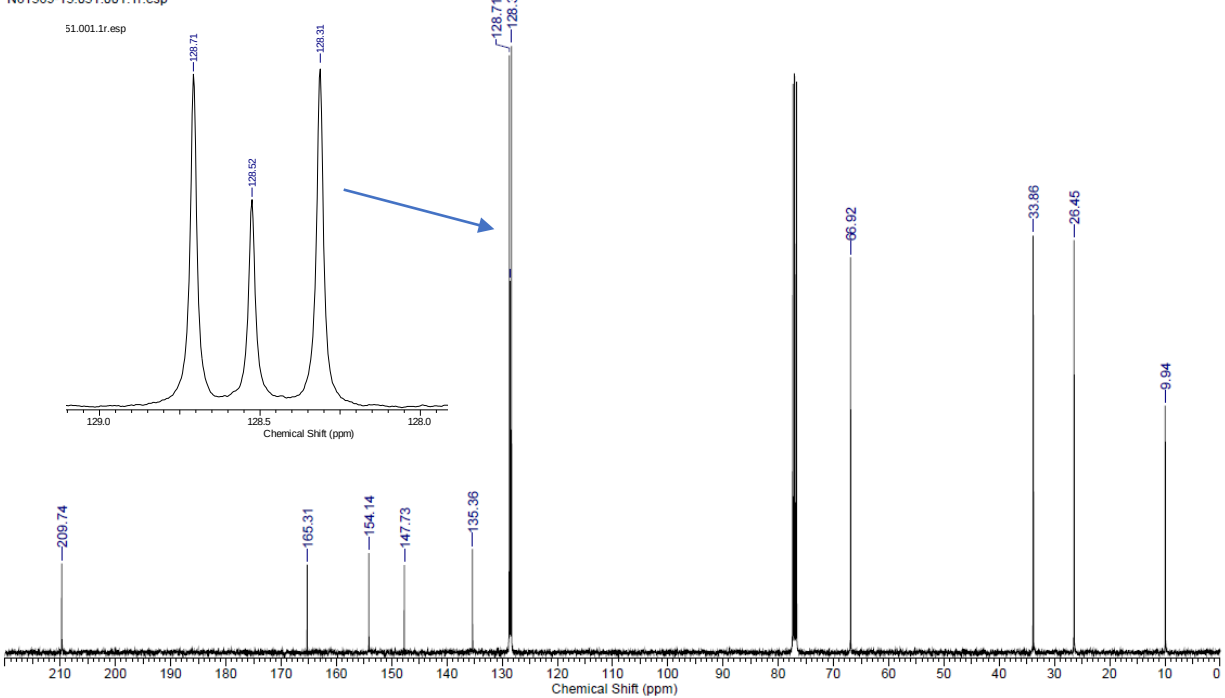


Figure S79: Crude LCMS trace of **5d**, with actual and calculated isotope pattern for pictured Pd cation.

Figure S80: ¹H NMR spectrum of 5d.Figure S81: ¹³C{¹H} NMR spectrum of 5d.

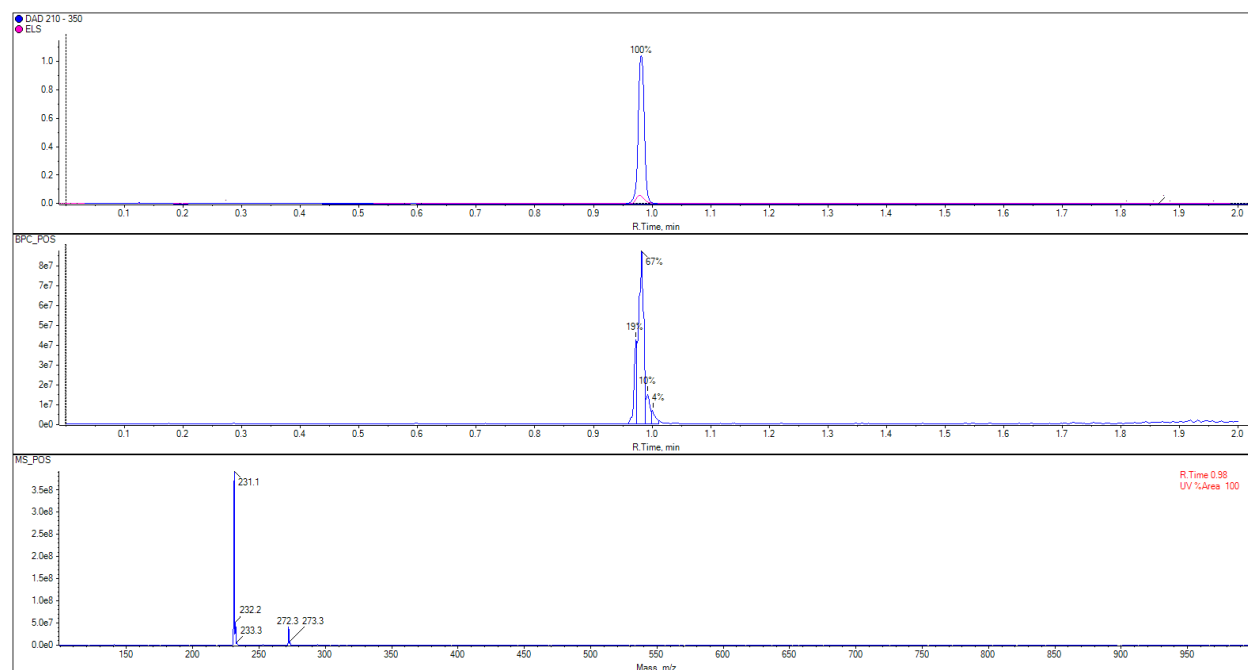
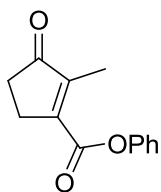


Figure S82: LCMS trace of 5d.



5j

71% (NMR)
61% (isolated)

Material charges: 5a (1.00 g, 7.66 mmol), PdCl₂(CH₃CN)₂ (39.7 mg, 0.153 mmol), P(Me)(*t*-Bu)₂-HBF₄ (76.0 mg, 0.306 mmol), triethylamine (1.16 g, 1.60 mL, 11.5 mmol), phenol (1.44 g, 15.3 mmol), toluene (5.0 mL), acetonitrile (5.0 mL). **5j:** 1.01 g isolated as a pale yellow oil that solidified upon standing (61% yield). ¹H NMR (400 MHz, CDCl₃) δ ppm 2.17 (t, *J* = 2.4 Hz, 3 H) 2.53 - 2.62 (m, 2 H) 2.88 - 3.00 (m, 2 H) 7.14 - 7.23 (m, 2 H) 7.27 - 7.35 (m, 1 H) 7.40 - 7.51 (m, 2 H). ¹³C{¹H} NMR (101 MHz, CDCl₃) δ ppm 10.11, 26.53, 33.98, 121.42, 126.32, 129.63, 149.19, 150.17, 153.39, 163.87 (-CO₂Ph), 209.49 (C=O). LRMS (ESI): *m/z* = 217 [M+H]⁺, 258 [M+H+CH₃CN]⁺.

N59767-80.010.001.1r.esp

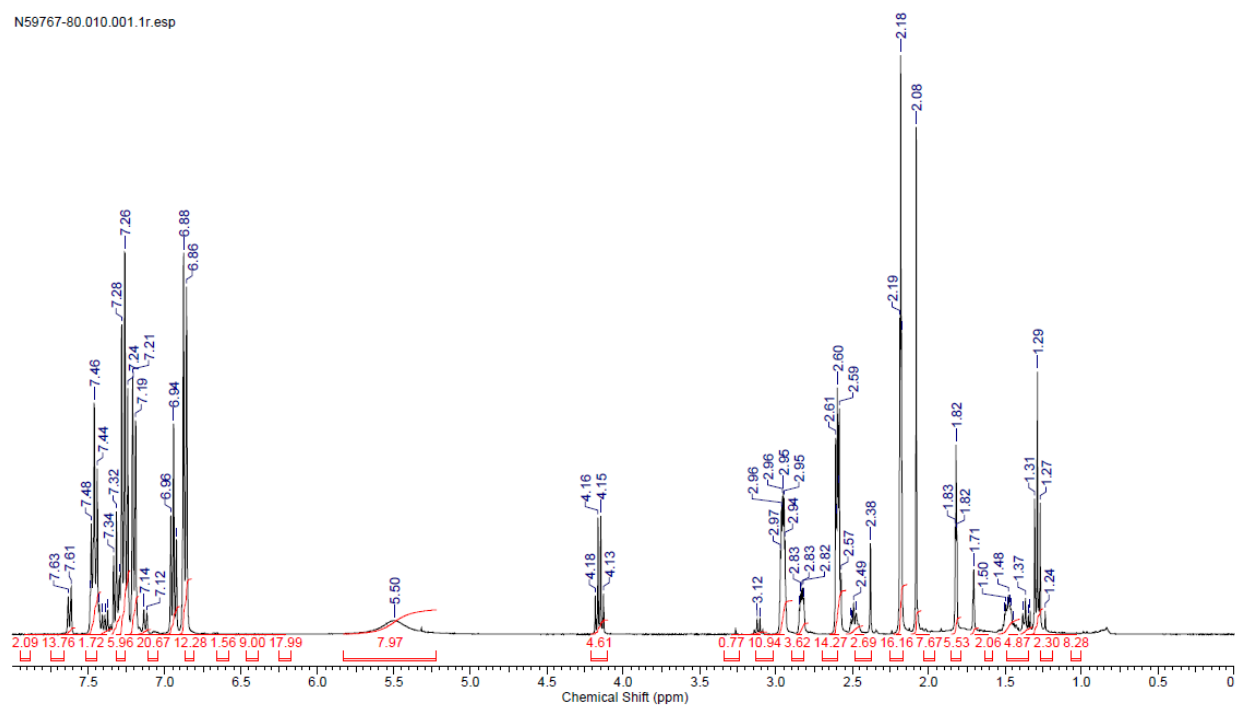


Figure S83: Crude ¹H NMR spectrum of **5j**.

NMR yield determination:

Amount of biphenyl standard added = 0.523 mmol (80.7 mg).

Peak at 7.62 ppm integration set to 0.523 mmol X 4 = 2.09 (signal corresponds to four protons)

Product peak at 2.95 ppm thus corresponds to 10.94 mmol / 2 = 5.47 mmol

NMR yield = 5.47 mmol / 7.66 mmol X 100% = **71%**

NMRz.170.001.1r.esp

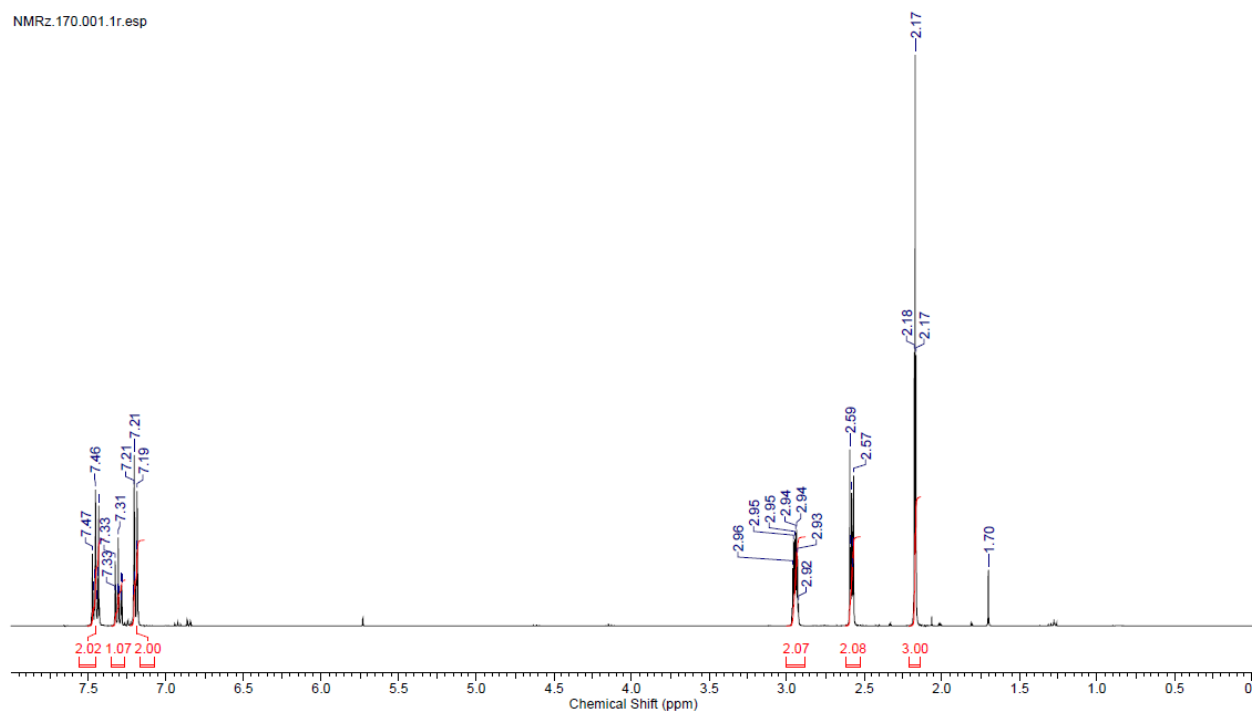


Figure S84: ¹H NMR spectrum of 5j.

N59767-80.171.001.1r.esp

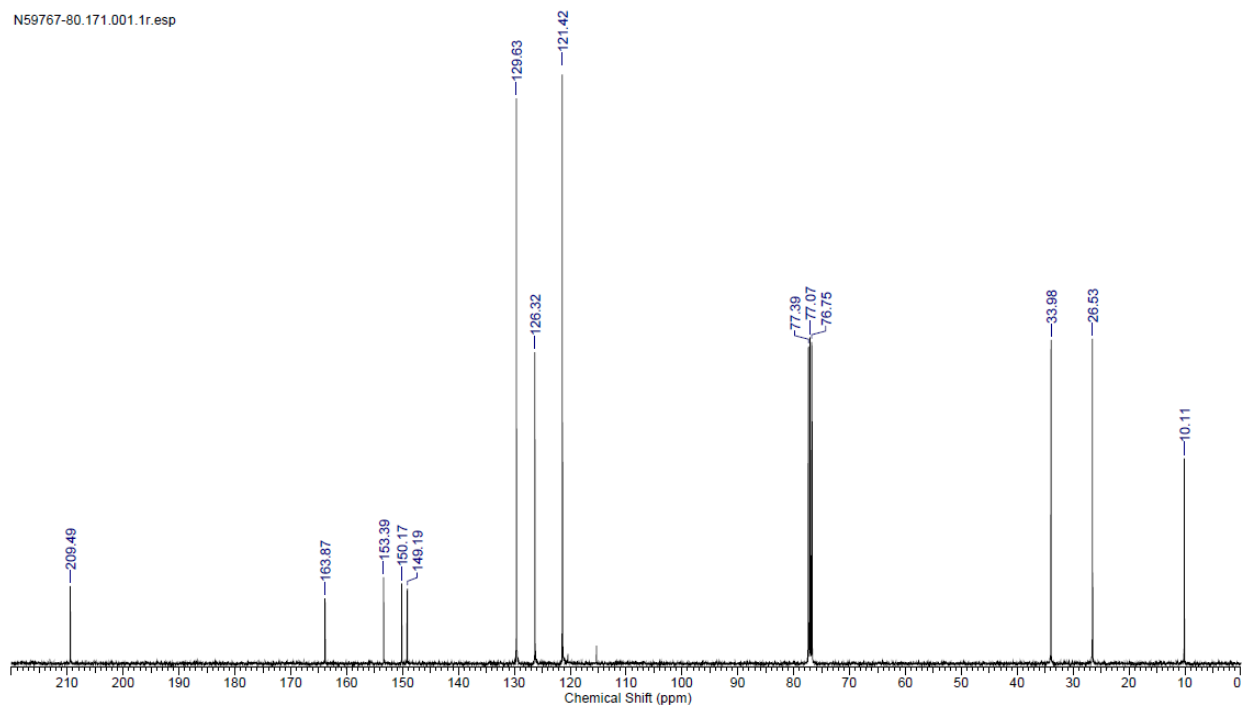


Figure S85: ¹³C{¹H} NMR spectrum of 5j.

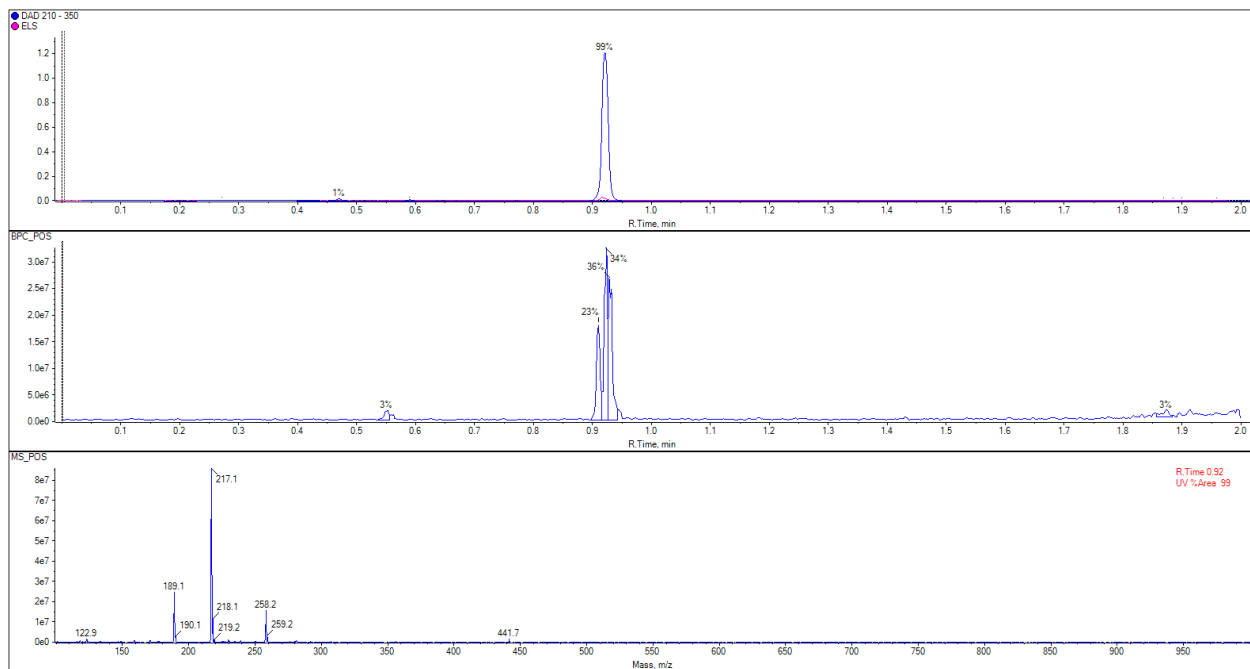
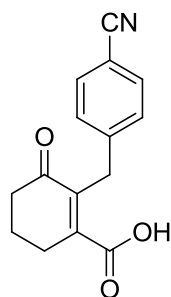


Figure S86: LCMS trace of 5j.



6c

88% (NMR)
81% (isolated)

Material charges: **6a** (1.00 g, 4.07 mmol), $\text{PdCl}_2(\text{CH}_3\text{CN})_2$ (21.1 mg, 0.0814 mmol), $\text{P}(\text{Me})(t\text{-Bu})_2\text{-HBF}_4$ (40.4 mg, 0.163 mmol), triethylamine (0.618 g, 0.85 mL, 6.11 mmol), water (0.147 g, 8.14 mmol), toluene (5.0 mL), acetonitrile (5.0 mL). **6c**: 0.841 g isolated as a tan solid (81% yield). ^1H NMR (400 MHz, CD_3OD) δ ppm 1.98 - 2.12 (m, 2 H, $-\text{CH}_2-$), 2.41 - 2.53 (m, 2 H, $-\text{CH}_2\text{-C}=\text{C}$), 2.71 (t, $J = 6.1$ Hz, 2 H, $-\text{CH}_2\text{-C}=\text{O}$), 3.88 (s, 2 H, $-\text{CH}_2\text{Ar}$), 7.37 - 7.46 (m, 2 H, Ar-H x 2), 7.54 - 7.65 (m, 2 H, Ar-H x 2). $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CD_3OD) δ ppm 21.76, 27.33, 31.81, 37.41, 109.22 ($-\text{C}\equiv\text{N}$), 118.51, 129.43, 131.57, 136.34, 145.87, 149.11, 169.70 ($-\text{CO}_2\text{H}$), 199.33 ($\text{C}=\text{O}$). LRMS (ESI): $m/z = 256$ $[\text{M}+\text{H}]^+$, 297 $[\text{M}+\text{H}+\text{CH}_3\text{CN}]^+$, 319 $[\text{M}+\text{Na}+\text{CH}_3\text{CN}]^+$, 533 $[2\text{M} + \text{Na}]^+$.

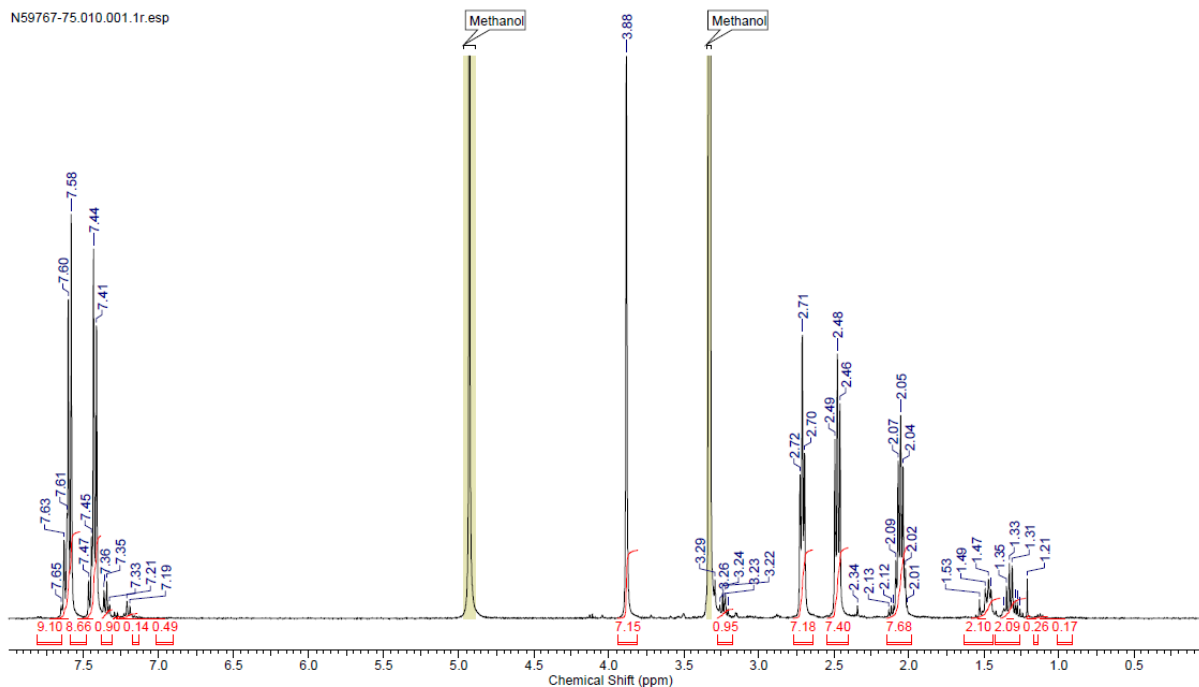


Figure S87: Crude ^1H NMR spectrum of **6c**.

NMR yield determination:

Amount of biphenyl standard added = 0.448 mmol (69.1 mg).

Peak at 7.35 ppm integration set to 0.448 mmol $\times 2 = 0.90$ (signal corresponds to two protons)

Product peak at 3.88 ppm thus corresponds to 7.15 mmol / 2 = 3.58 mmol

NMR yield = 3.58 mmol / 4.07 mmol $\times 100\%$ = **88%**

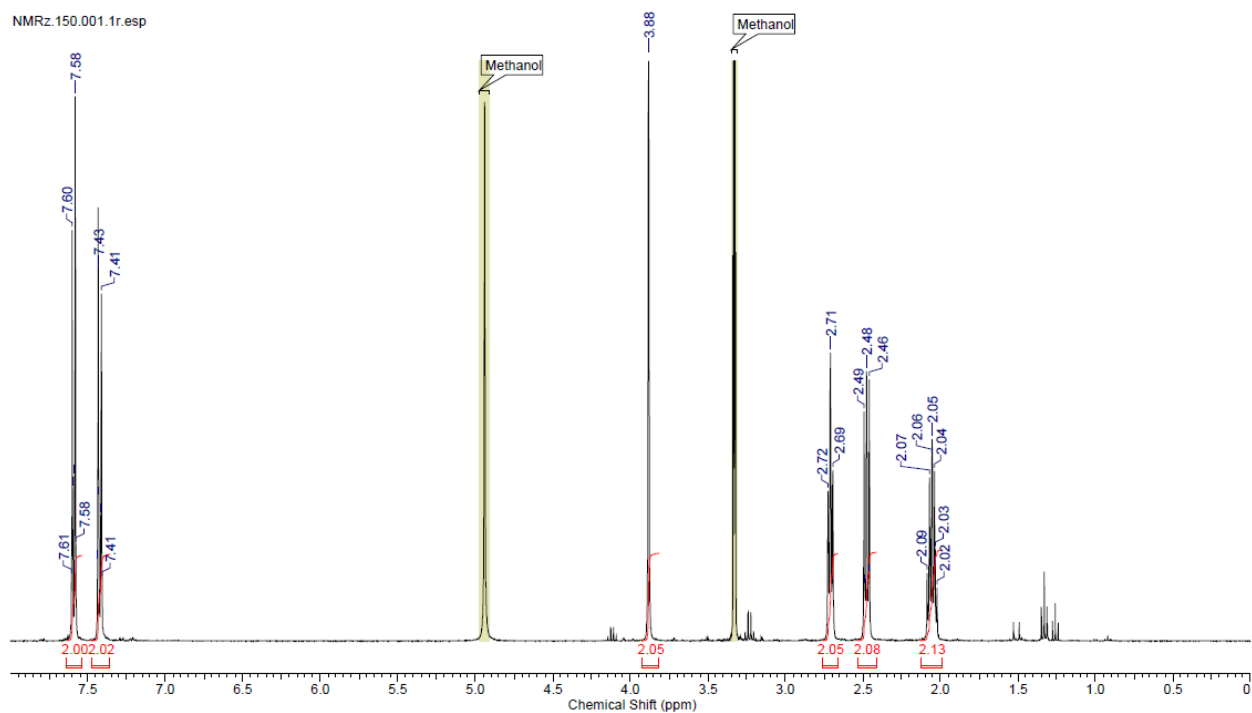


Figure S88: ^1H NMR spectrum of **6c**. Peaks denoted 'methanol' correspond to residual protio solvent from CD_3OD .

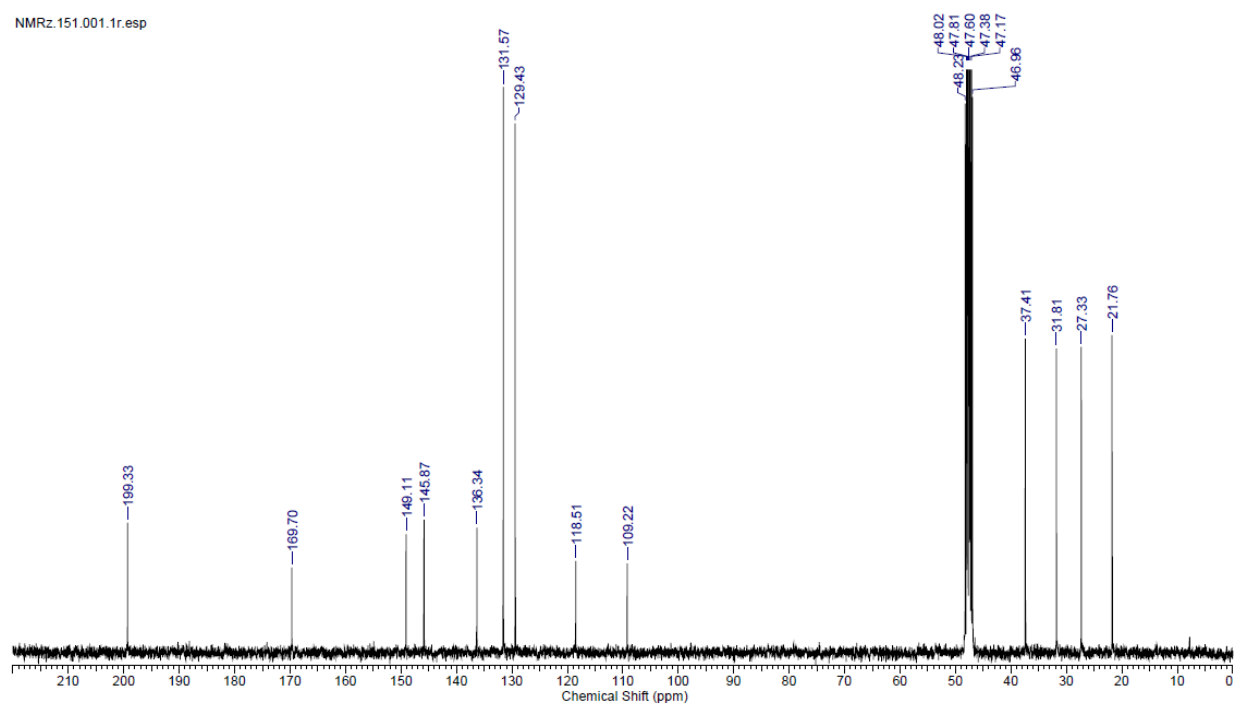


Figure S89: $^{13}\text{C}\{^1\text{H}\}$ NMR spectrum of **6c**.

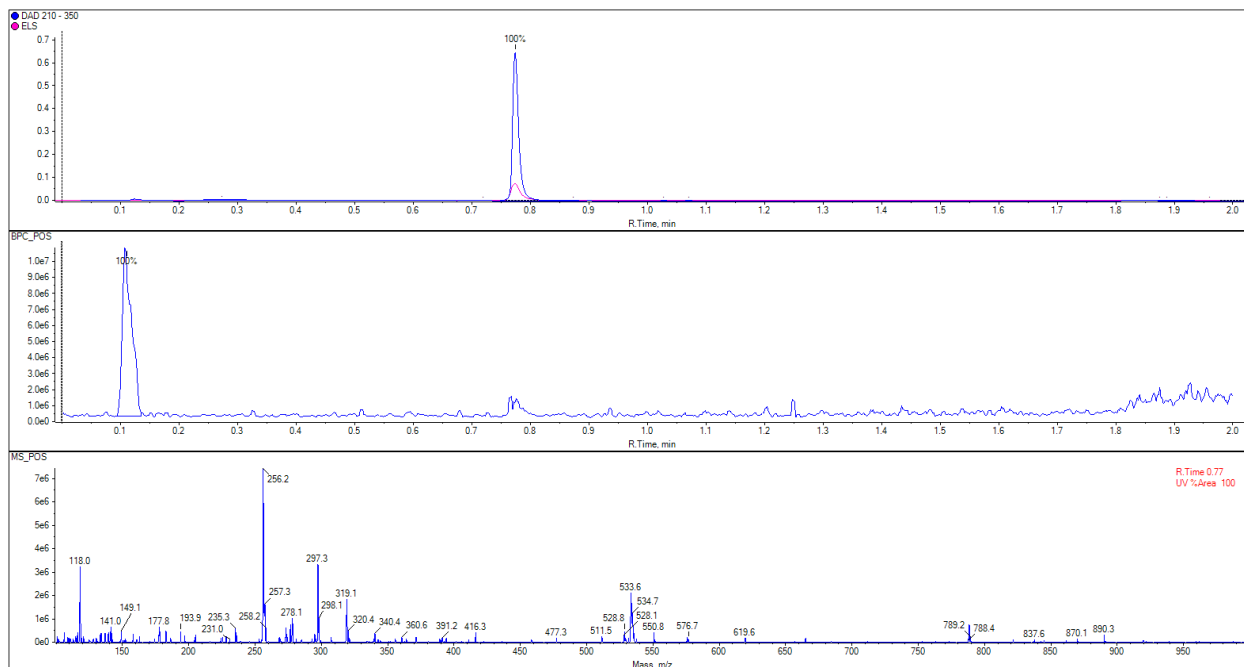
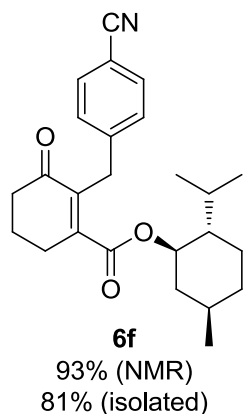


Figure S90: LCMS trace of 6c.



Material charges: **6a** (1.00 g, 4.07 mmol), $\text{PdCl}_2(\text{CH}_3\text{CN})_2$ (21.1 mg, 0.0814 mmol), $\text{P}(\text{Me})(t\text{-Bu})_2\text{-HBF}_4$ (40.4 mg, 0.163 mmol), triethylamine (0.618 g, 0.85 mL, 6.11 mmol), menthol (1.27 g, 8.14 mmol), toluene (5.0 mL), acetonitrile (5.0 mL). **6f**: 1.30 g isolated as a yellow oil (81% yield). ^1H NMR (400 MHz, CDCl_3) δ ppm 0.75 (d, $J = 6.9$ Hz, 3 H) 0.84 - 0.89 (m, 3 H) 0.89 - 0.94 (m, 3 H) 0.94 - 1.02 (m, 1 H) 1.02 - 1.16 (m, 1 H) 1.40 (tt, $J = 11.6, 3.1$ Hz, 1 H) 1.45 - 1.60 (m, 1 H) 1.64 - 1.75 (m, 2 H) 1.75 - 1.86 (m, 1 H) 1.91 - 2.02 (m, 1 H) 2.02 - 2.13 (m, 2 H) 2.43 - 2.53 (m, 2 H) 2.58 - 2.73 (m, 2 H) 3.76 - 3.91 (m, 2 H) 4.83 (td, $J = 10.9, 4.4$ Hz, 1 H) 7.36 (m, $J = 8.5$ Hz, 2 H) 7.47 - 7.59 (m, 2 H). $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3) δ ppm 16.00, 20.75, 21.96, 23.15, 26.24, 27.70, 31.43, 32.31, 34.03, 37.88, 40.72, 46.87, 76.02, 109.80, 119.11, 129.54, 131.98, 137.32, 145.17, 147.69, 167.64 ($-\text{CO}_2\text{R}$), 198.48 ($\text{C}=\text{O}$). LRMS (ESI): $m/z = 394$ $[\text{M}+\text{H}]^+$, 435 $[\text{M}+\text{H}+\text{CH}_3\text{CN}]^+$.

N59767-76.010.001.1r.esp

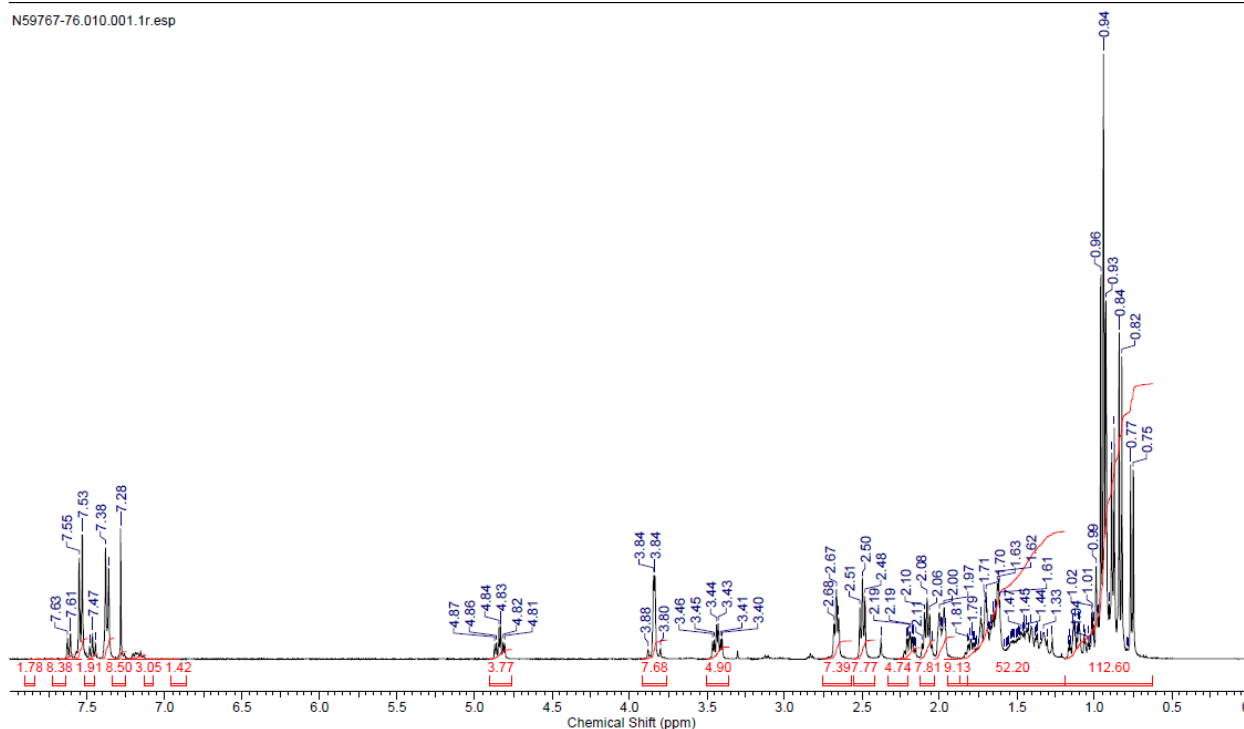


Figure S91: Crude ^1H NMR spectrum of **6f**.

NMR yield determination:

Amount of biphenyl standard added = 0.446 mmol (68.8 mg).

Peak at 7.62 ppm integration set to 0.446 mmol X 4 = 1.78 (signal corresponds to four protons)

Product peak at 4.84 ppm thus corresponds to 3.77 mmol

NMR yield = 3.77 mmol / 4.07 mmol X 100% = **93%**

N59767-76.090.001.1r.esp

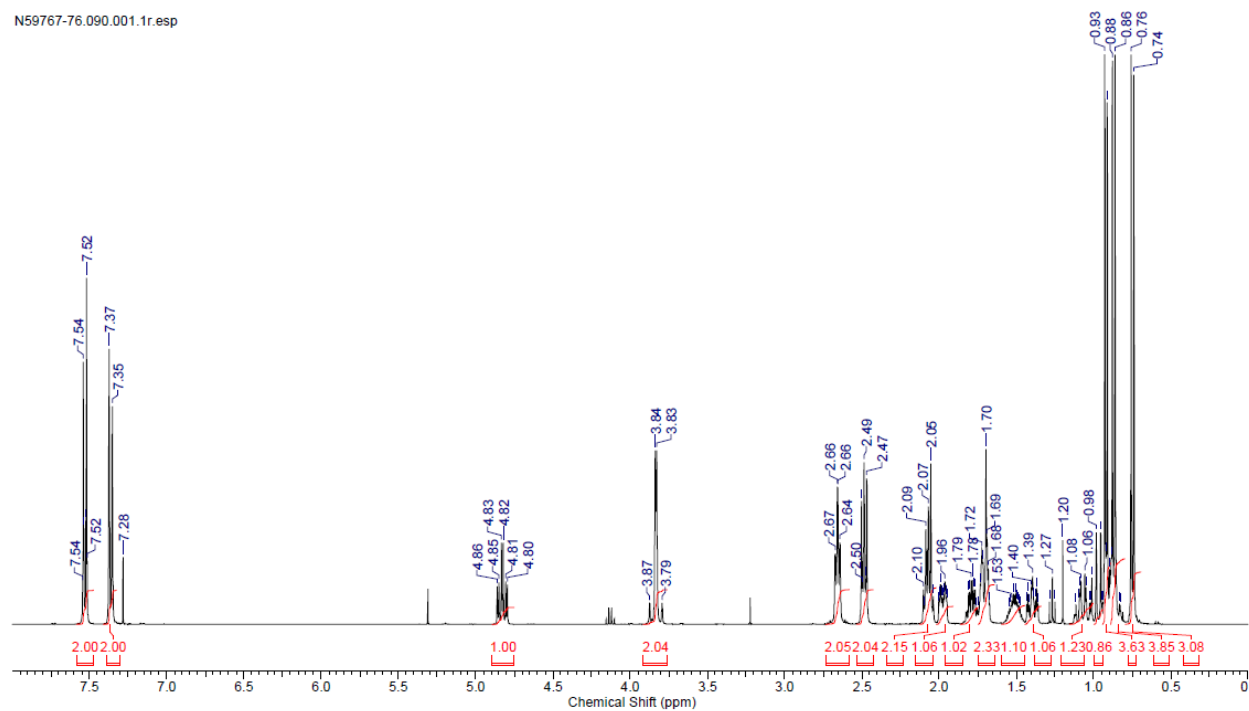


Figure S92: ¹H NMR spectrum of **6f**.

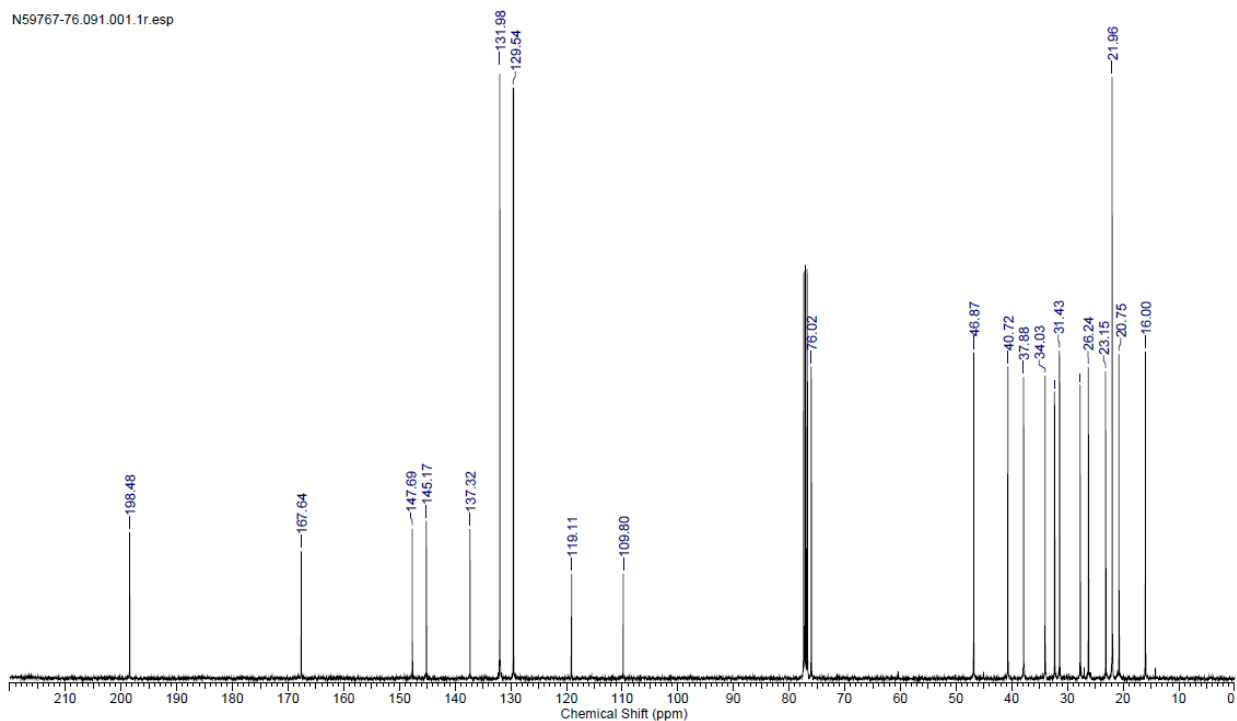
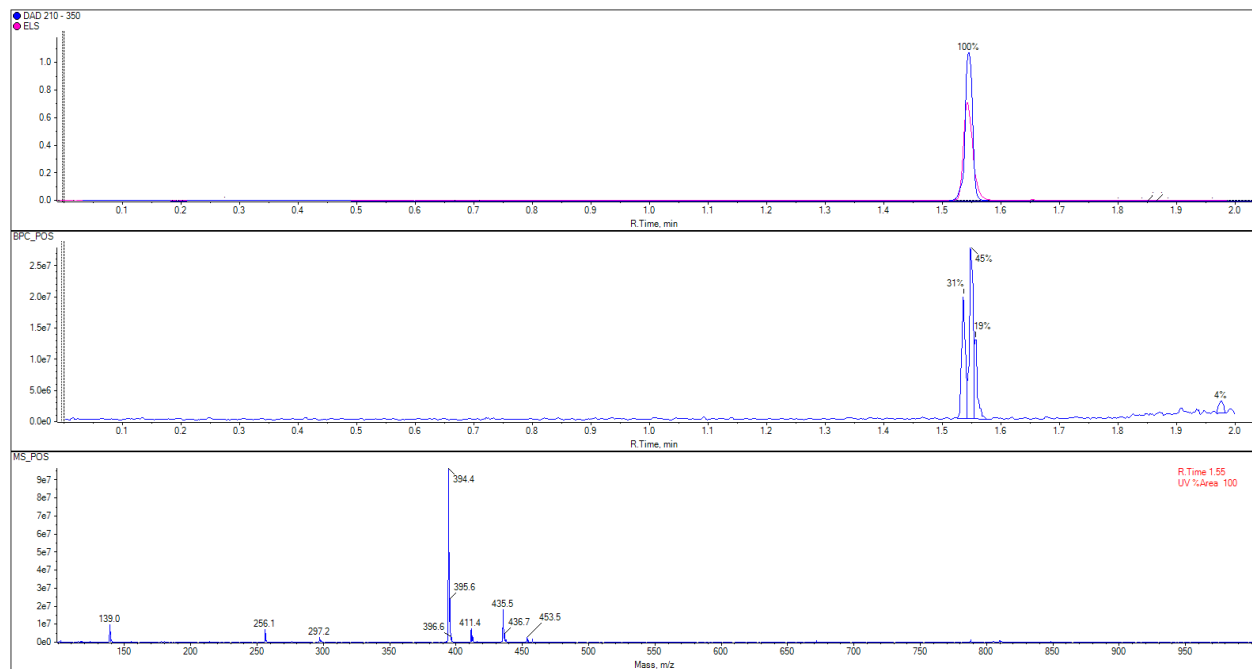
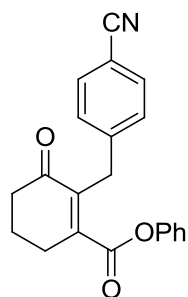
Figure S93: $^{13}\text{C}\{^1\text{H}\}$ NMR spectrum of 6f.

Figure S94: LCMS trace of 6f.



6j

85% (isolated)
(NMR yield n.d.)

Material charges: **6a** (1.00 g, 4.07 mmol), $\text{PdCl}_2(\text{CH}_3\text{CN})_2$ (21.1 mg, 0.0814 mmol), $\text{P}(\text{Me})(t\text{-Bu})_2\text{-HBF}_4$ (40.4 mg, 0.163 mmol), triethylamine (0.618 g, 0.85 mL, 6.11 mmol), phenol (0.766 g, 8.14 mmol), toluene (5.0 mL), acetonitrile (5.0 mL). **6j**: 1.15 g isolated as a yellow oil that partially solidified upon standing (85% yield). ^1H NMR (400 MHz, CDCl_3) δ ppm 2.15 (quin, $J=6.41$ Hz, 2 H) 2.53 - 2.62 (m, 2 H) 2.87 (t, $J=6.02$ Hz, 2 H) 4.01 (s, 2 H) 7.04 - 7.11 (m, 2 H) 7.31 (tt, $J=7.50$, 1.30 Hz, 1 H) 7.38 - 7.44 (m, 2 H) 7.44 - 7.48 (m, 1 H) 7.52 - 7.58 (m, 2 H). $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3) δ ppm 21.87, 27.71, 32.24, 37.95, 109.98, 119.07, 121.22, 126.56, 129.70, 129.75, 132.10, 140.09, 144.89, 145.56, 149.94, 166.25, 198.30. LRMS (ESI): m/z = 332 $[\text{M}+\text{H}]^+$, 349 $[\text{M}+\text{NH}_4]^+$, 373 $[\text{M}+\text{H}+\text{CH}_3\text{CN}]^+$.

N59767-82.010.001.1r.esp

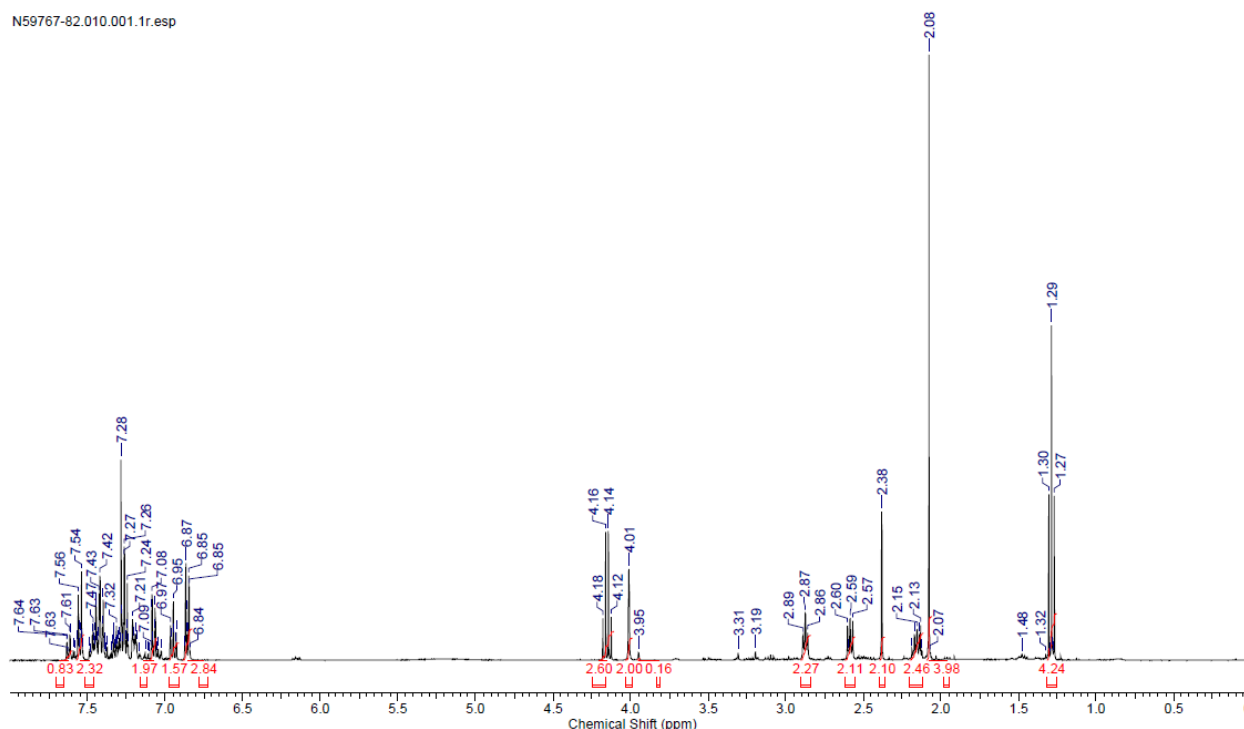


Figure S95: Crude ^1H NMR spectrum of **6j**.

NMR yield determination:

NMR yield not determined due to peak overlap in the aromatic region obscuring the biphenyl signals.

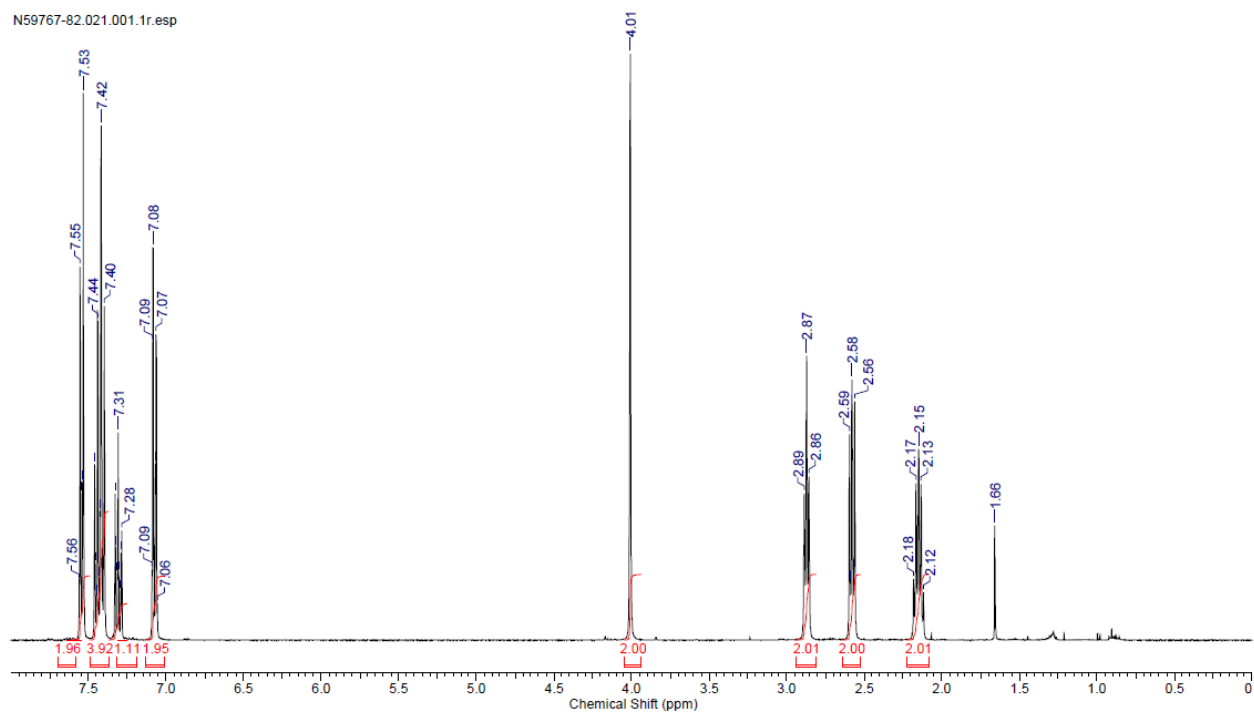


Figure S96: ^1H NMR spectrum of **6j**.

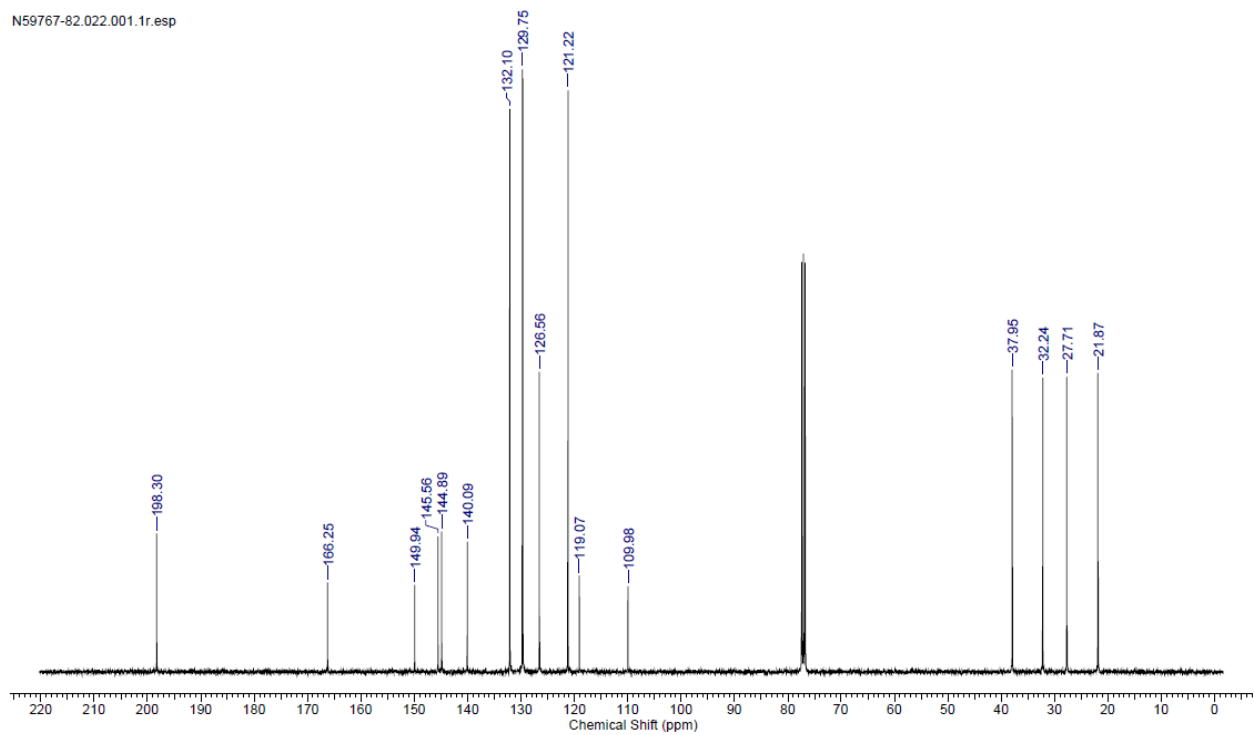


Figure S97: $^{13}\text{C}\{^1\text{H}\}$ NMR spectrum of **6j**.

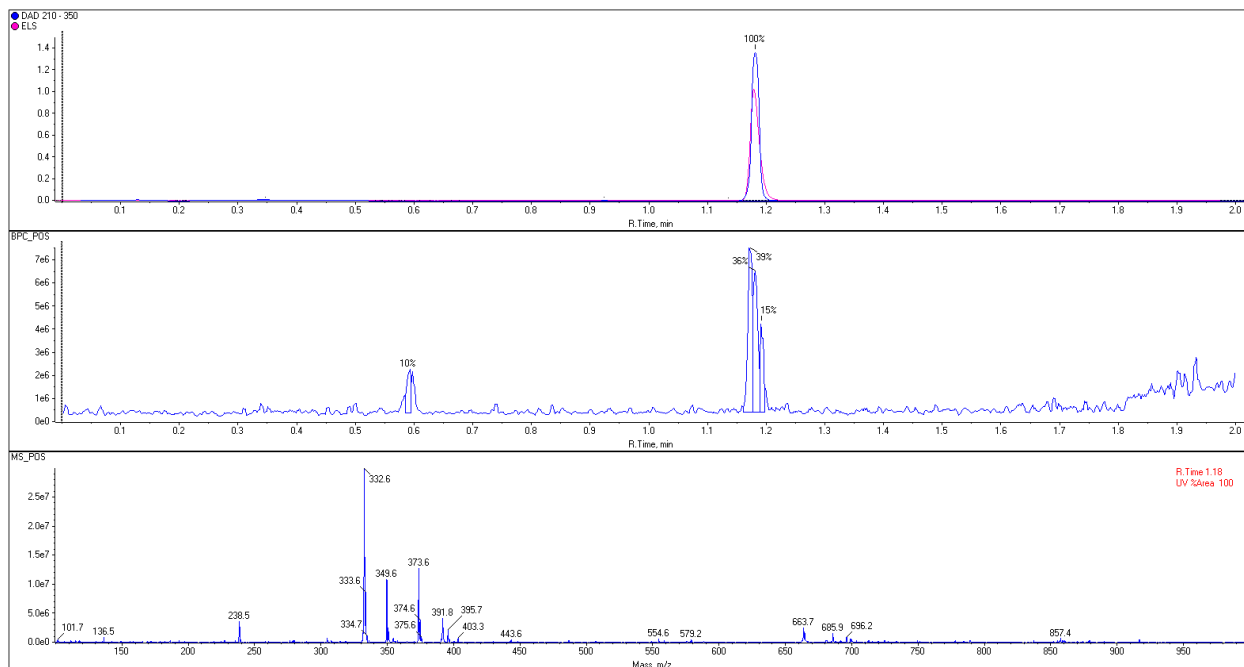
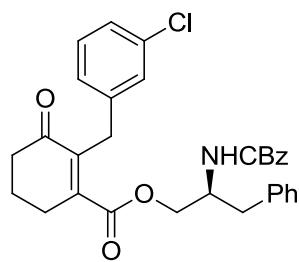


Figure S98: LCMS trace of 6j.



7h

54% (NMR)

44% (isolated)

(27% **7a** recovered)

Material charges: **7a** (0.90 g, 3.53 mmol), $\text{PdCl}_2(\text{CH}_3\text{CN})_2$ (18.3 mg, 0.071 mmol), $\text{P}(\text{Me})(t\text{-Bu})_2\text{-HBF}_4$ (35.0 mg, 0.141 mmol), triethylamine (0.535 g, 0.738 mL, 5.29 mmol), *N*-CBz-L-phenylalaninol (1.21 g, 4.23 mmol), toluene (5.0 mL), acetonitrile (5.0 mL). **7h**: 0.798 g isolated as a yellow oil (44% yield); a further 0.243 g of **7a** was isolated after column chromatography (27% recovered starting material). ^1H NMR (400 MHz, CDCl_3) δ ppm 1.99 - 2.13 (m, 2 H) 2.45 - 2.55 (m, 2 H) 2.63 (td, $J=6.00, 2.00$ Hz, 2 H) 2.81 (qd, $J = 13.0, 6.0$ Hz, 2 H) 3.72 - 3.87 (m, 2 H) 4.11 - 4.29 (m, 3 H) 4.71 (br. d, $J=7.00$ Hz, 1 H) 5.00 - 5.16 (m, 2 H) 7.02 - 7.18 (m, 5 H) 7.19 - 7.22 (m, 1 H) 7.23 - 7.46 (m, 9 H). $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3) δ ppm 21.94, 27.62, 31.72, 37.84, 37.91, 51.08, 65.95, 66.85, 126.38, 126.87, 126.98, 128.10, 128.25, 128.57, 128.61, 128.77, 129.14, 129.56, 134.08, 136.26, 136.48, 139.03, 141.23, 145.83, 155.63, 167.81, 198.34. LRMS (ESI): $m/z = 532$ $[\text{M}+\text{H}]^+$.

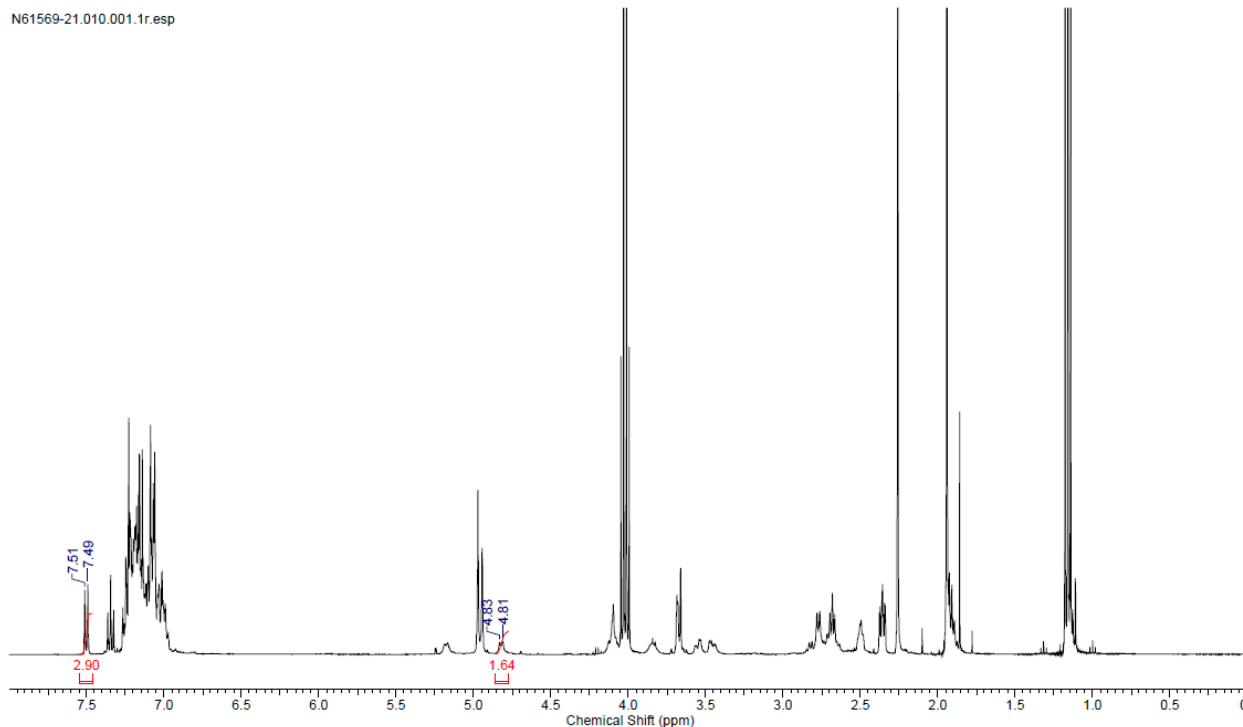


Figure S99: Crude ^1H NMR spectrum of **7h**.

NMR yield determination:

Amount of biphenyl standard added = 0.726 mmol (111.9 mg).

Peak at 7.50 ppm integration set to 0.726 mmol X 4 = 2.90 (signal corresponds to four protons)

Product peak at 4.82 ppm thus corresponds to 1.64 mmol / 0.86 = 1.91 mmol

(0.86 is response factor for methine C-H signal – see ^1H NMR spectrum for isolated material)

NMR yield = 1.91 mmol / 3.53 mmol X 100% = **54%**

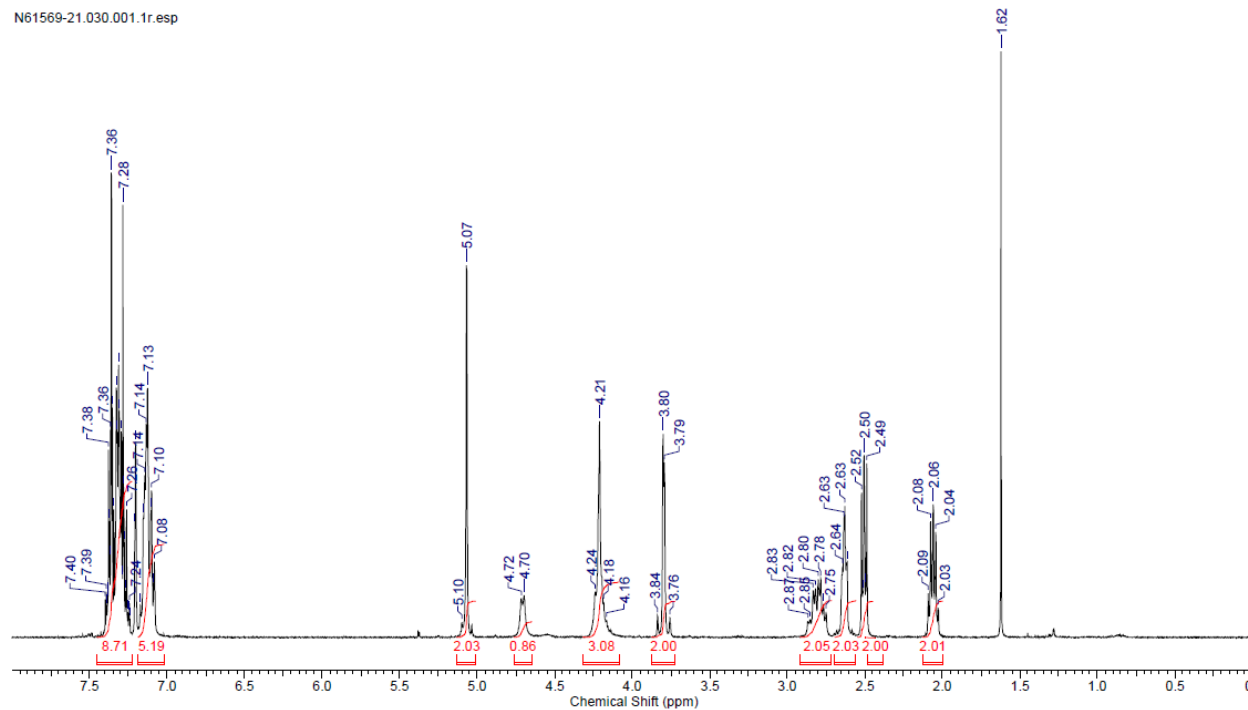


Figure S100: ^1H NMR spectrum of **7h**.

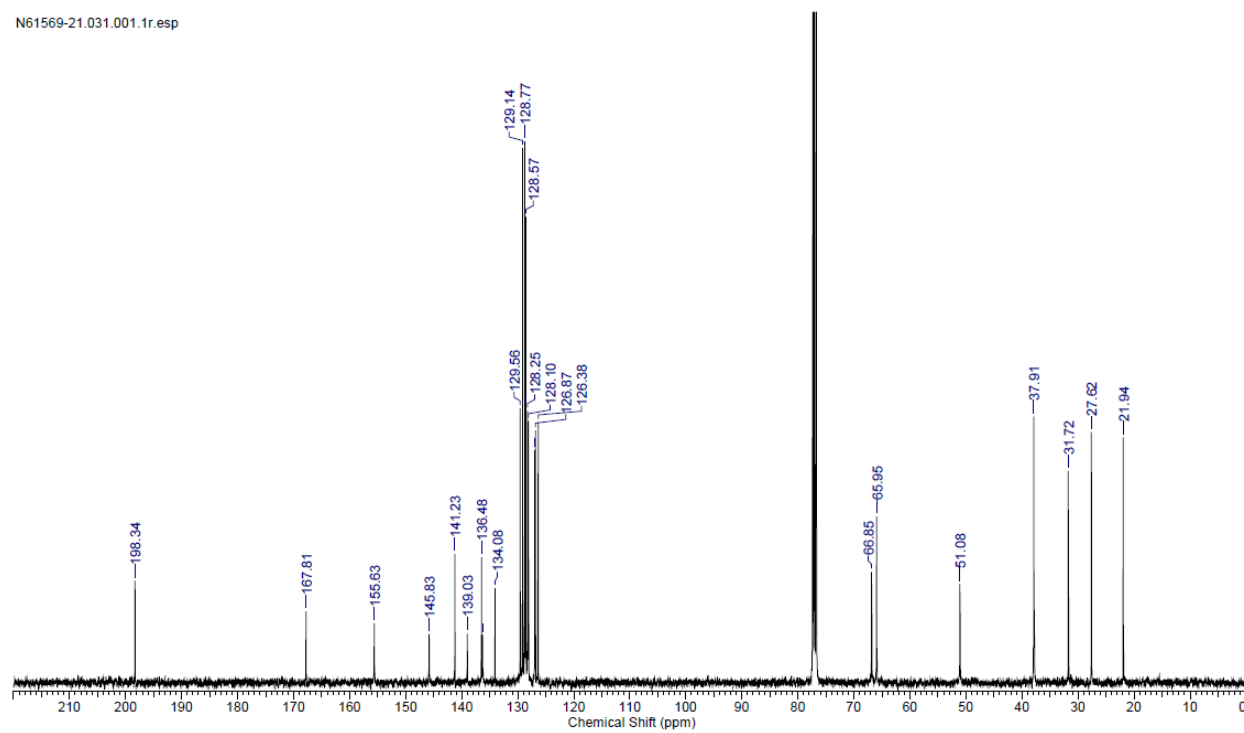
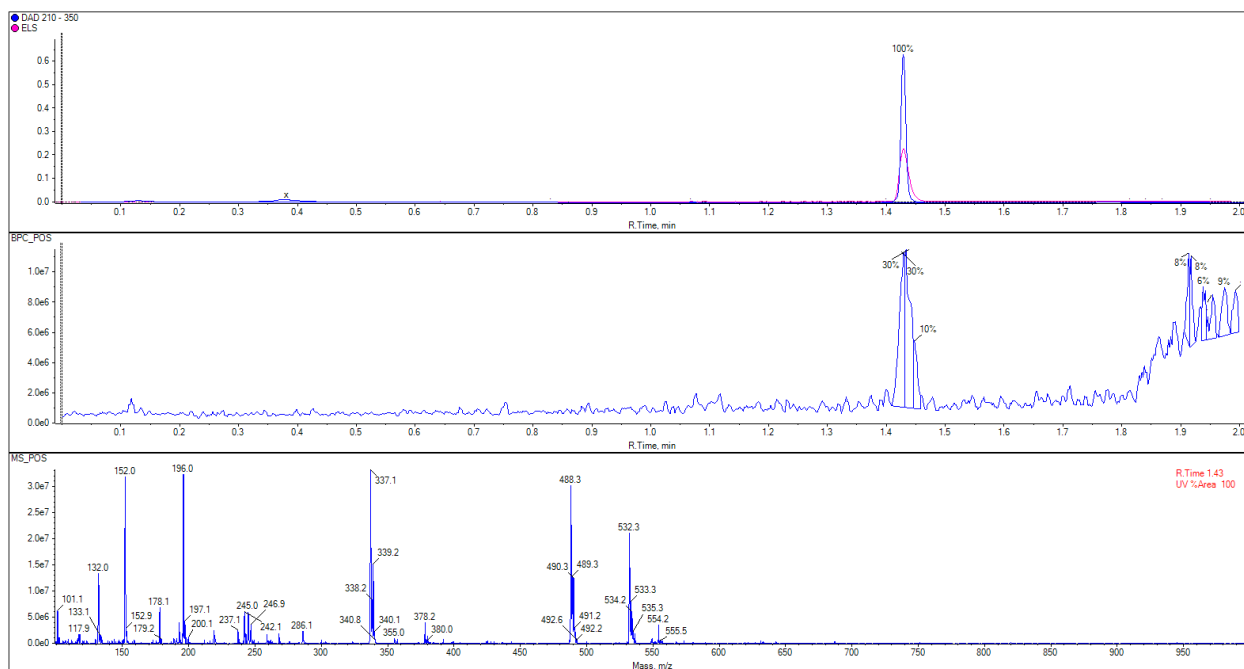
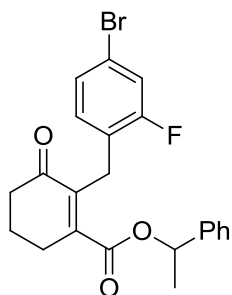
Figure S101: $^{13}\text{C}\{^1\text{H}\}$ NMR spectrum of 7h.

Figure S102: LCMS trace of 7h.



8e (10 mol% Pd)
53% (NMR)
50% (isolated)

Material charges: **8a** (1.00 g, 3.15 mmol), PdCl₂(CH₃CN)₂ (82.0 mg, 0.315 mmol), P(Me)(*t*-Bu)₂-HBF₄ (156.0 mg, 0.630 mmol), triethylamine (0.478 g, 0.66 mL, 4.72 mmol), 1-phenylethanol (0.769 g, 6.30 mmol), toluene (5.0 mL), acetonitrile (5.0 mL). **8e**: 0.684 g isolated as a yellow oil (50% yield). ¹H NMR (400 MHz, CDCl₃) δ ppm 1.56 (d, *J*=6.55 Hz, 3 H) 2.03 - 2.14 (m, 2 H) 2.46 - 2.54 (m, 2 H) 2.68 (td, *J*=6.00, 1.00 Hz, 2 H) 3.77 (s, 2 H) 5.99 (q, *J*=6.55 Hz, 1 H) 6.95 (t, *J*=8.00 Hz, 1 H) 7.13 (td, *J*=9.00, 1.50 Hz, 2 H) 7.25 - 7.30 (m, 2 H) 7.31 - 7.38 (m, 3 H). ¹⁹F NMR (376 MHz, CDCl₃) δ ppm -113.86 (s, 1 F). ¹³C{¹H} NMR (101 MHz, CDCl₃) δ ppm 21.86, 22.07, 24.73 (d, *J*=3.41 Hz, 1 C) 27.73, 37.89, 74.01, 118.67 (d, *J*=24.00 Hz, 1 C) 119.70 (d, *J*=9.54 Hz, 1 C) 125.59 (d, *J*=15.33 Hz, 1 C) 126.20 (s, 2 C) 126.99 (d, *J*=3.41 Hz, 1 C) 128.30, 128.62 (s, 2 C) 131.29 (d, *J*=4.77 Hz, 1 C) 137.15, 140.54, 147.44, 160.57 (d, *J*=250.00 Hz, 1 C) 167.20, 198.38 (s, 1 C). LRMS (ESI): *m/z* = 431/433 [M+H]⁺.

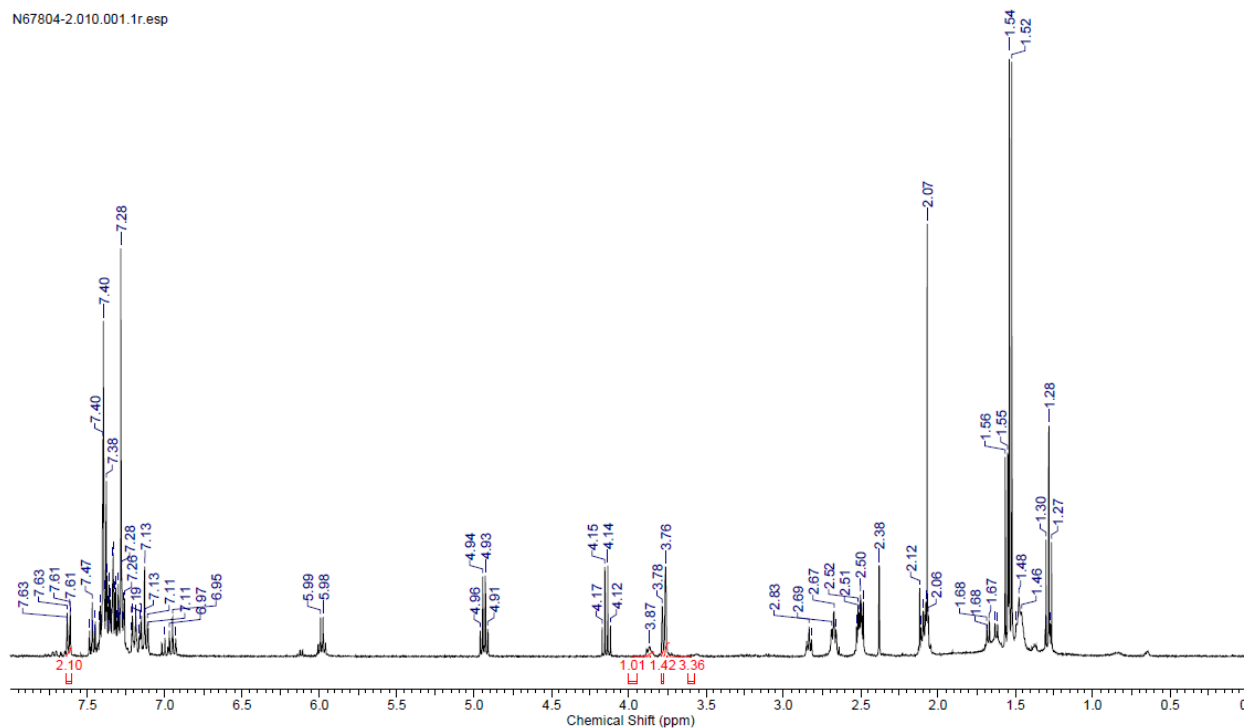


Figure S103: Crude ¹H NMR spectrum of **8e**.

NMR yield determination:

Amount of biphenyl standard added = 0.525 mmol (81.0 mg).

Peak at 7.62 ppm integration set to 0.525 mmol X 4 = 2.10 (signal corresponds to four protons)

Product peak at 3.76 ppm thus corresponds to 3.36 mmol / 2 = 1.68 mmol

NMR yield = 1.68 mmol / 3.15 mmol X 100% = **53%**

(note that this is likely a slight underestimate due to peak overlap for the internal standard signal, and the product methylene signal)

Similarly, the NMR yield of residual starting material (**8a**) is **23%** (peak at 3.78).

The LCMS trace of the crude reaction mixture (Figure S104) also reveals the presence of the double carbonylation product (**8e''**) in ~10% yield.

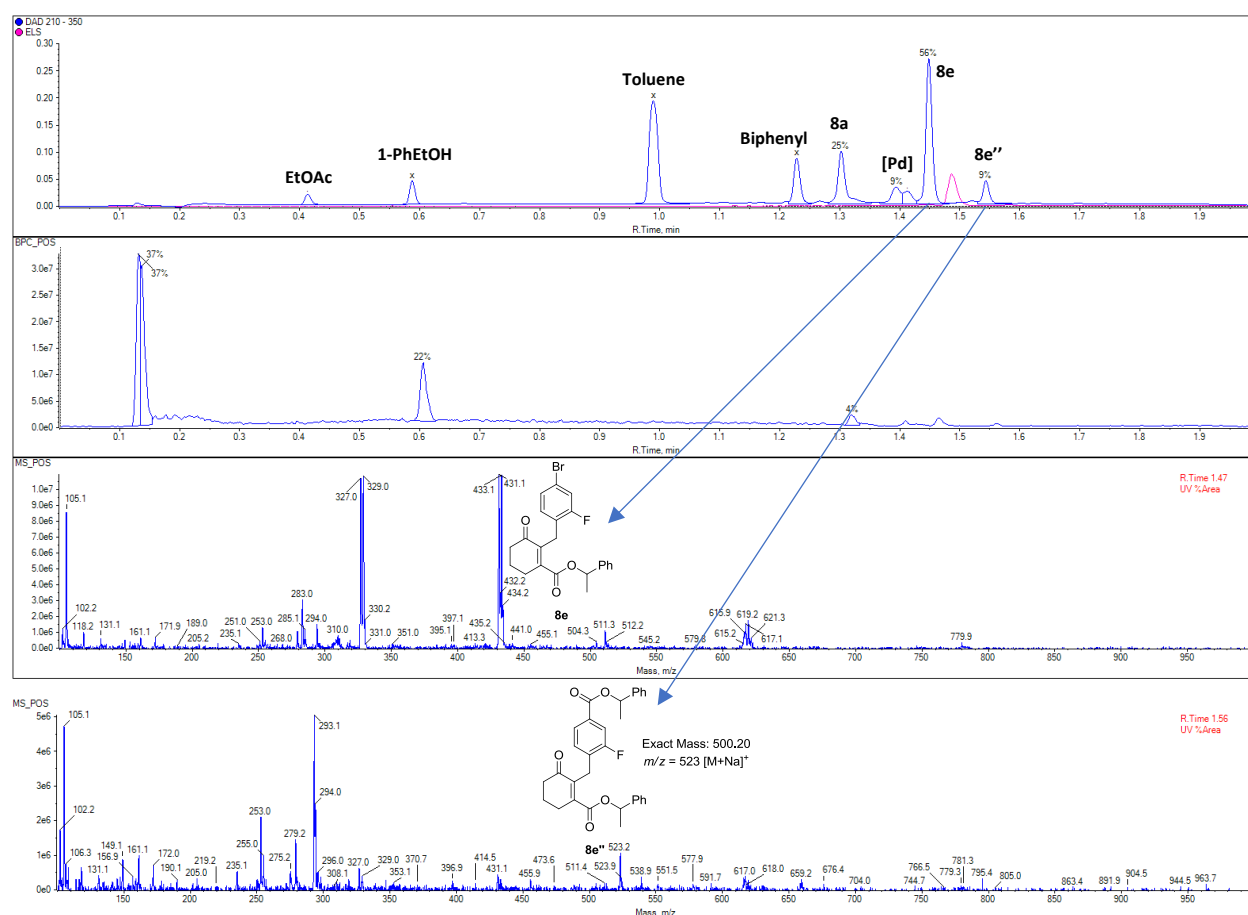
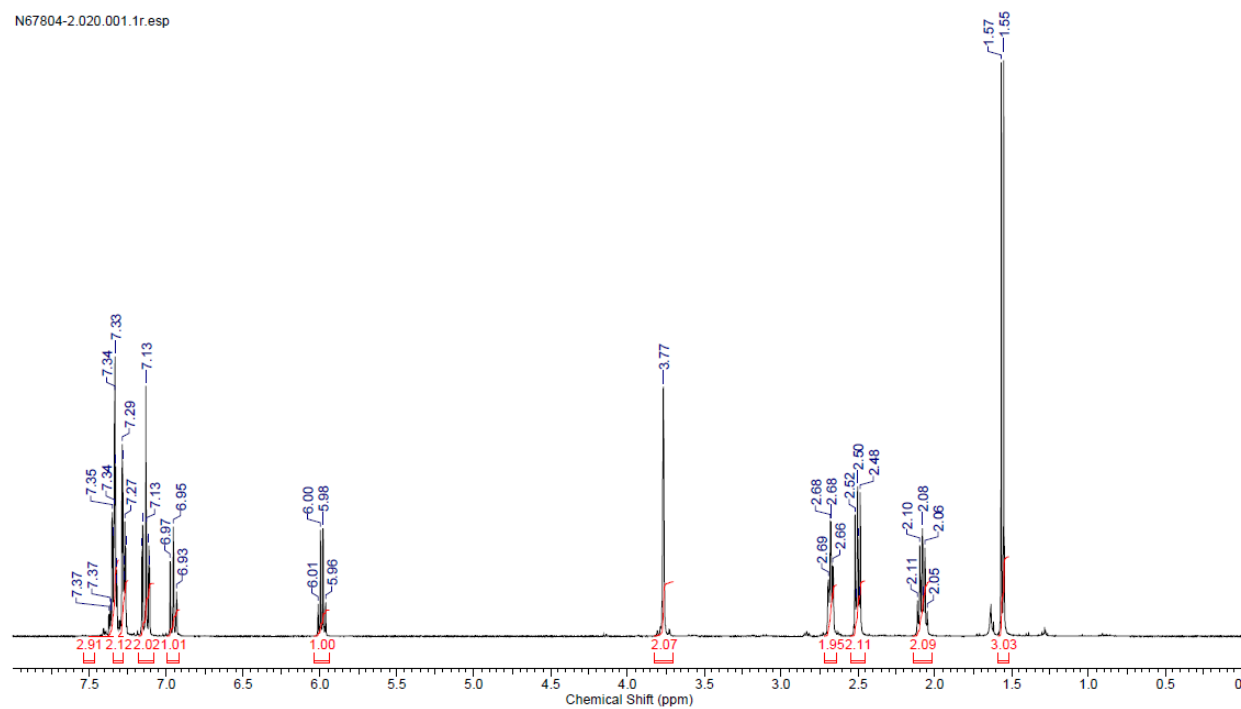
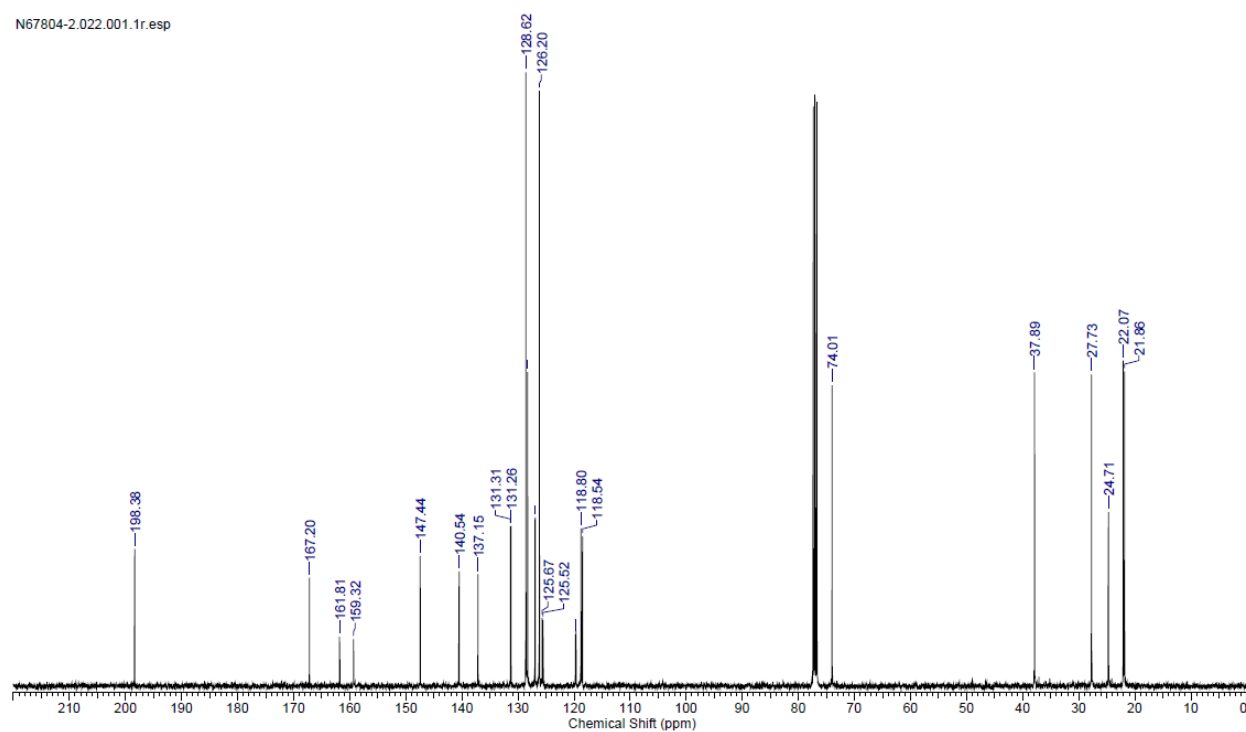


Figure S104: Crude LCMS trace of **8e**.

Figure S105: ¹H NMR spectrum of **8e**.Figure S106: ¹³C{¹H} NMR spectrum of **8e**.

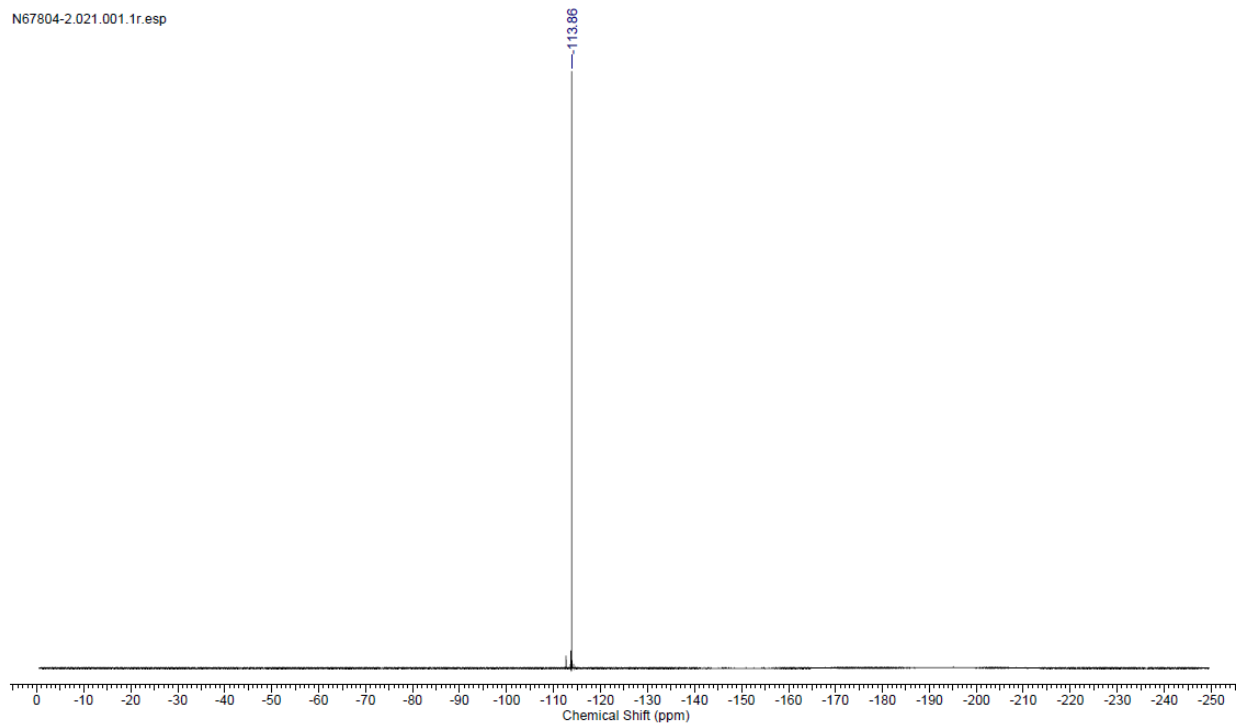


Figure S107: ^{19}F NMR spectrum of **8e**.

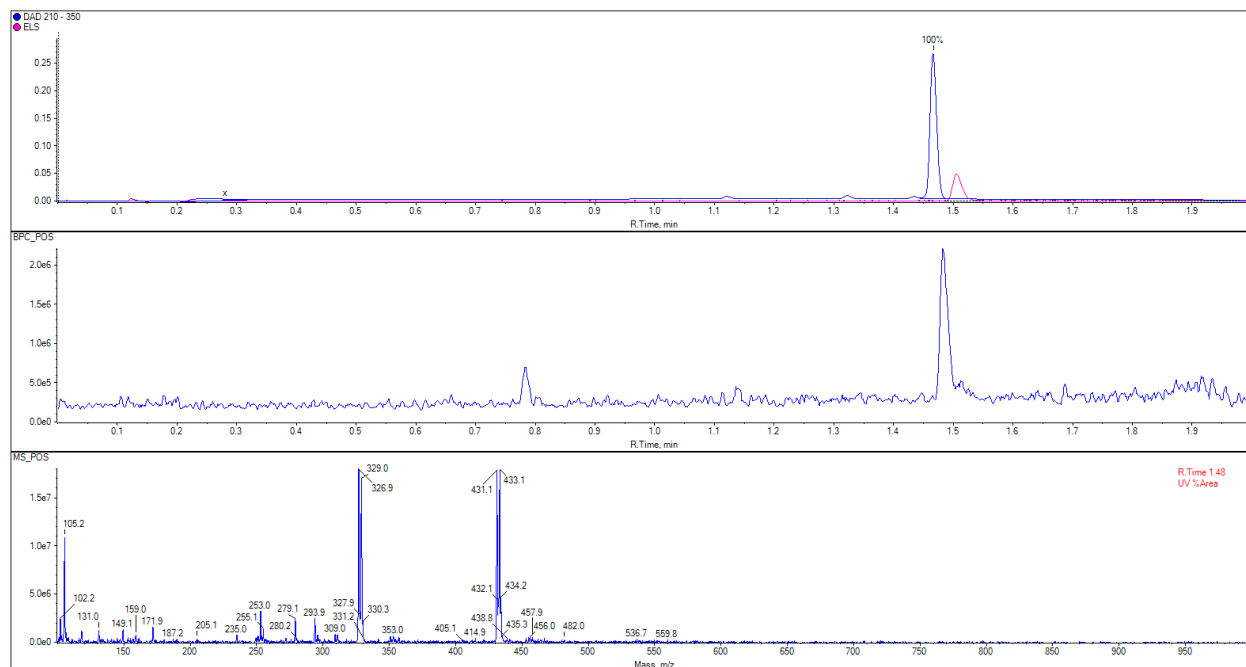
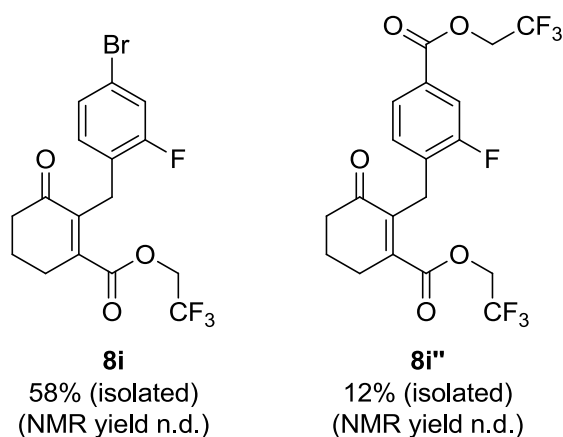


Figure S108: LCMS trace of **8e**.



Material charges: **8a** (1.00 g, 3.15 mmol), PdCl₂(CH₃CN)₂ (82.0 mg, 0.315 mmol), P(Me)(*t*-Bu)₂-HBF₄ (156.0 mg, 0.630 mmol), triethylamine (0.478 g, 0.66 mL, 4.72 mmol), trifluoroethanol (0.630 g, 6.30 mmol), toluene (5.0 mL), acetonitrile (5.0 mL). **8i**: 0.745 g isolated as a yellow oil (58% yield). The double-carbonylation product **8i''** was also isolated by column chromatography (0.176 g, 12% yield).

8i: ¹H NMR (400 MHz, CDCl₃) δ ppm 2.04 - 2.16 (m, 2 H) 2.48 - 2.57 (m, 2 H) 2.70 (t, *J*=6.06 Hz, 2 H) 3.85 (s, 2 H) 4.57 (q, *J*=8.28 Hz, 2 H) 7.04 (t, *J*=8.20 Hz, 1 H) 7.13 - 7.21 (m, 2 H). ¹³C{¹H} NMR (101 MHz, CDCl₃) δ ppm 21.90, 24.88 (d, *J*=3.07 Hz, 1 C) 27.55, 37.85, 60.87 (q, *J*=37.00 Hz, 1 C) 118.79 (d, *J*=25.50 Hz, 1 C) 120.04 (d, *J*=9.88 Hz, 1 C) 122.67 (q, *J*=277.00 Hz, 1 C) 125.03 (d, *J*=14.99 Hz, 1 C) 127.16 (d, *J*=3.75 Hz, 1 C) 131.69 (d, *J*=5.11 Hz, 1 C) 139.65, 144.45, 160.65 (d, *J*=250.00 Hz, 1 C) 166.07, 197.87 (s, 1 C). ¹⁹F NMR (376 MHz, CDCl₃) δ ppm -114.37 (s, 1 F, Ar-F) -73.55 (s, 3 F, -CH₂CF₃). LRMS (ESI): *m/z* = 409/411 [M+H]⁺.

8i'': ¹H NMR (400 MHz, CDCl₃) δ ppm 2.08 - 2.17 (m, 2 H) 2.51 - 2.59 (m, 2 H) 2.73 (t, *J*=6.02 Hz, 2 H) 3.98 (s, 2 H) 4.58 (q, *J*=8.28 Hz, 2 H) 4.69 (q, *J*=8.41 Hz, 2 H) 7.25 (t, *J*=7.80 Hz, 1 H) 7.69 (dd, *J*=10.37, 1.66 Hz, 1 H) 7.76 (dd, *J*=8.02, 1.66 Hz, 1 H). ¹³C{¹H} NMR (101 MHz, CDCl₃) δ ppm 21.87, 25.55 (d, *J*=3.41 Hz), 27.53, 37.79, 60.87 (q, *J*=37.00 Hz), 60.88 (q, *J*=37.00 Hz), 116.65 (d, *J*=24.60 Hz), 122.63 (q, *J*=278.00 Hz), 122.98 (q, *J*=277.50 Hz), 125.60 (d, *J*=3.40 Hz), 128.21 (d, *J*=7.83 Hz), 130.63 (d, *J*=4.09 Hz), 132.68 (d, *J*=15.33 Hz), 139.51, 144.82, 160.51 (d, *J*=247.30 Hz), 163.81 (d, *J*=2.73 Hz), 165.92, 197.78. ¹⁹F NMR (376 MHz, CDCl₃) δ ppm -115.67 (s, 1 F) -73.70 (s, 3 F) -73.58 (s, 3 F). LRMS (ESI): *m/z* = 457 [M+H]⁺.

Note that biphenyl was omitted from this preparation, so no NMR yield was determined. The LCMS trace of the crude reaction mixture (Figure S109) reveals the presence of **8a**, **8i**, and **8i''**; however, due to peak overlap, quantification cannot be established. Therefore, both **8i** and **8i''** were isolated to quantify the amount of each product.

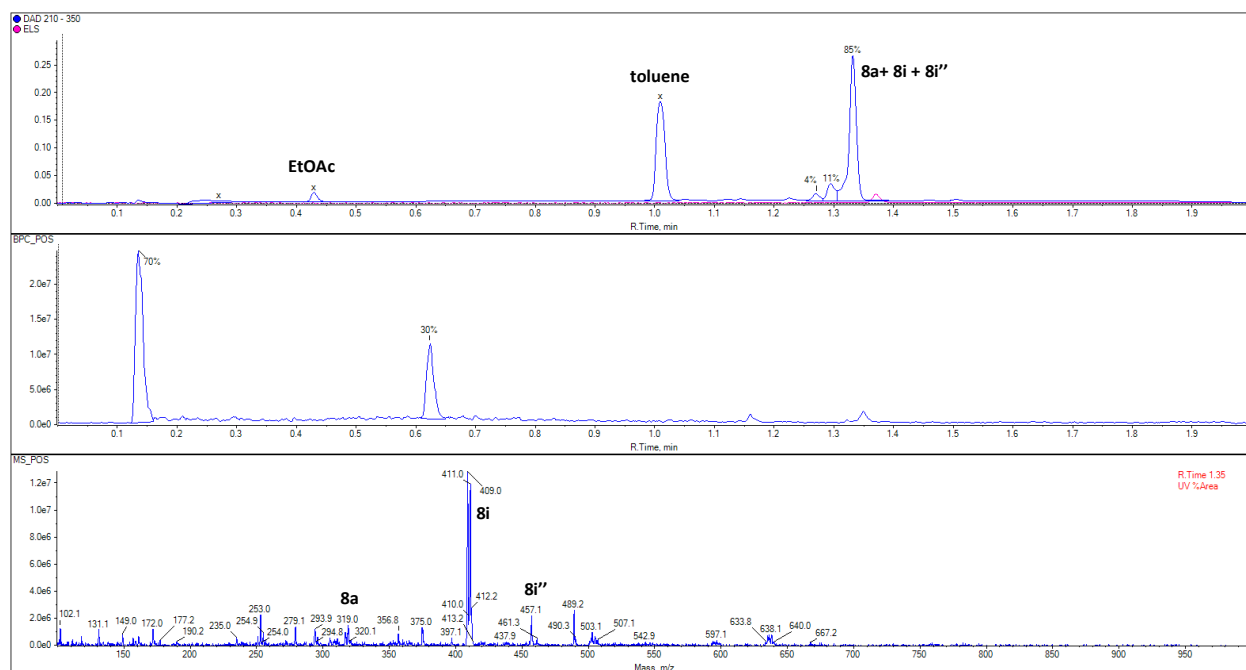


Figure S109: Crude LCMS trace of **8i**.

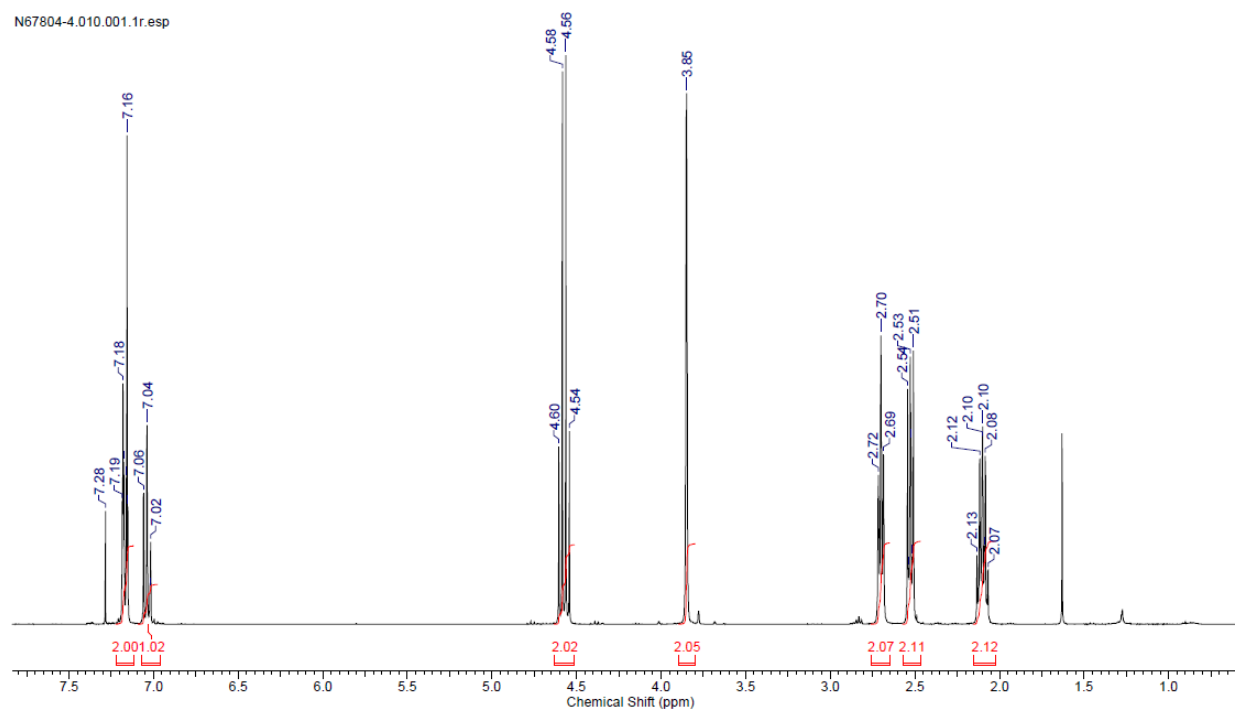


Figure S110: ¹H NMR spectrum of **8i**.

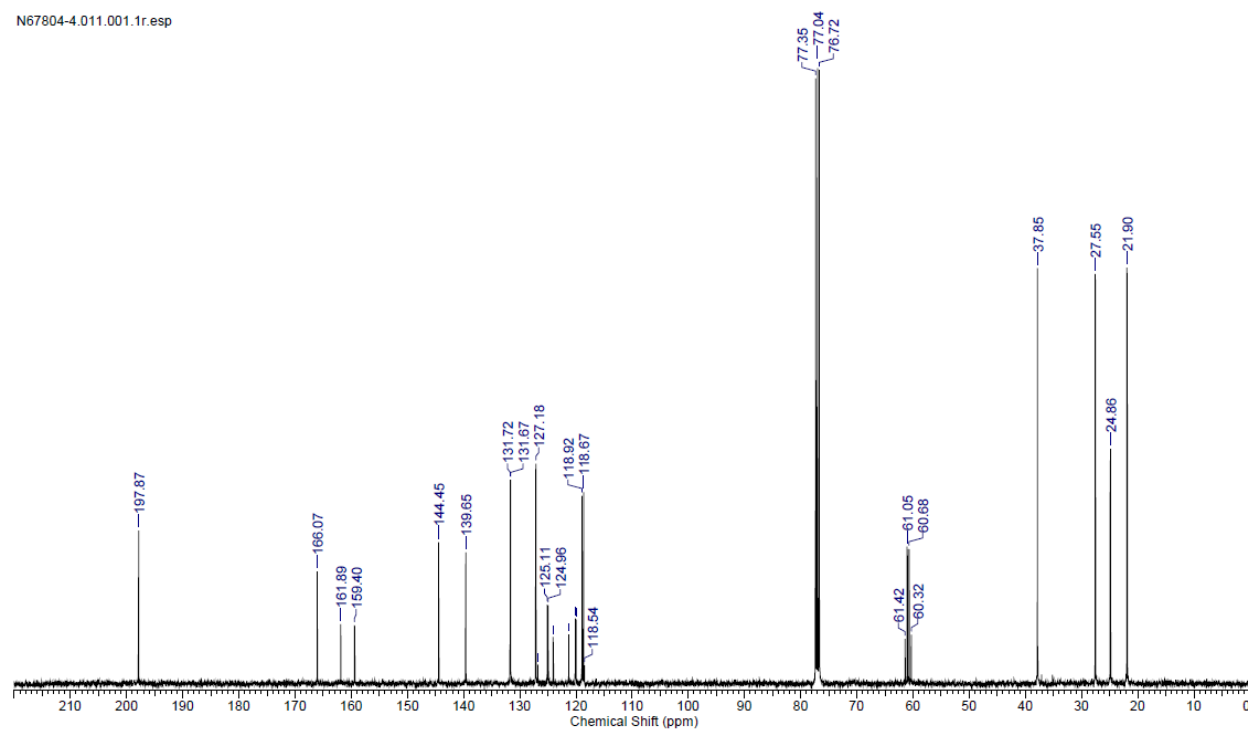


Figure S111: $^{13}\text{C}\{^1\text{H}\}$ NMR spectrum of **8i**.

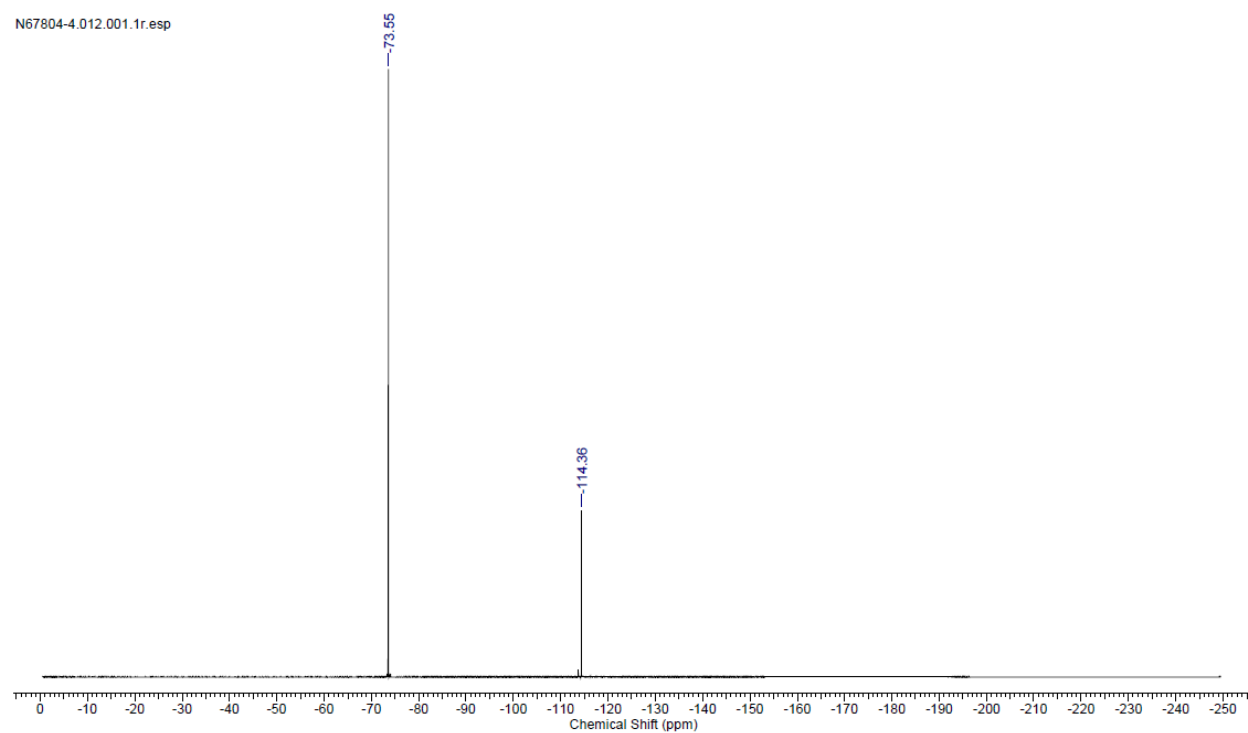


Figure S112: ^{19}F NMR spectrum of **8i**.

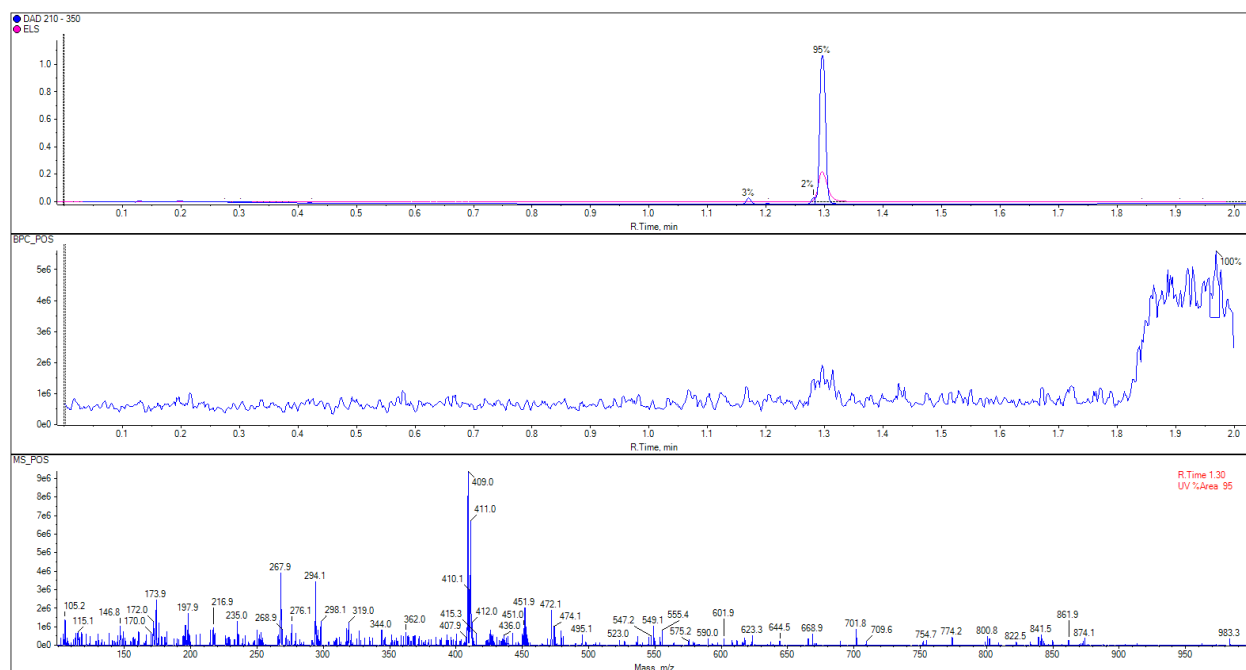


Figure S113: LCMS trace of 8i.

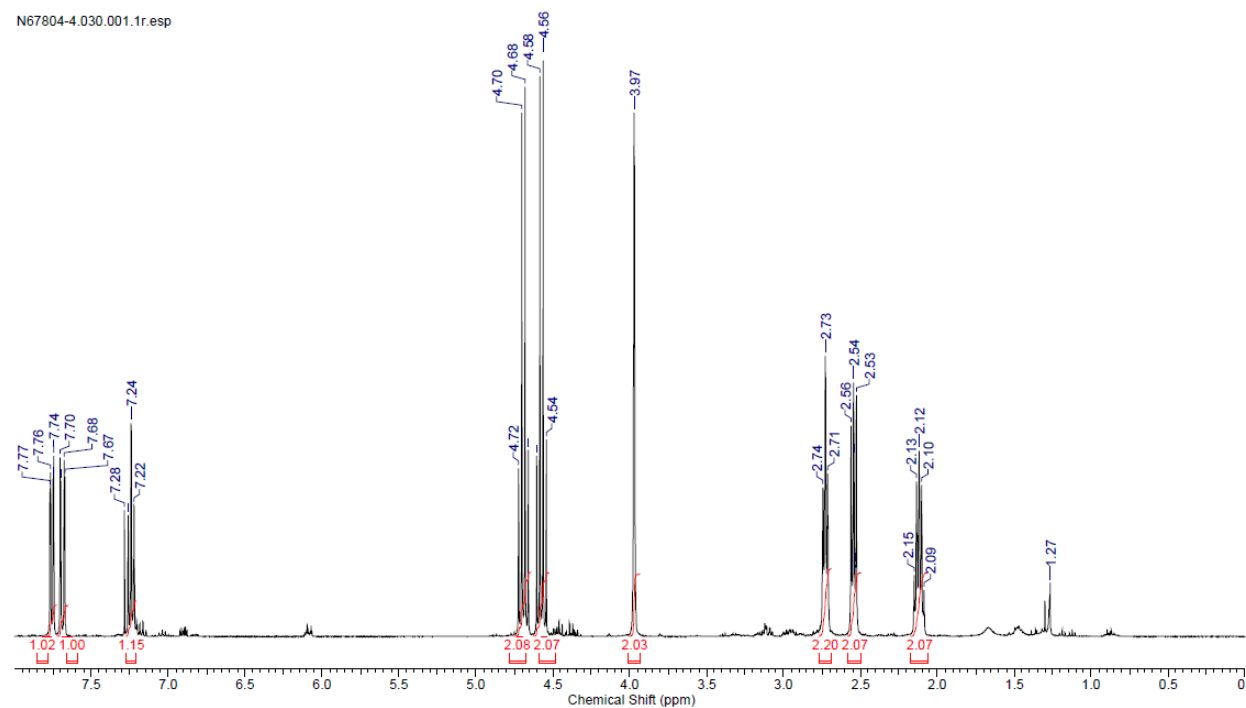


Figure S114: ¹H NMR spectrum of 8i''.

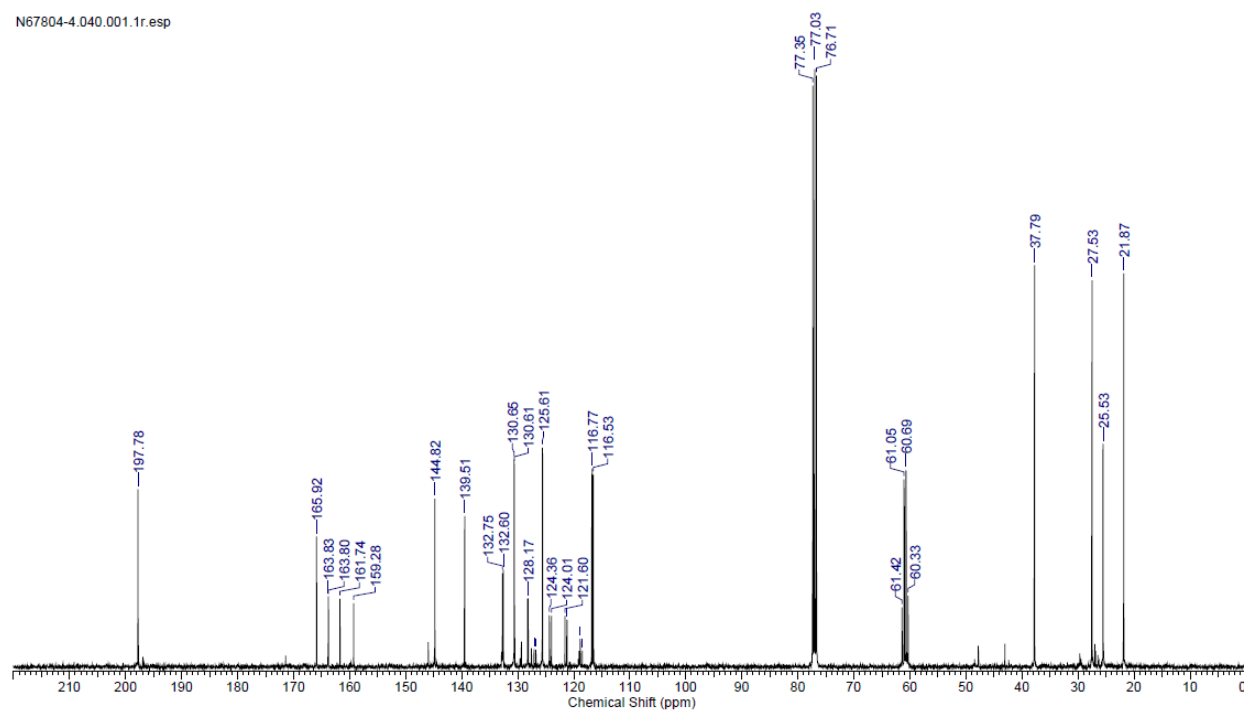


Figure S115: $^{13}\text{C}\{^1\text{H}\}$ NMR spectrum of **8i''**.

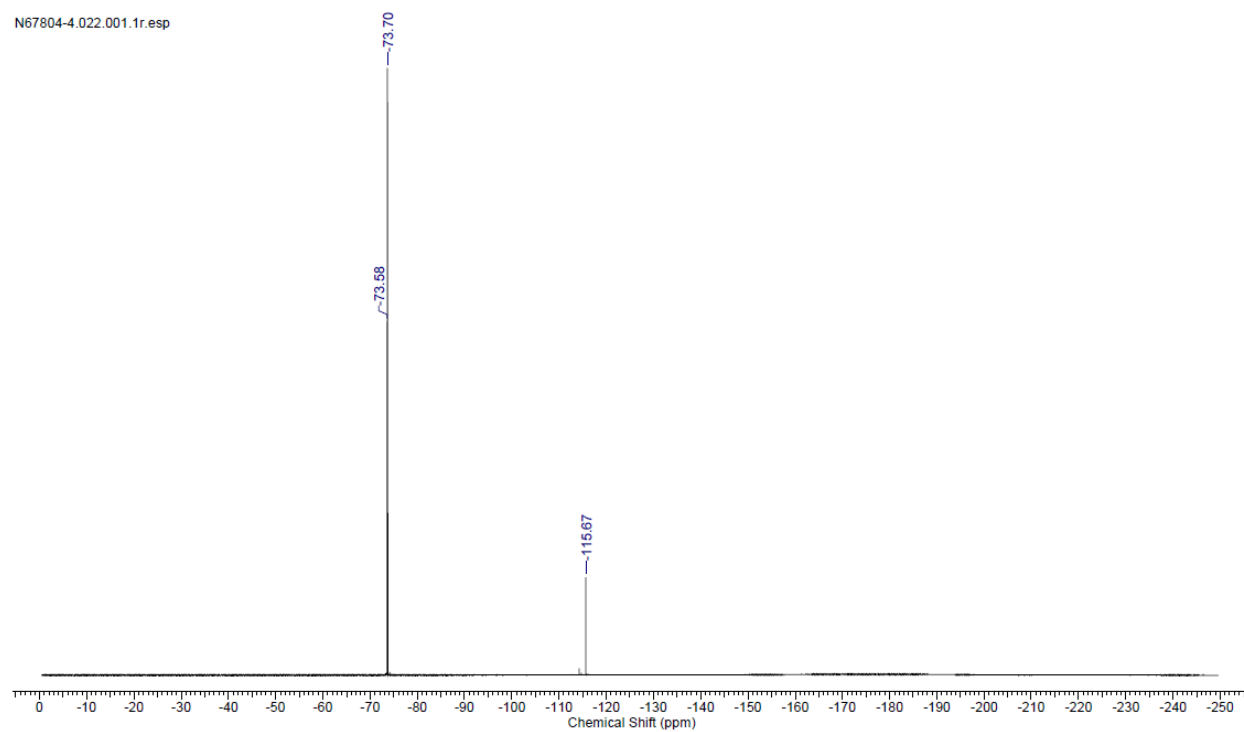


Figure S116: ^{19}F NMR spectrum of **8i''**.

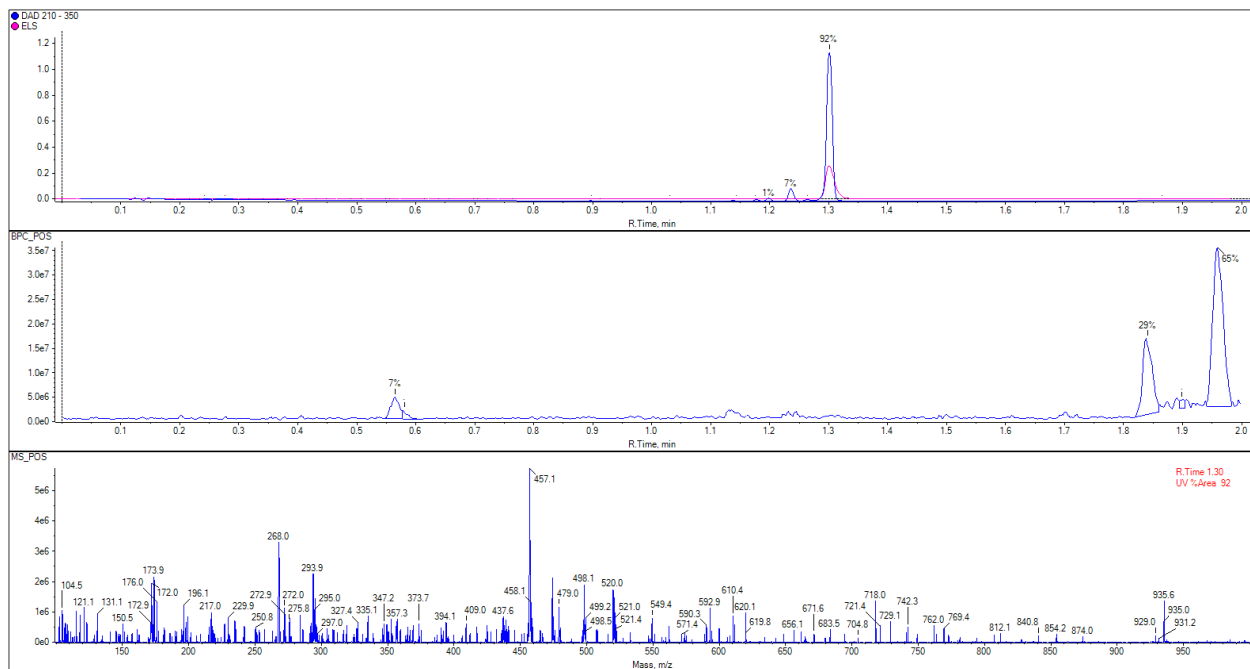


Figure S117: LCMS trace of 8i''.

Large-Scale Preparation of 1b.

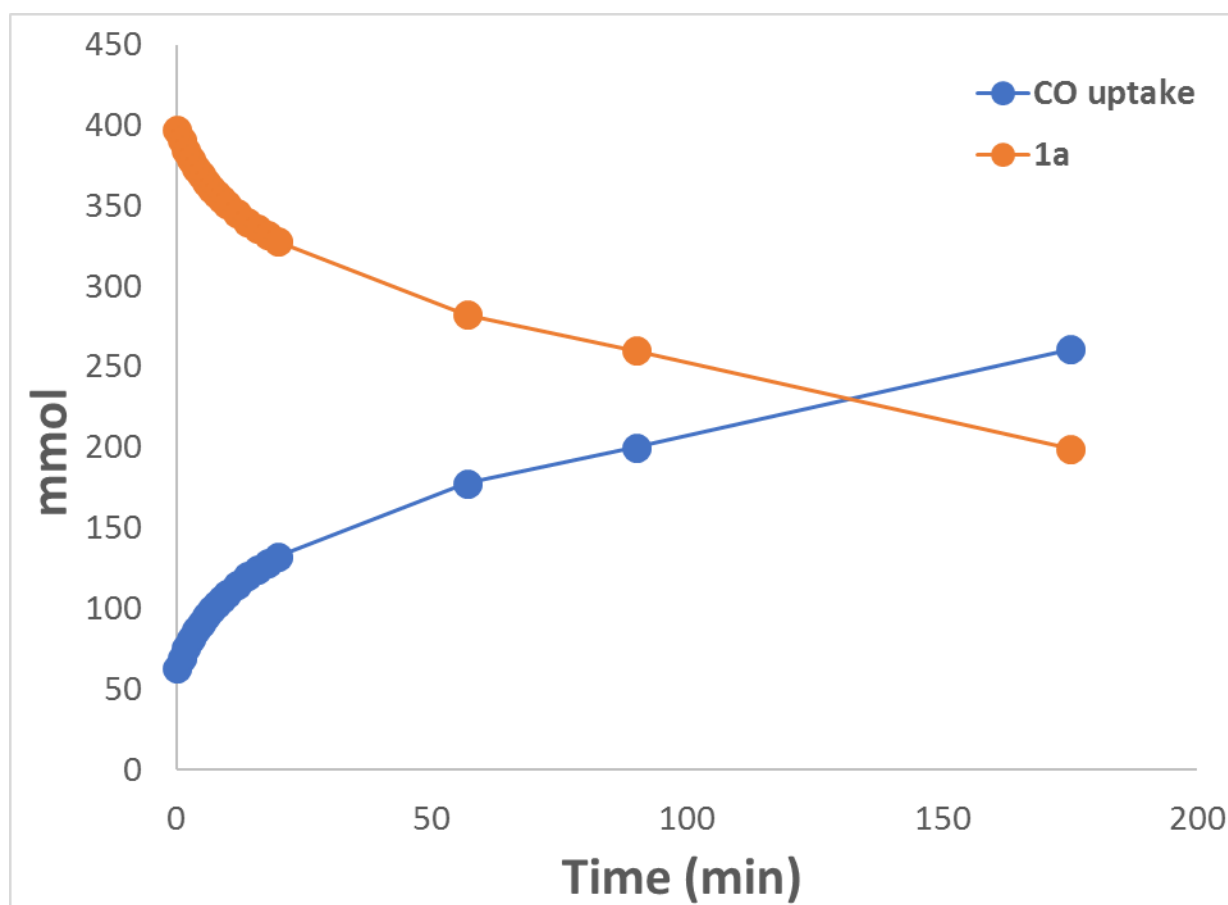
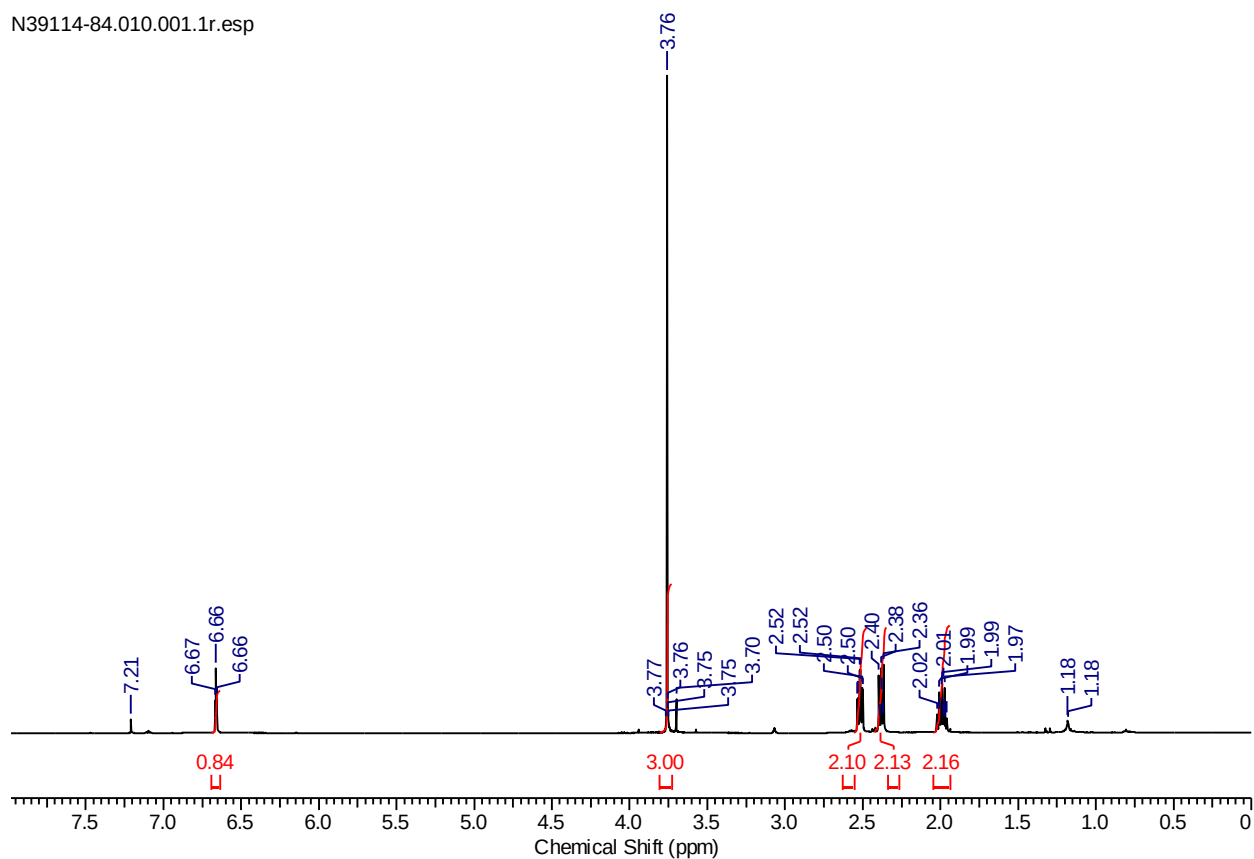
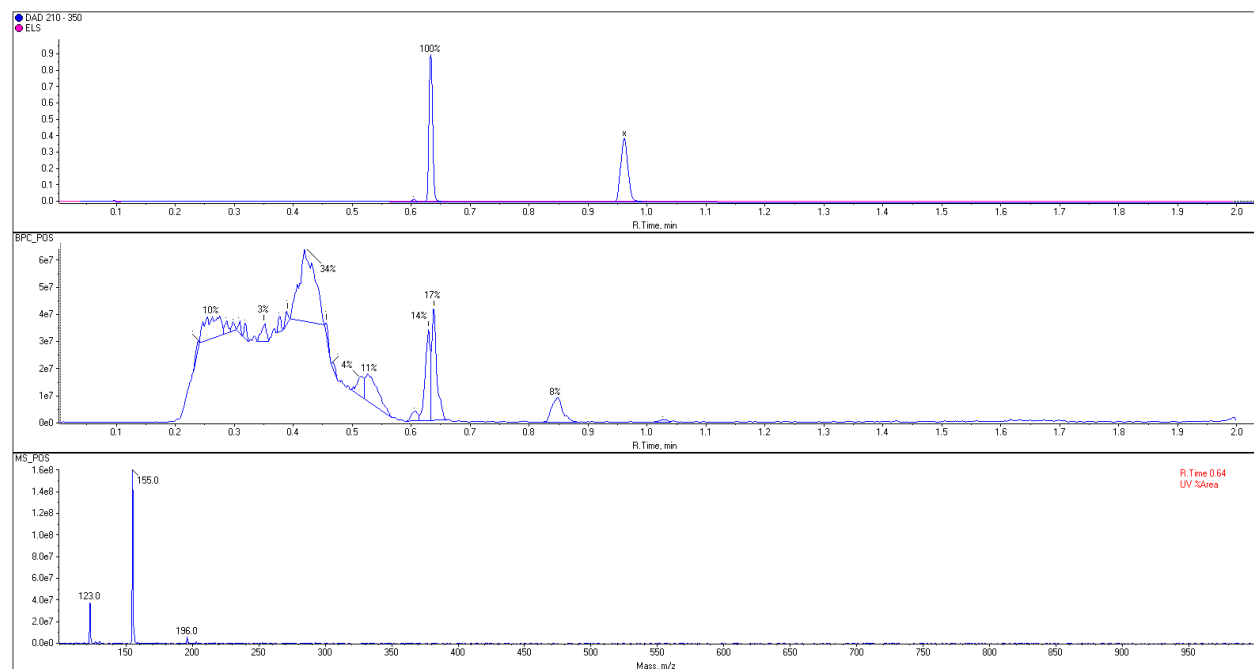


Figure S118. Initial CO uptake curve, with calculated substrate (**1a**) mmol.

Figure S119. ¹H NMR spectrum of **1b** after workup.Figure S120. LCMS trace of **1b** after workup.

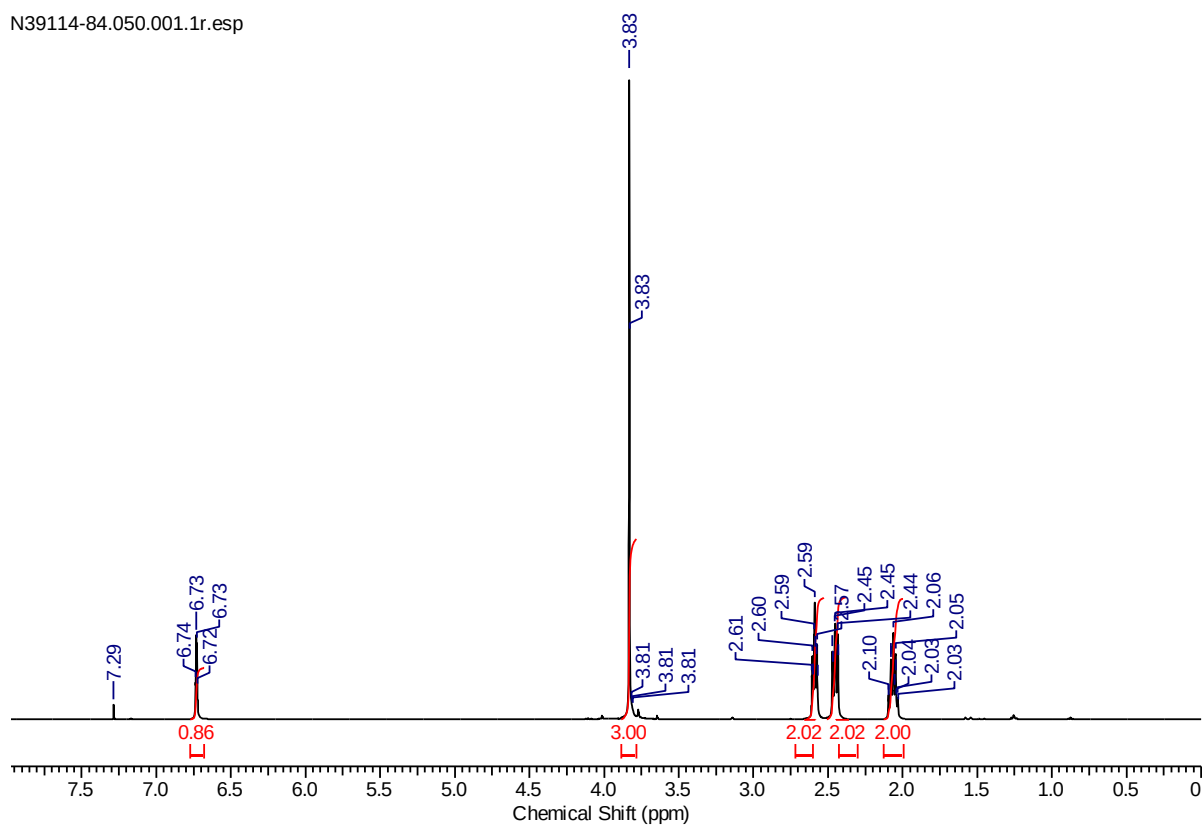


Figure S121. ¹H NMR spectrum of **1b** after purification.

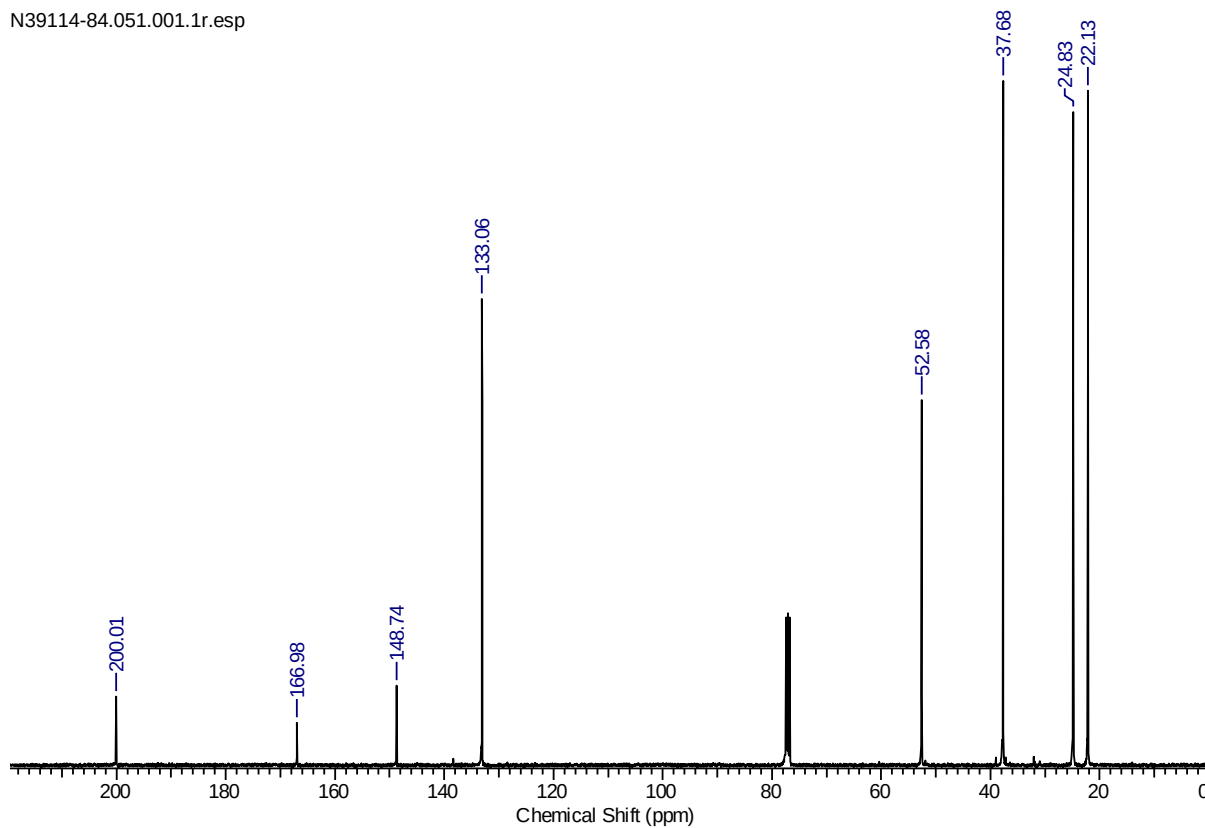


Figure S122. ¹³C{¹H} NMR spectrum of **1b** after purification.

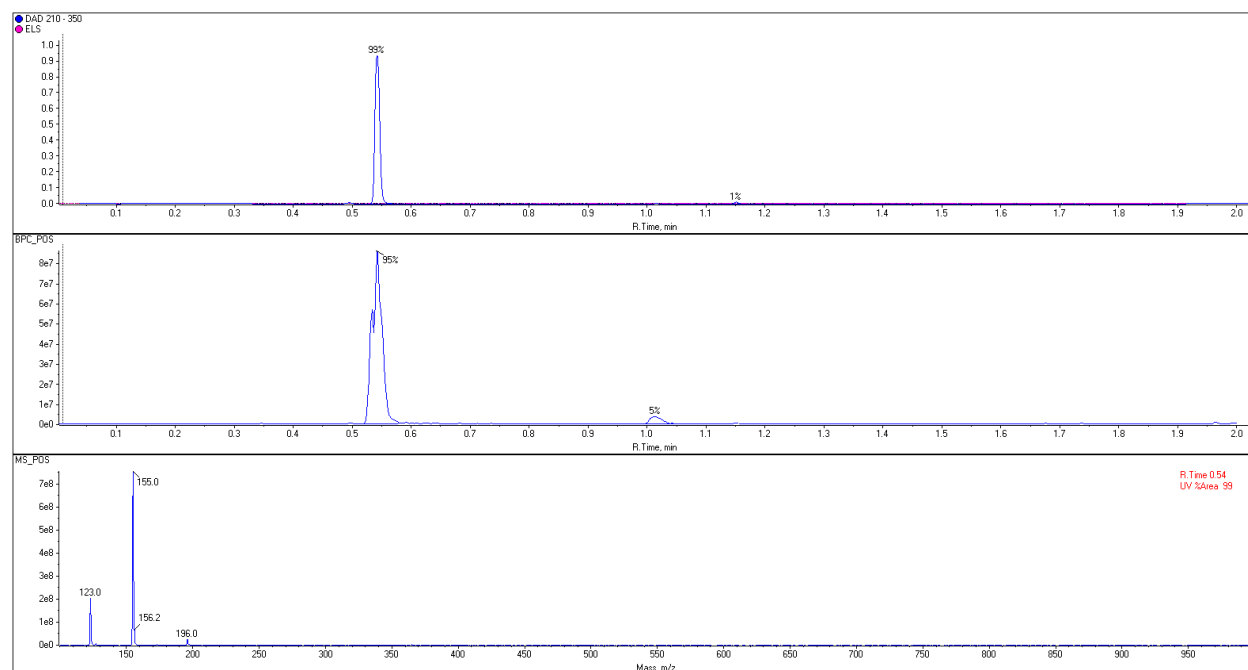


Figure S123. LCMS trace of **1b** after purification.

IV: Mechanistic Studies

Reaction Profile Curves.

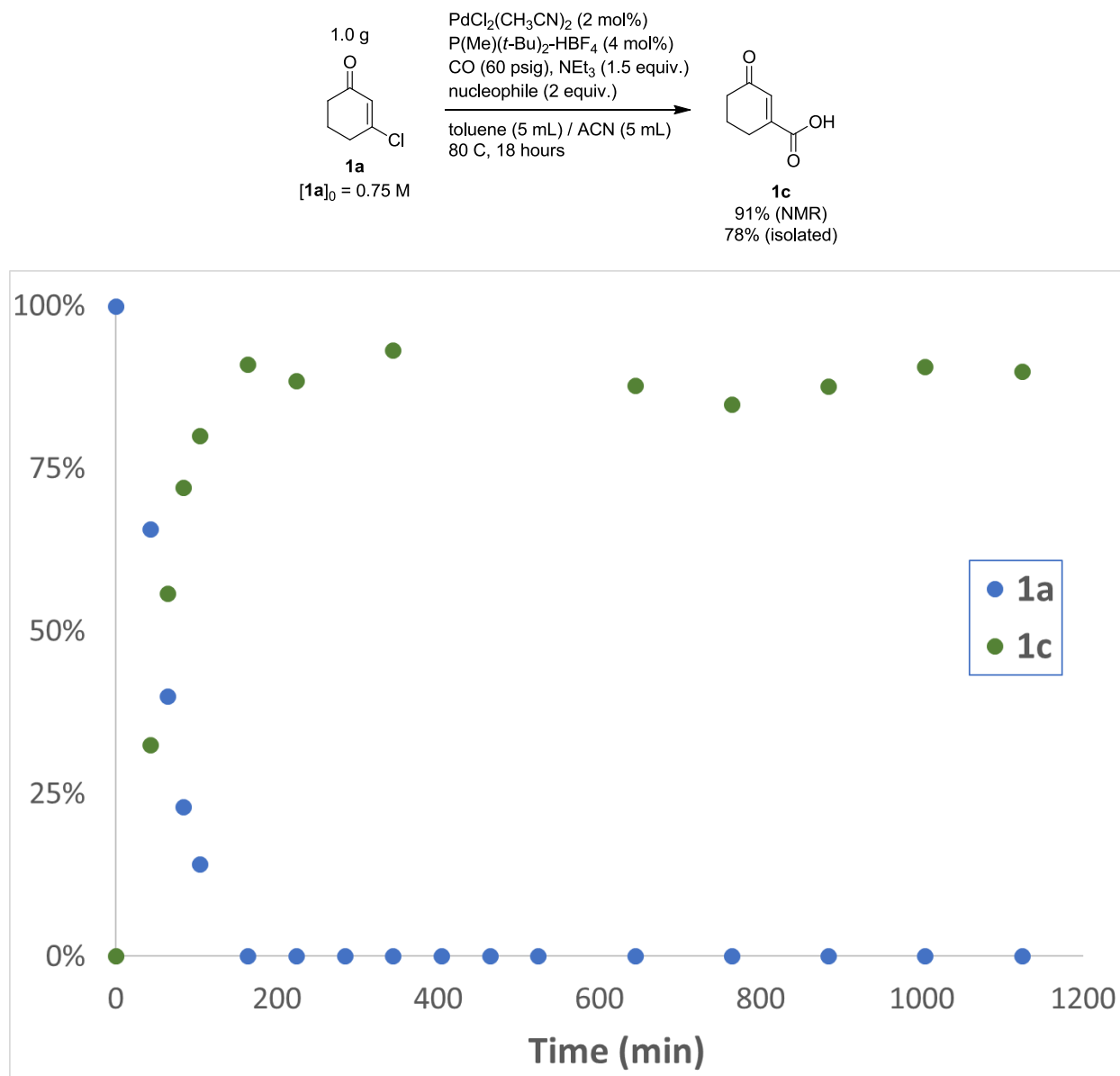


Figure S124. Reaction progress curve for the formation of **1c**.

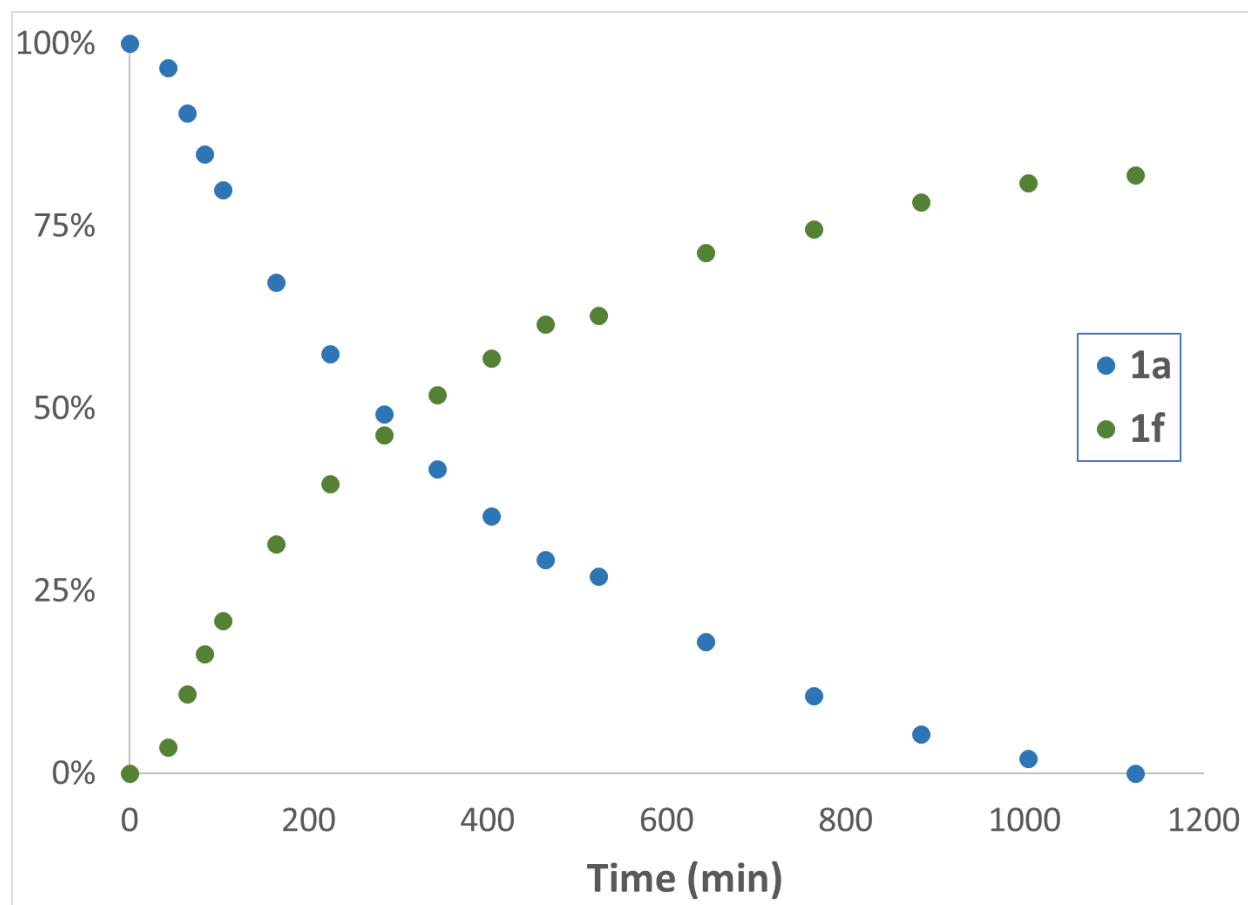
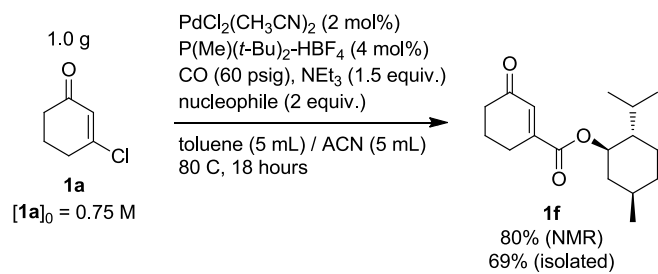


Figure S125. Reaction progress curve for the formation of **1f**.

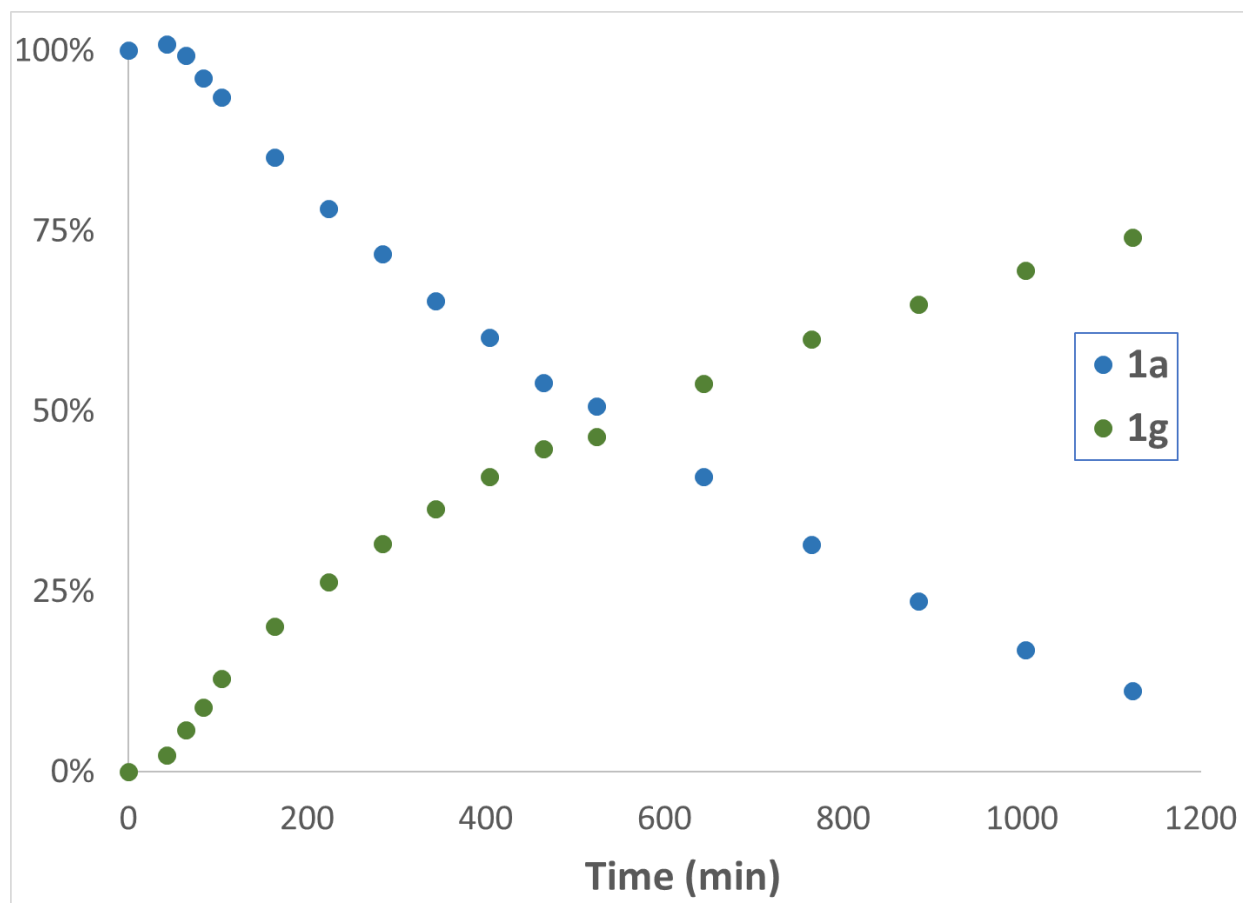
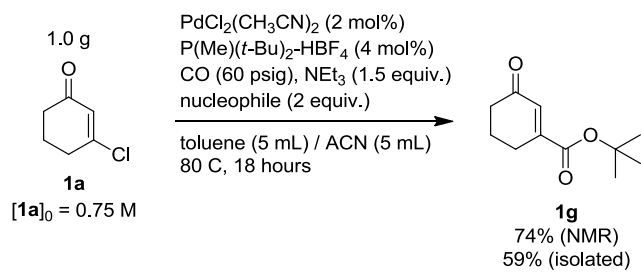


Figure S126. Reaction progress curve for the formation of **1g**.

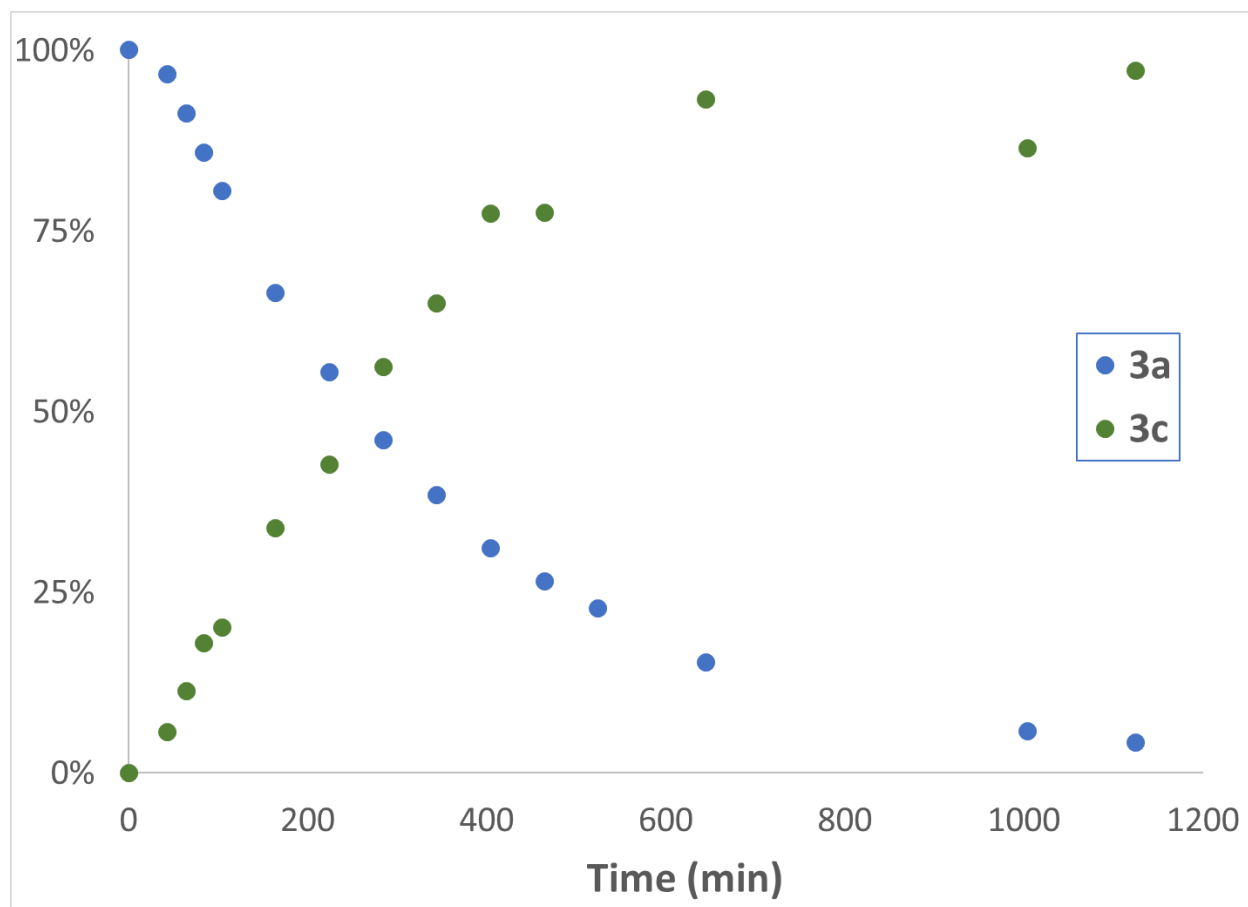
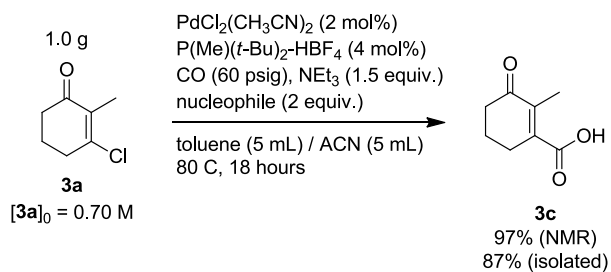


Figure S127. Reaction progress curve for the formation of **3c**.

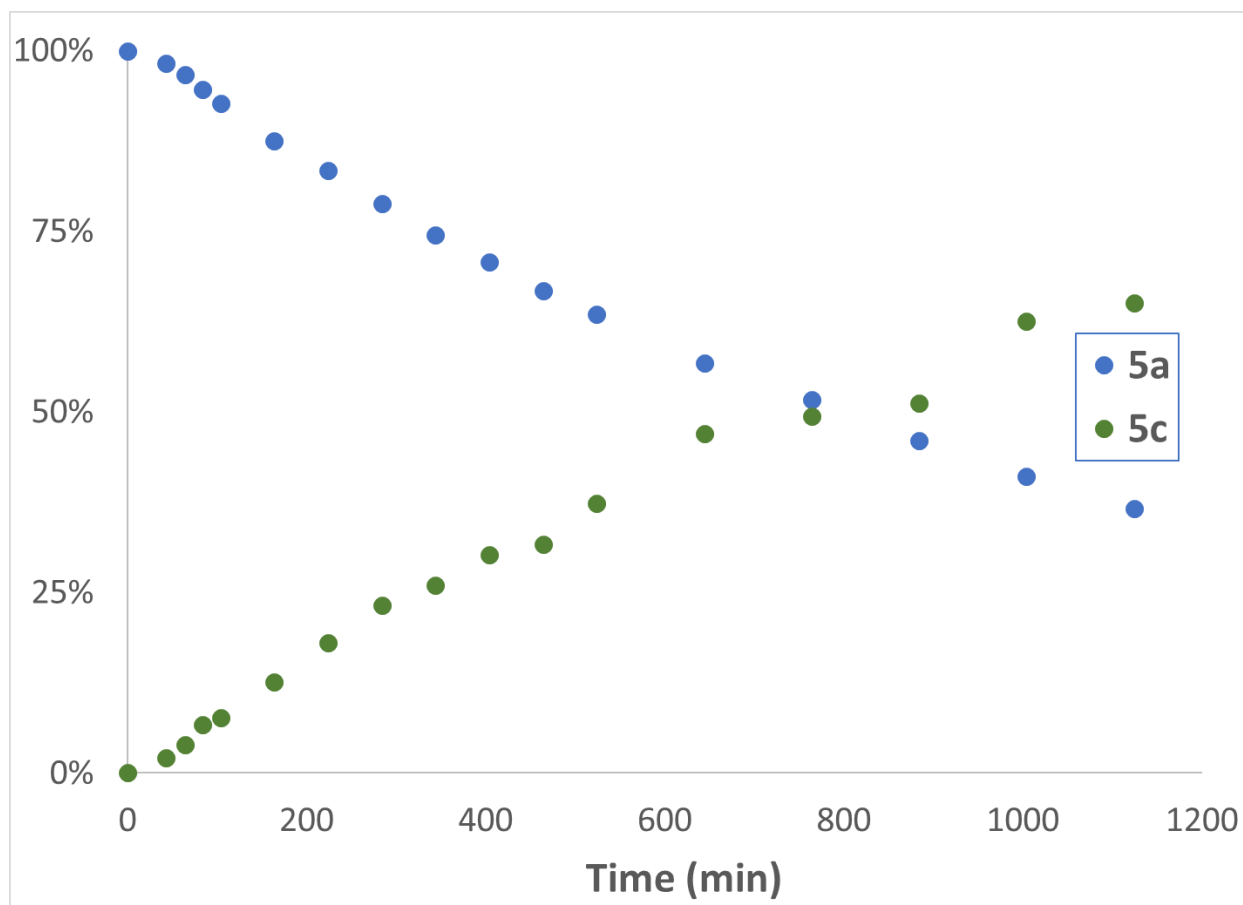
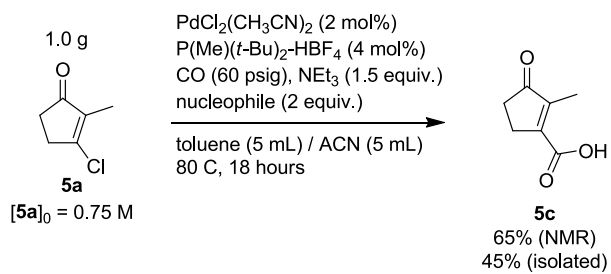


Figure S128. Reaction progress curve for the formation of **5c**.

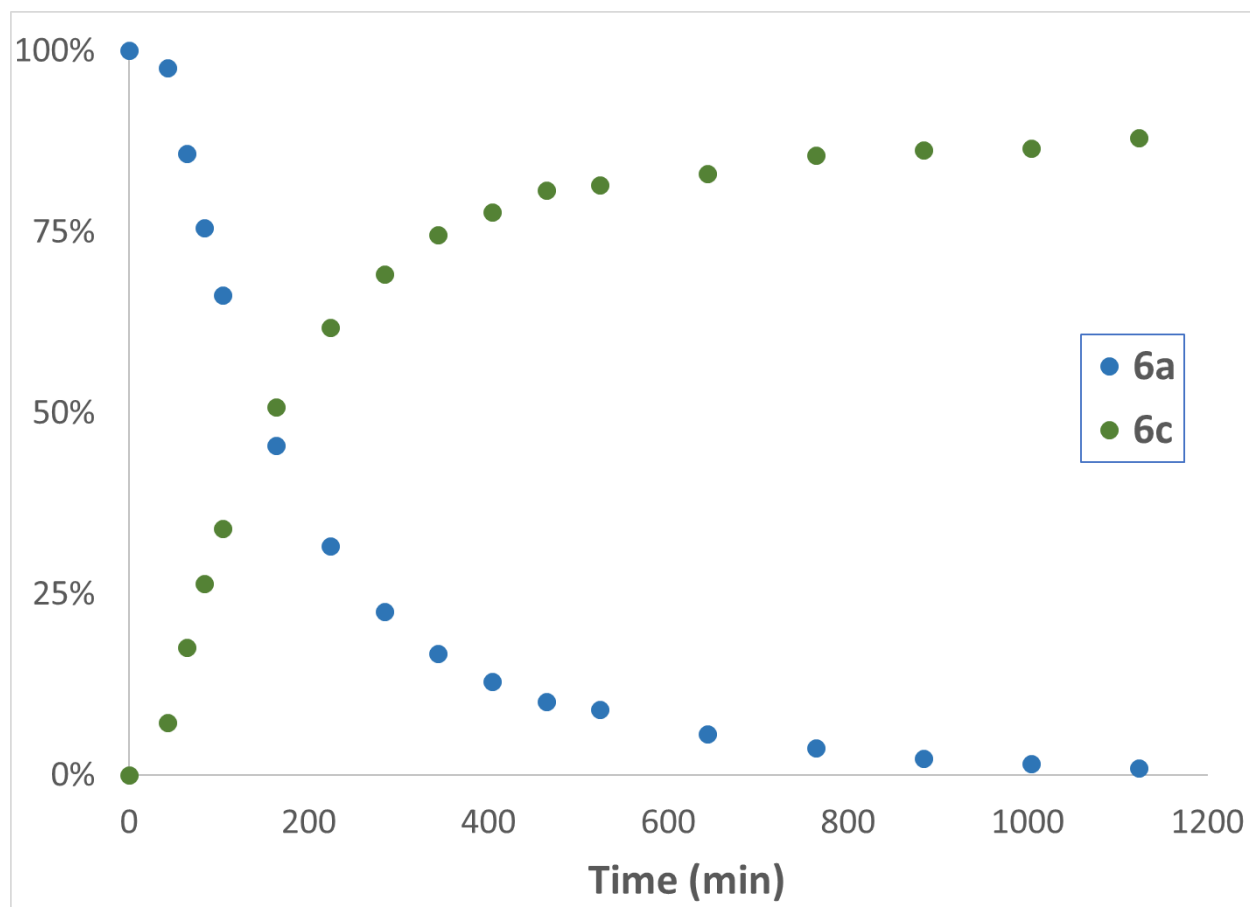
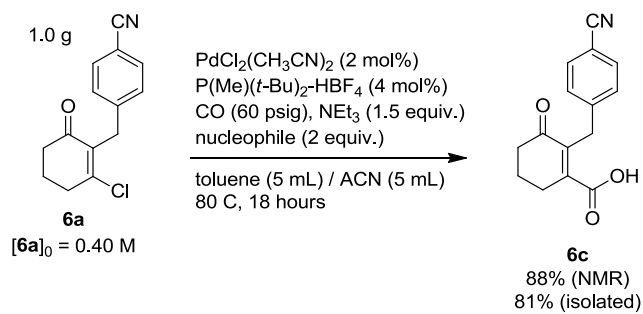


Figure S129. Reaction progress curve for the formation of **6c**.

Reaction Progress for the Formation of **1b** using Pd[P(*t*-Bu)₃]₂ as the Precatalyst

Two reactions were set up following the general procedure for using the Unchained Labs OSR (see Experimental in main text) with a reaction temperature of 70 °C using the following material charges:

“1 mol% Pd”: **1a** (1.33 g, 10.2 mmol), Pd[P(*t*-Bu)₃]₂ (52.3 mg, 0.102 mmol), trimethoxybenzene (internal standard, 0.33 g, 1.98 mmol), DIPEA (1.98 g, 2.67 mL, 15.3 mmol), methanol (0.40 g, 0.50 mL, 12.4 mmol), and toluene (13 mL).

“0.5 mol% Pd”: **1a** (1.33 g, 10.2 mmol), Pd[P(*t*-Bu)₃]₂ (26.2 mg, 0.051 mmol), trimethoxybenzene (internal standard, 0.33 g, 1.98 mmol), DIPEA (1.98 g, 2.67 mL, 15.3 mmol), methanol (0.40 g, 0.50 mL, 12.4 mmol), and toluene (13 mL).

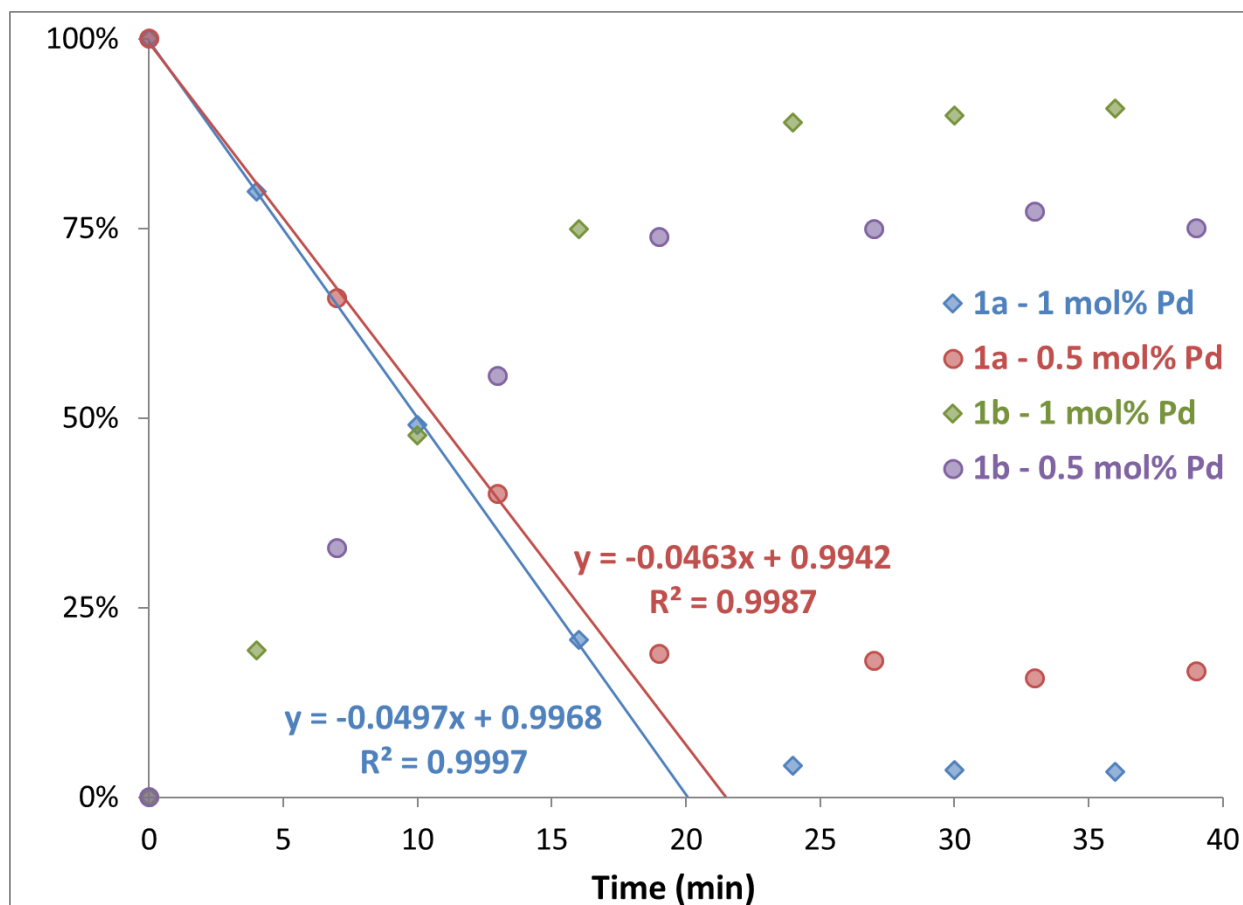
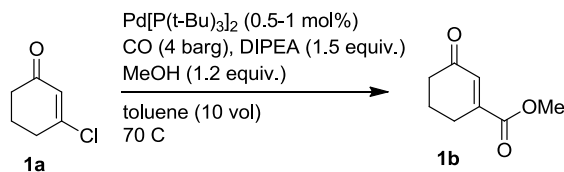
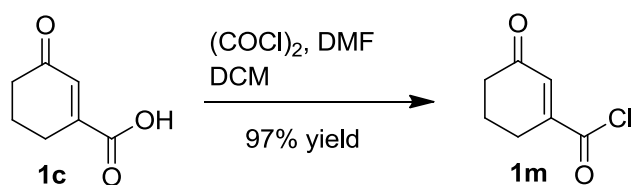


Figure S130. Reaction progress curves for the formation of **1b** using Pd[P(*t*-Bu)₃]₂ as the catalyst; apparent zero order in catalyst.

Synthesis of **1m**:



1c (prepared via carbonylation as above, 0.289 g, 2.06 mmol) was suspended in dichloromethane (5 mL) in a 20 mL vial containing a stir bar. Oxalyl chloride (0.20 mL, 2.29 mmol) was added carefully via syringe, followed by DMF (0.010 mL, 0.129 mmol) via micropipette. The resulting mixture was stirred at room temperature for 1.5 h. The reaction mixture was diluted with dichloromethane (5 mL) and quenched by addition of brine (10 mL). The biphasic mixture was separated, and the aqueous phase extracted with dichloromethane (2 x 5 mL). The organic phase was dried by passage through a plug of MgSO_4 , followed by concentration *in vacuo* to afford **1m** as a yellow oil (0.318 g, 97% yield), which was used without further purification. ^1H NMR (400 MHz, CDCl_3) δ ppm 2.06 - 2.18 (m, 2 H) 2.47 - 2.57 (m, 2 H) 2.61 - 2.72 (m, 2 H) 7.00 (t, $J=1.76$ Hz, 1 H). $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3) δ ppm 21.83, 25.54, 37.66, 137.57, 151.14, 169.13, 199.18.

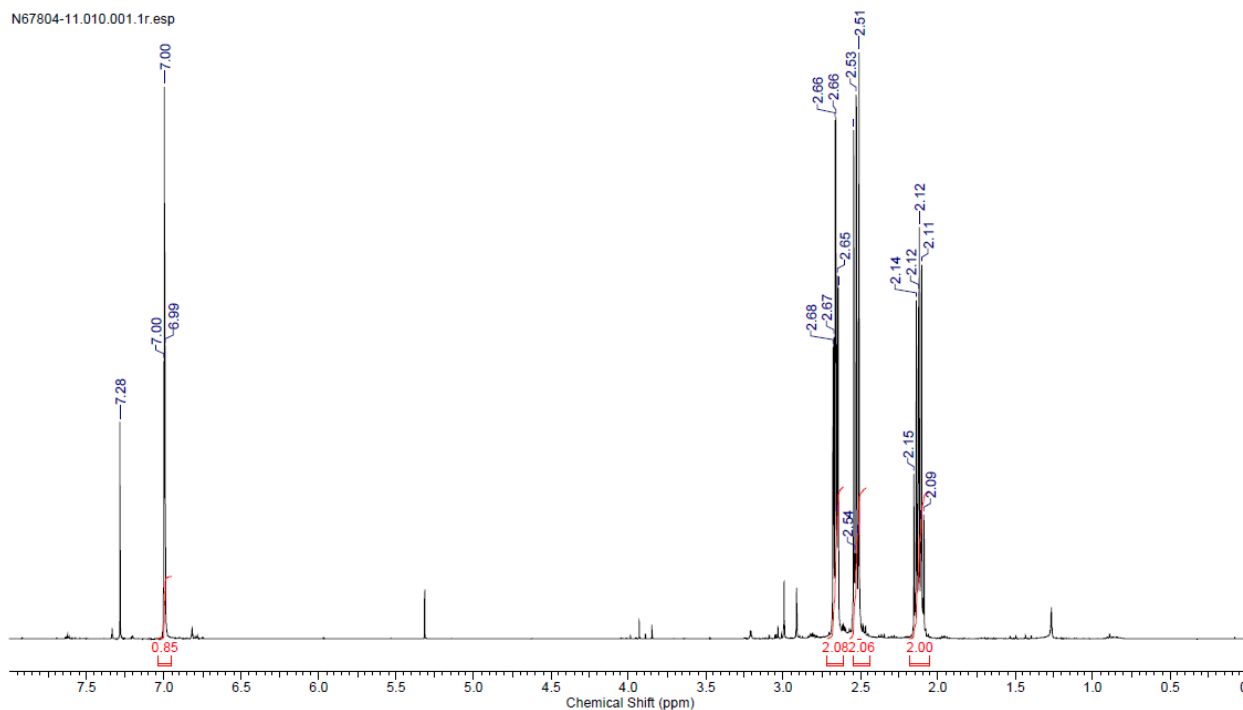


Figure S131. ^1H NMR spectrum of **1m**.

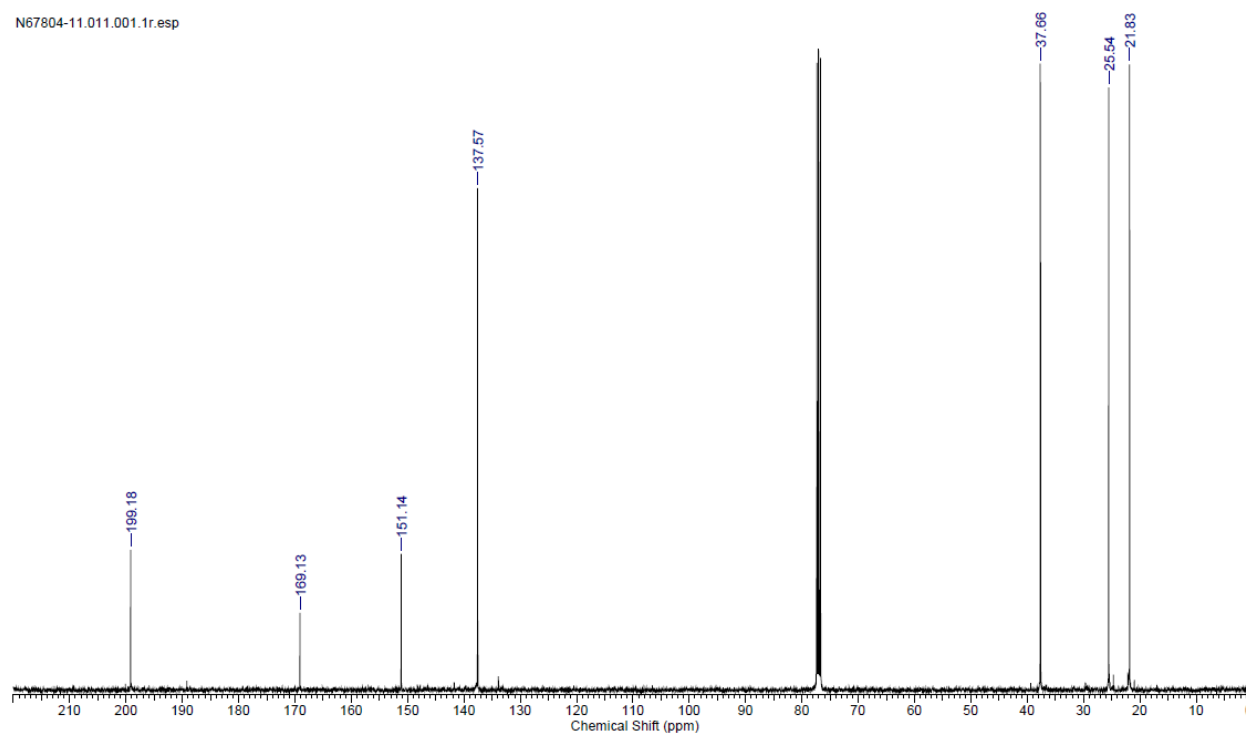
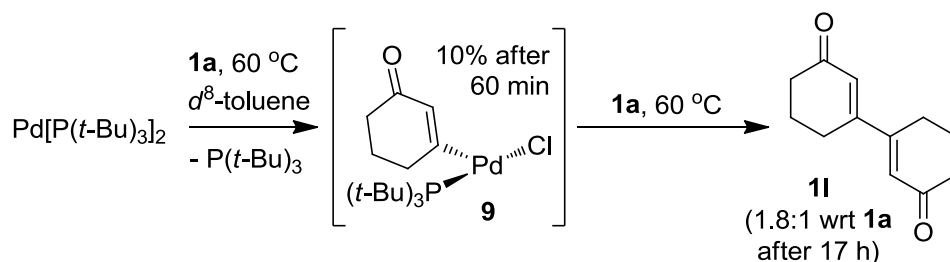


Figure S132. $^{13}\text{C}\{^1\text{H}\}$ NMR spectrum of **1m**.

Oxidative Addition Studies:



In a nitrogen glovebox, **1a** (10.0 mg, 0.077 mmol) and $\text{Pd}[\text{P}(\text{t-Bu})_3]_2$ (30.0 mg, 0.059 mmol) were dissolved in d_8 -toluene (1.0 mL) in an NMR tube. After initial ^1H and ^{31}P spectra were obtained, the tube was heated to 60°C for one hour, followed by reacquisition of ^1H and ^{31}P spectra (Figure S133 and S134 respectively). The tube was then heated to 60°C for 17 hours. The solution was removed from the tube, and the volatiles removed in vacuo. The product mixture was analyzed by ^1H NMR spectroscopy (CDCl_3) and LCMS (Figures S135 and 136 respectively), revealing a 1.8:1 ratio of **1l** to **1a**. The Pd-containing byproducts were not characterized.

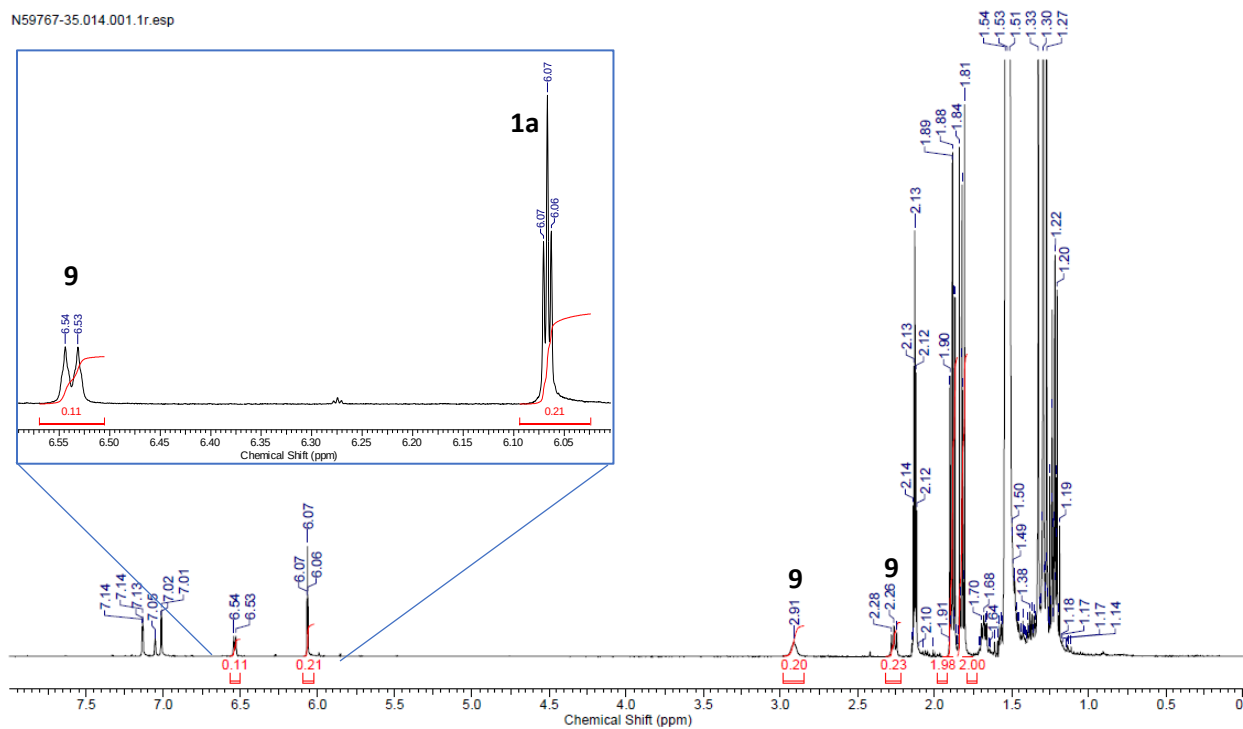


Figure S133. ^1H NMR spectrum (400 MHz, d^8 -tol) of reaction between **1a** and $\text{Pd}[\text{P}(t\text{-Bu})_3]_2$ at 1 h, 60 °C. Key signals for complex **9**: δ ppm 2.26 (m, 2 H), 2.91 (br t, $J=5.5$ Hz, 2 H), 6.54 (br dt, $J=5.0$, 1.0 Hz, 1 H).

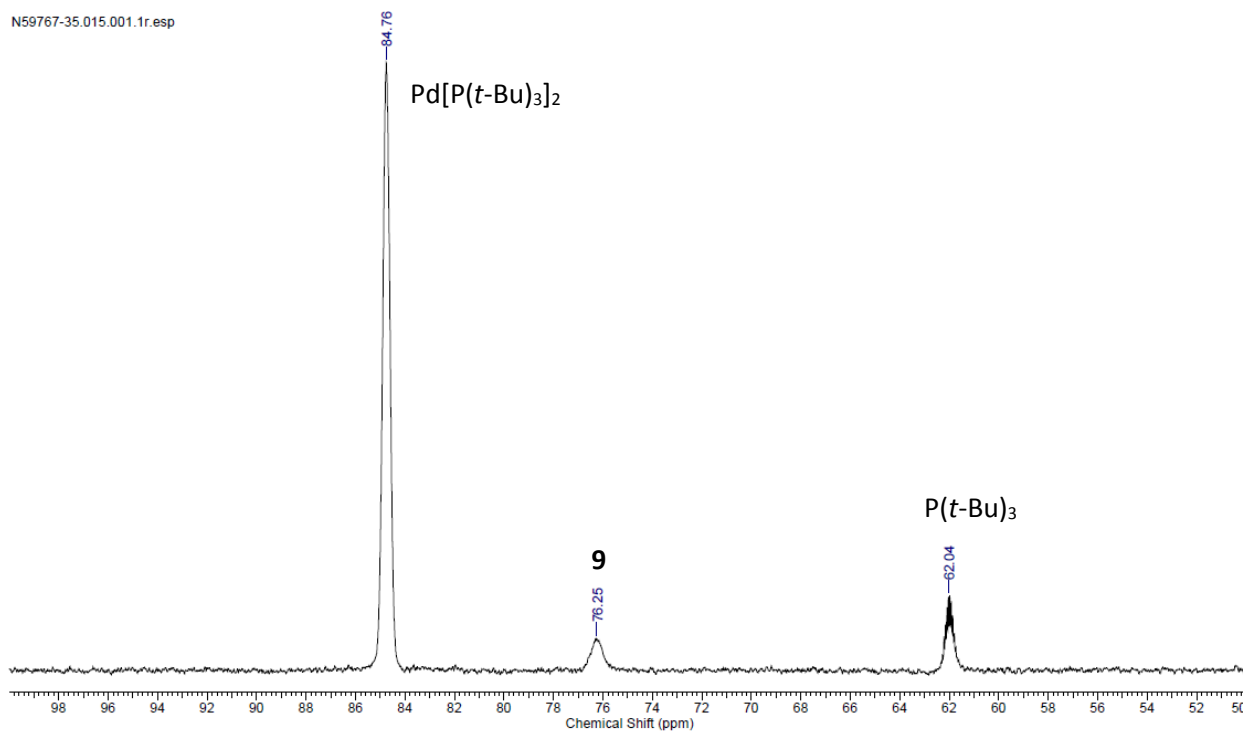


Figure S134. $^{31}\text{P}\{^1\text{H}\}$ NMR spectrum (162 MHz, d^8 -tol) of reaction between **1a** and $\text{Pd}[\text{P}(t\text{-Bu})_3]_2$ at 1 h, 60 °C. Signals assigned as pictured.

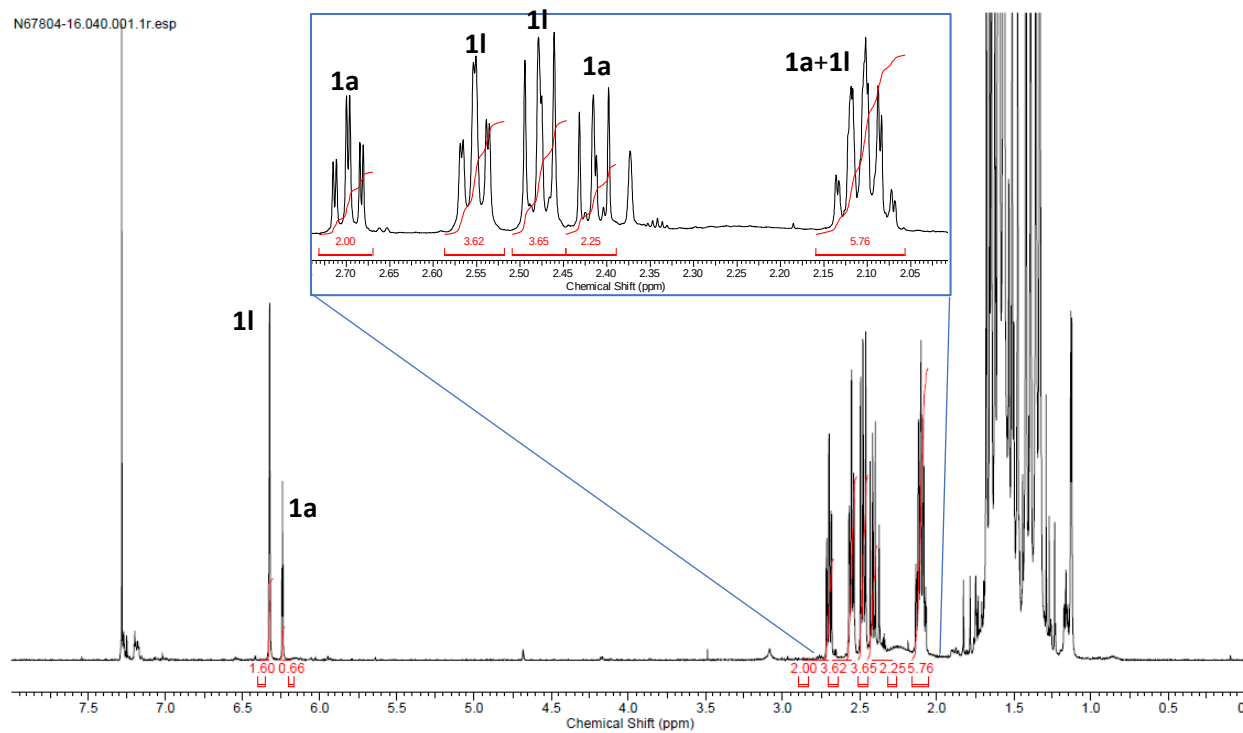


Figure S135. ^1H NMR spectrum (400 MHz, CDCl_3) of reaction between **1a** and $\text{Pd}[\text{P}(\text{t-Bu})_3]_2$ at 17 h, 60 °C, after removal of volatiles. **1a** and **1l** as assigned.

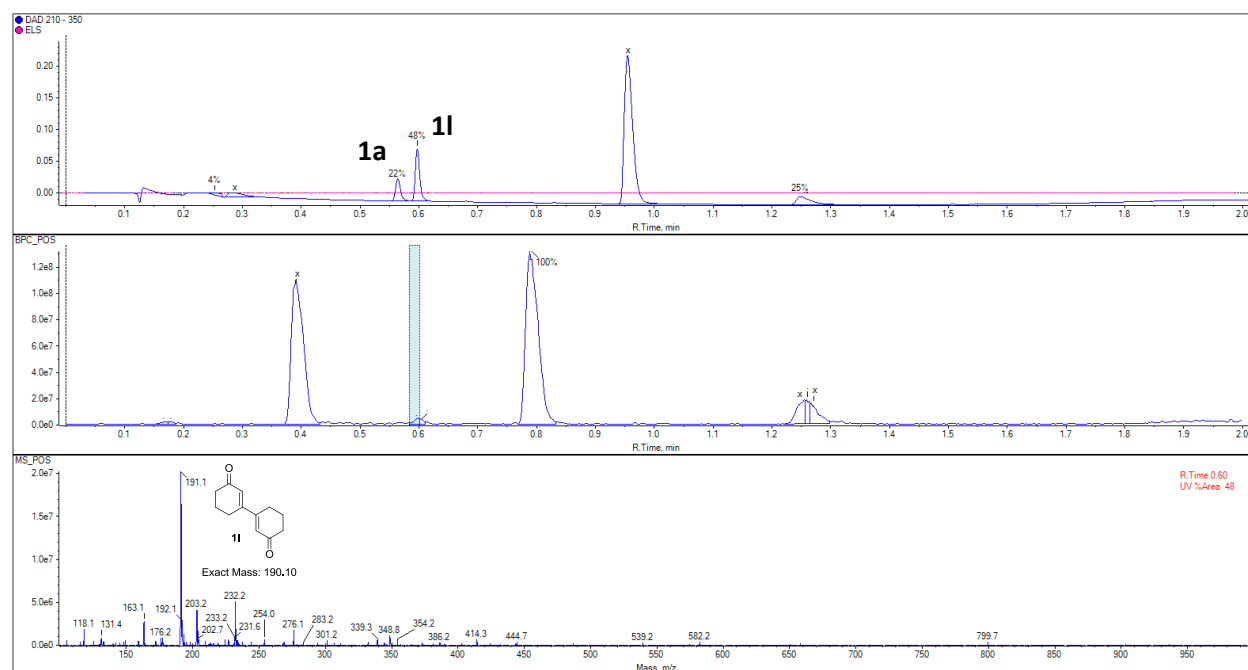
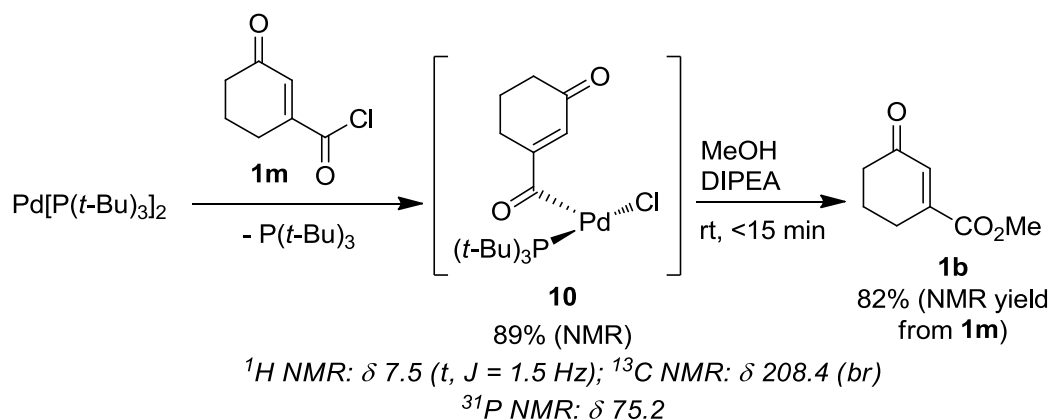


Figure S136. LCMS trace of reaction between **1a** and $\text{Pd}[\text{P}(\text{t-Bu})_3]_2$ at 17 h, 60 °C. **1a** and **1l** as assigned.



In a nitrogen glovebox, **1m** (10.0 mg, 0.063 mmol), Pd[P(t-Bu)₃]₂ (30.0 mg, 0.059 mmol), and 1,1'-biphenyl (2.0 mg, 0.013 mmol) were dissolved in d₈-toluene (1.0 mL) in an NMR tube. An initial ¹H NMR spectrum was obtained to establish extent of reaction and calculate NMR yield of **10** (Figure S137).

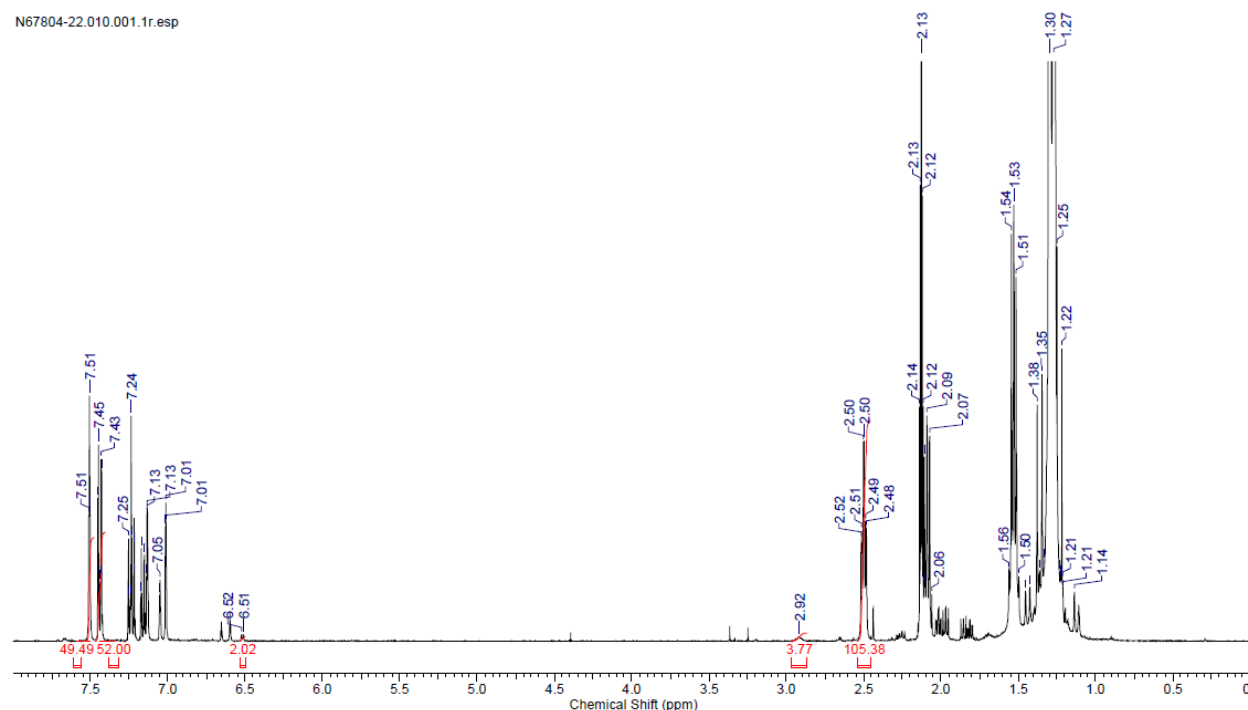


Figure S137. ¹H NMR spectrum (400 MHz, d⁸-tol) of reaction between **1m** and Pd[P(t-Bu)₃]₂. NMR yield calculated by setting biphenyl signal at 7.44 ppm to (13 μmol × 4 H) = 52 μmol, and comparing to methylene signal of **10** at 2.50 ppm: 105.37 μmol / 2 H = 52.685 μmol / 59 μmol = 89% yield. A small amount (~3%) of **9** is also present, presumably generated via decarbonylation of **10**.

This tube was left to sit overnight (19 h total time), and a ¹H NMR spectrum obtained the next morning showed a reduction in solution yield of **10** to 81%. This tube was then returned to the glovebox, and methanol (18.8 mg, 24 μL, 0.59 mmol) and DIPEA (76.0 mg, 102 μL, 0.59 mmol) were added. The orange solution immediately darkened upon mixing. A ¹H NMR spectrum obtained after 15 minutes revealed **1b** formation in 82% yield (based on **1m** charged, Figure S138). The identity of **1b** was further confirmed by LCMS (Figure S139).

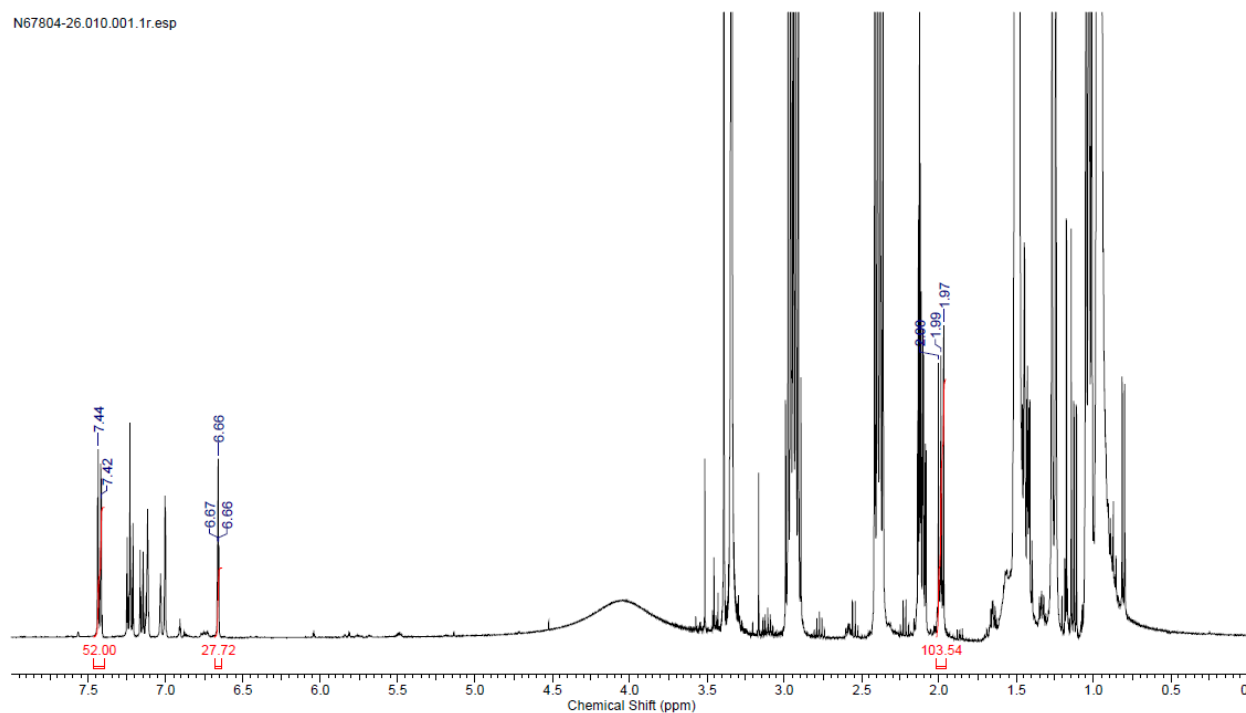


Figure S138. ^1H NMR spectrum (400 MHz, d^8 -tol) of reaction between **10** and MeOH/DIPEA. NMR yield calculated by setting biphenyl signal at 7.44 ppm to $(13\ \mu\text{mol} \times 4\ \text{H}) = 52\ \mu\text{mol}$, and comparing to methylene signal of **1b** at 1.99 ppm: $103.54\ \mu\text{mol} / 2\ \text{H} = 51.77\ \mu\text{mol} / 63\ \mu\text{mol} = 82\%$ yield.

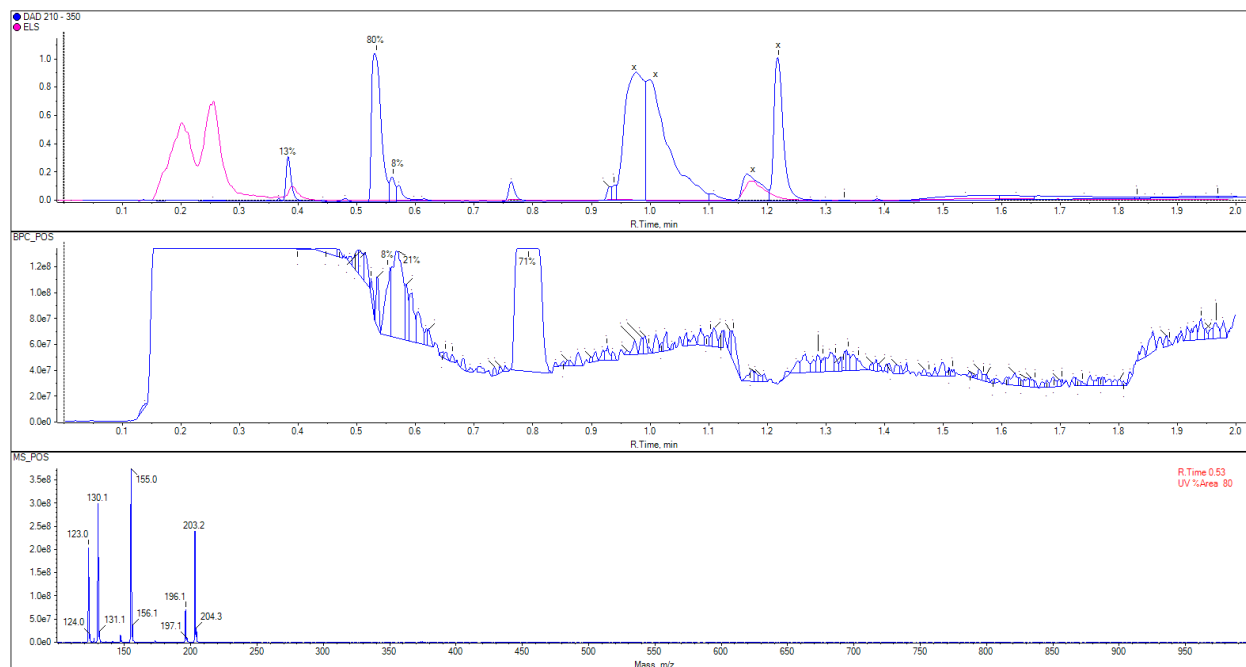


Figure S139. LCMS trace of reaction between **10** and MeOH/DIPEA. Peak at 0.53 min corresponds to **1b**.

A subsequent preparation of **10** in an NMR tube using identical reagent charges, but omitting biphenyl, was conducted to obtain ^1H , ^{31}P , and ^{13}C spectra for characterization (Figures S140, 141, and 142).

10: ^1H NMR (400 MHz, d^8 -tol) δ ppm 1.28 (d, $J=11.2$ Hz, 54 H, overlapping signals for free and ligated $\text{P}(t\text{-Bu})_3$), 1.48 - 1.57 (m, 2 H), 2.06 - 2.11 (m, 2 H), 2.50 (td, $J=5.99, 1.52$ Hz, 2 H), 7.51 (t, $J = 1.5$ Hz, 1 H). $^{31}\text{P}\{^1\text{H}\}$ NMR (162 MHz, d^8 -tol) δ ppm 75.2. $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, d^8 -tol) δ ppm 22.18, 26.72, 32.0, 37.89, 39.35 (d, $J = 8.6$ Hz), 137.23, 154.88 (d, $J = 13.6$ Hz), 198.11, 208.4 (br).

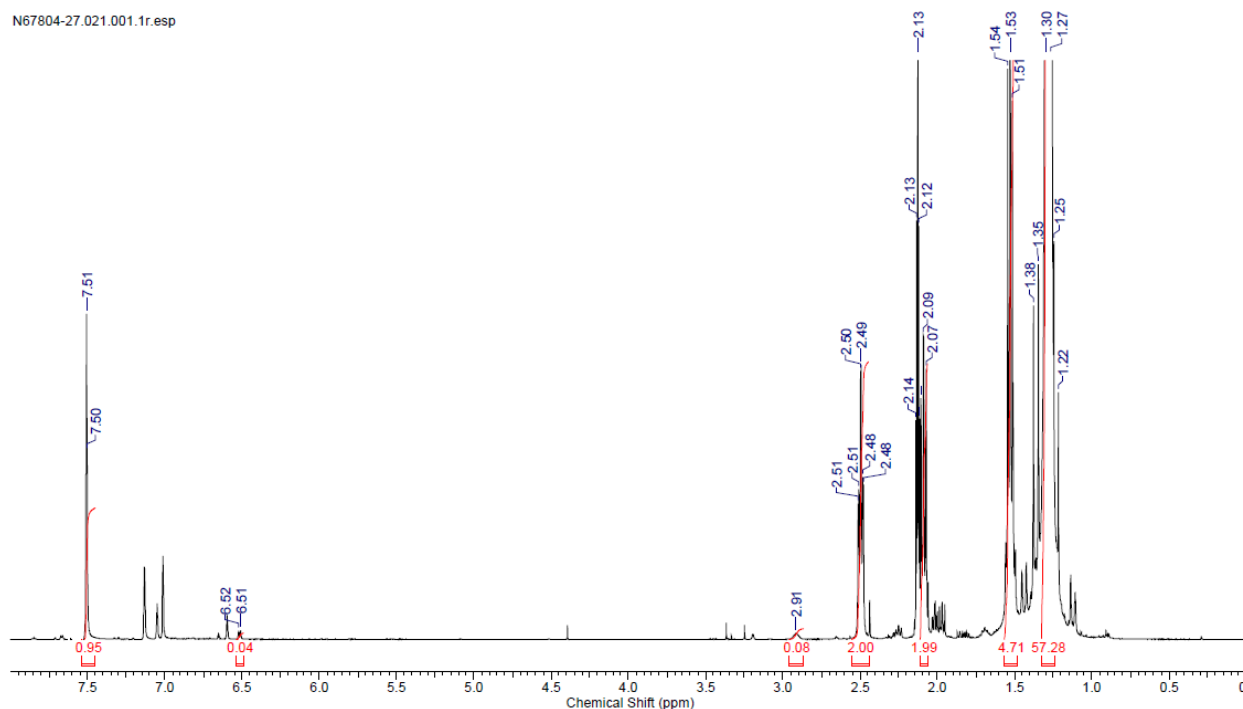


Figure S140. ^1H NMR spectrum (400 MHz, d^8 -tol) of reaction between **1m** and $\text{Pd}[\text{P}(t\text{-Bu})_3]_2$ to give **10**.

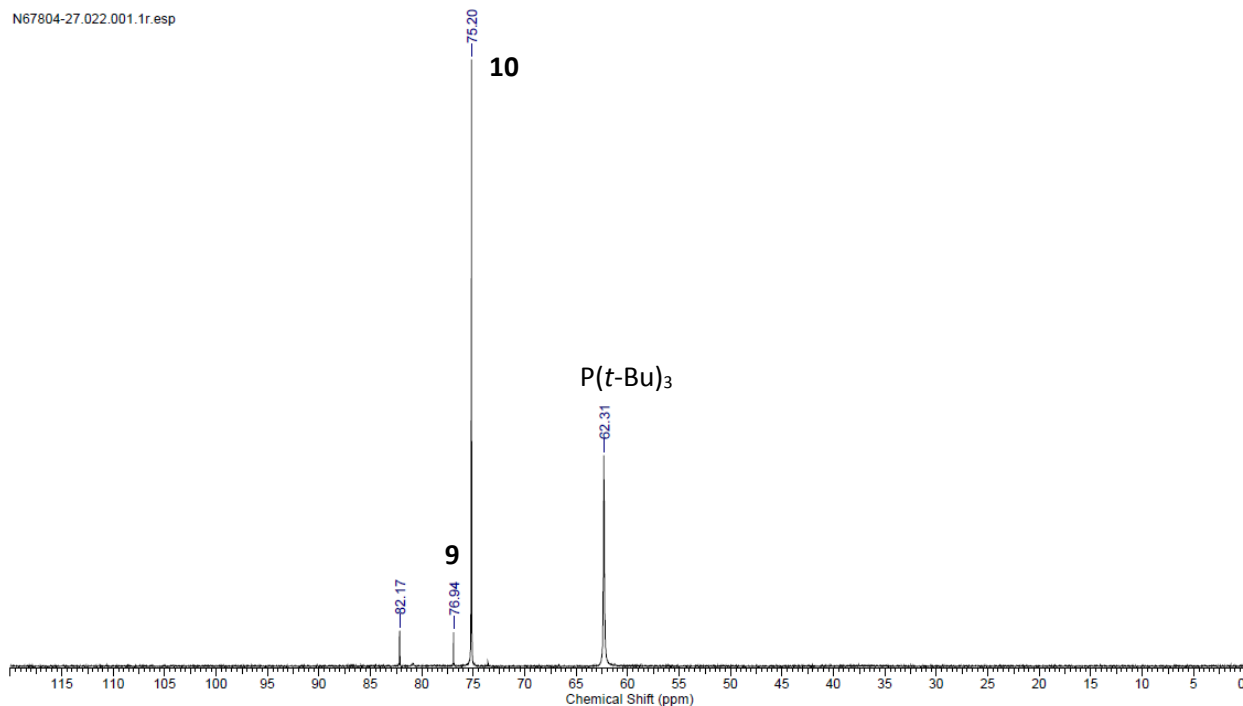


Figure S141. $^{31}\text{P}\{^1\text{H}\}$ NMR spectrum (162 MHz, d^8 -tol) of reaction between **1m** and $\text{Pd}[\text{P}(t\text{-Bu})_3]_2$ to give **10**. Signals assigned as pictured.

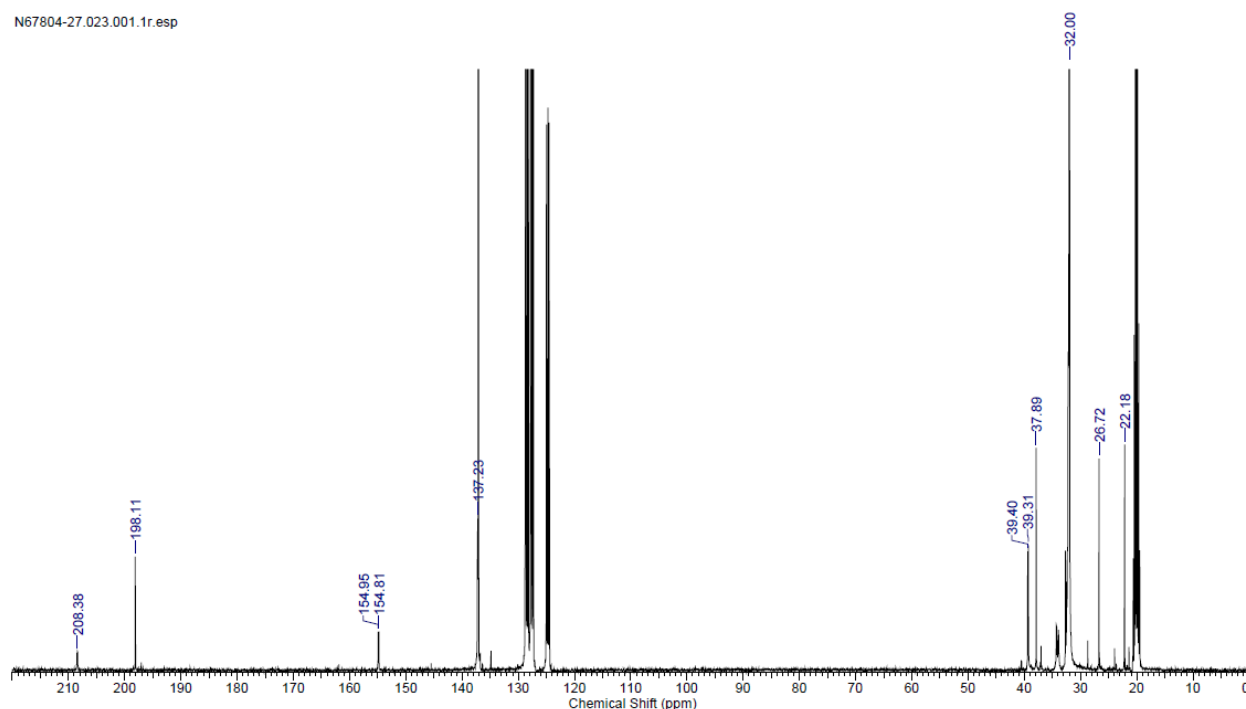
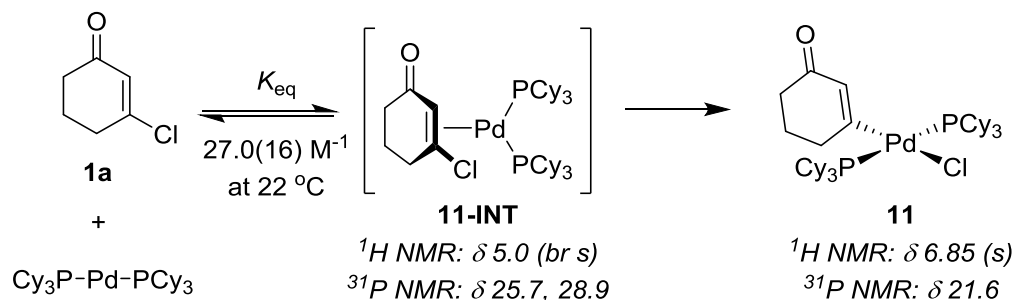


Figure S142. $^{13}\text{C}\{^1\text{H}\}$ NMR spectrum (101 MHz, d^8 -tol) of reaction between **1m** and $\text{Pd}[\text{P}(t\text{-Bu})_3]_2$ to give **10**.



In a nitrogen glovebox, **1a** (7.5 mg, 0.057 mmol) and 1,1'-biphenyl (3.2 mg, 0.021 mmol) were dissolved in d_8 -toluene (0.5 mL) in an NMR tube topped with a septum. A 1 mL syringe was charged with a solution of $\text{Pd}(\text{PCy}_3)_2$ (29.3 mg, 0.044 mmol) in d_8 -toluene (0.5 mL). The materials were brought to the NMR lab, and an single-scan spectrum of the **1a**/biphenyl solution was obtained to establish relative integration for time zero. The solution of $\text{Pd}(\text{PCy}_3)_2$ was added via syringe to the NMR tube, and alternating ^1H (single-scan) and $^{31}\text{P}\{^1\text{H}\}$ NMR spectra were collected for several hours to monitor the oxidative addition reaction. Concentrations were determined by relative integration to biphenyl (**1a**, **11-INT**, and **11**), or calculated assuming perfect mass balance ($\text{Pd}(\text{PCy}_3)_2$).

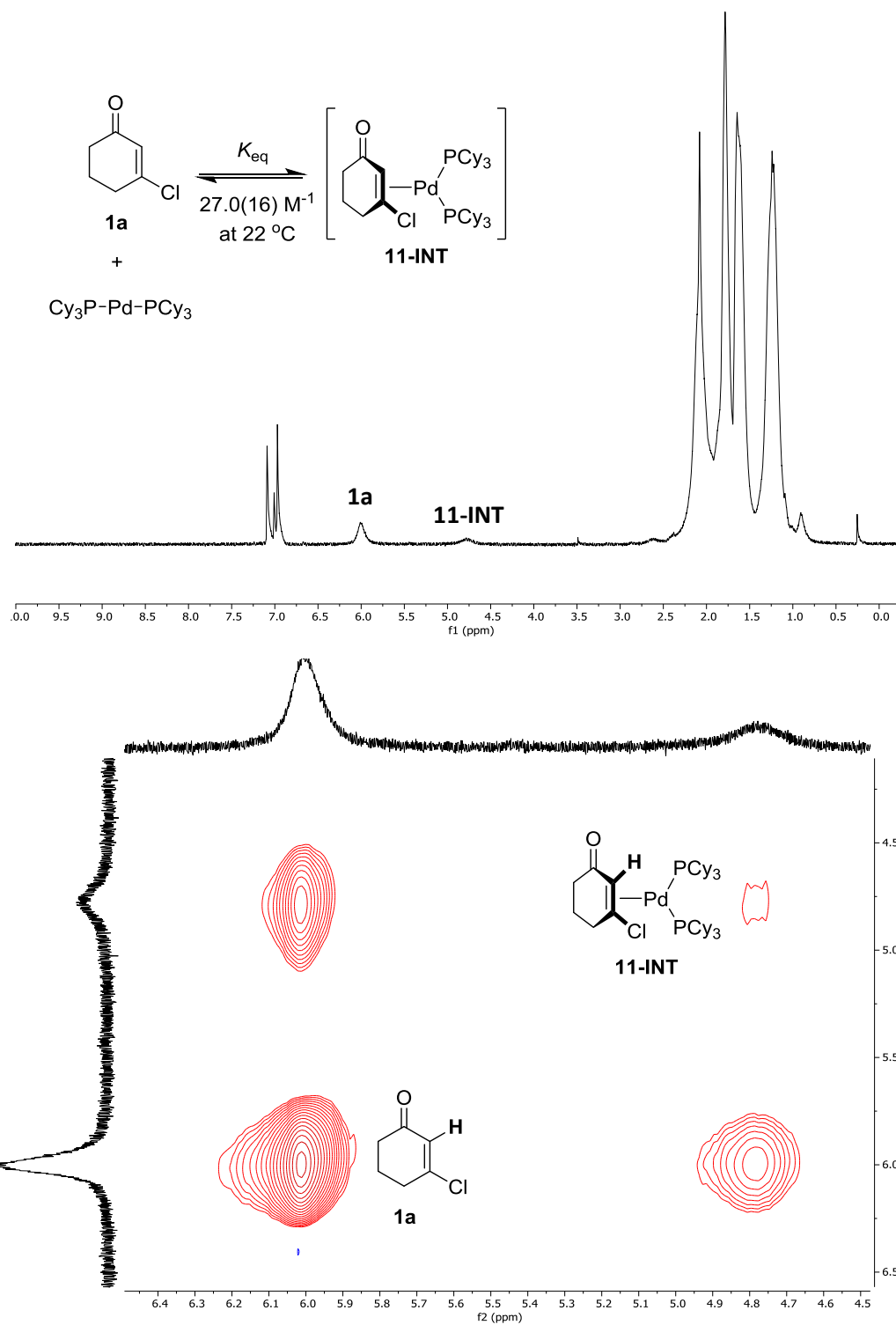


Figure S143. Top: ^1H NMR spectrum (500 MHz, tol-d_8) after addition of $\text{Pd}(\text{PCy}_3)_2$ to **1a**. Bottom: Truncated 2D ROESY NMR spectrum (500 MHz, tol-d_8) acquired after mixing **1a** and $\text{Pd}(\text{PCy}_3)_2$, showing chemical exchange between vinyl protons for **1a** (6.2 ppm) and **11-INT** (5.0 ppm). Cross-peaks are the same phase as the diagonal peaks, confirming exchange (and not through-space coupling).¹²

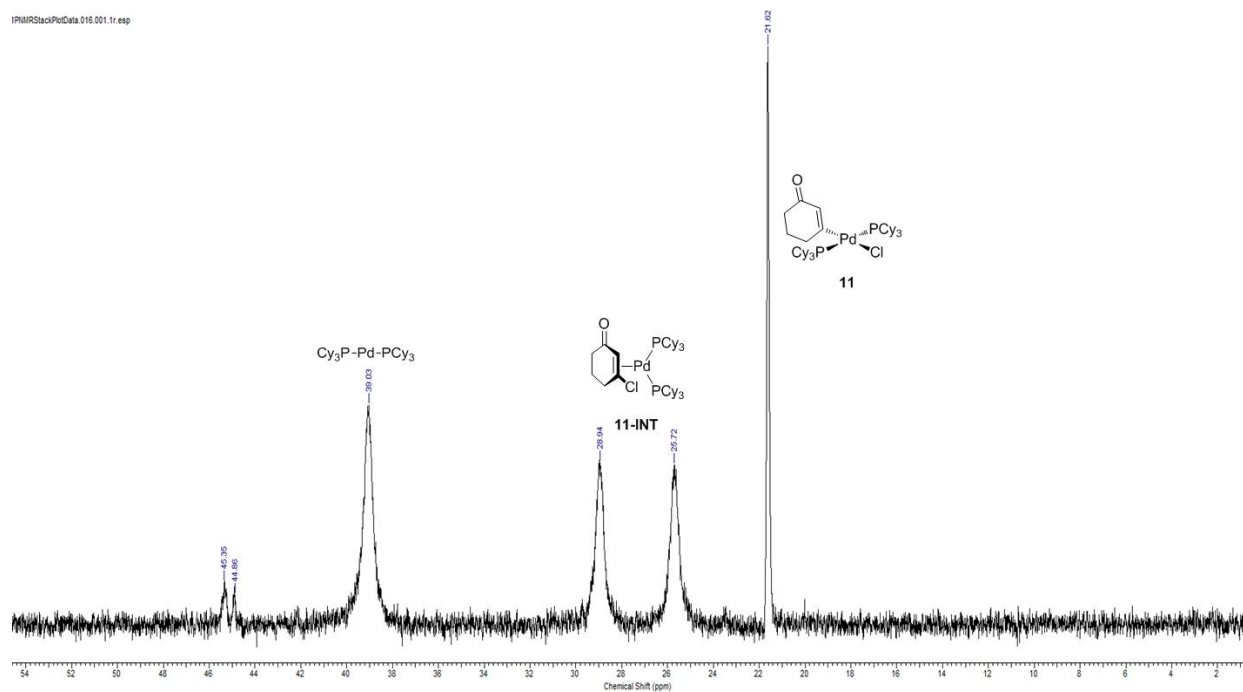


Figure S144. $^{31}\text{P}\{^1\text{H}\}$ NMR spectrum at $t = 30$ min, with major peaks assigned.

Table S3. Concentrations of components in oxidative addition reaction (determined by relative ^1H NMR signal integration to biphenyl as internal standard), and values of K_{eq} calculated for alkene coordination.

Time (min)	[1a] (M)	[$\text{Pd}(\text{PCy}_3)_2$] (M)	[11-INT] (M)	[11] (M)	K_{eq} (M^{-1})
0	0.057	0.045	0	0.000	n/a
6	0.035	0.023	0.020	0.002	24.8
23	0.032	0.020	0.017	0.008	26.6
31	0.031	0.019	0.016	0.010	27.2
51	0.028	0.016	0.013	0.016	29.0
60	0.028	0.016	0.012	0.018	26.8
91	0.025	0.013	0.008	0.024	24.6
99	0.024	0.012	0.008	0.025	27.8
108	0.023	0.011	0.007	0.027	27.7
116	0.022	0.011	0.007	0.028	28.9
141	0.020	0.008	0.005	0.032	31.3
167	0.020	0.008	0.004	0.033	25.0
192	0.020	0.008	0.003	0.034	18.8
286	0.014	0.002	0.001	0.042	35.7
380	0.012	0.000	0.000	0.045	n/a

The equilibrium constant $K_{\text{eq}} = 27(2) \text{ M}^{-1}$ was determined by averaging the values obtained between 6–167 min, with the error estimated from the standard deviation of these 11 values. The final two values were excluded due to the peak shape of the vinyl C-H for **11-INT** making integration less reliable. Including all values in the average simply increases the standard deviation from 2 to 4.

Characterization Data for 11.

N59767-45.020.001.1r.esp

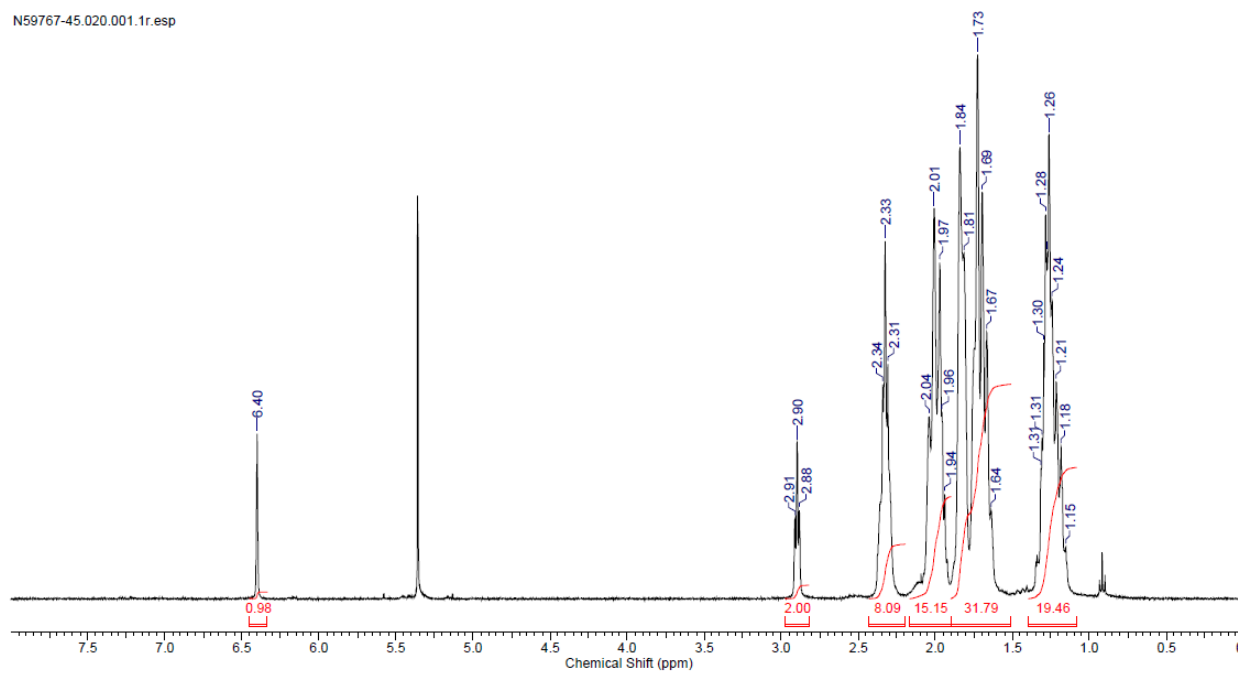


Figure S145. ¹H NMR spectrum of 11.

N59767-45.031.001.1r.esp

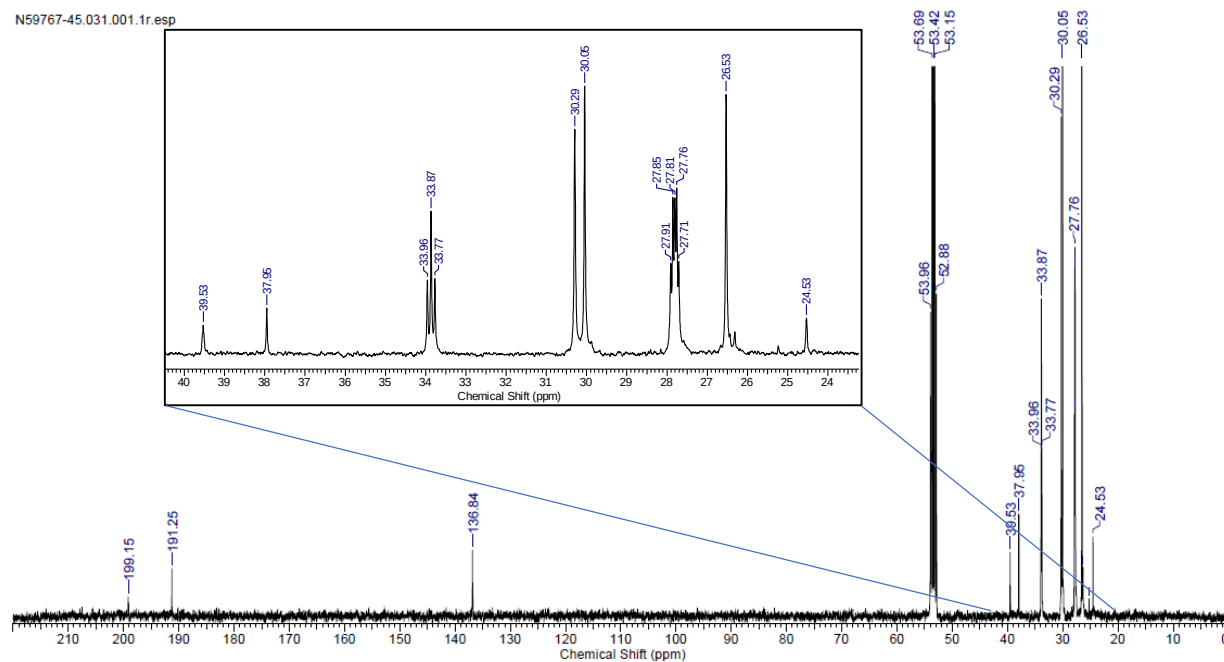


Figure S146. ¹³C{¹H} NMR spectrum of 11.

N59767-45.011.001.1r.esp

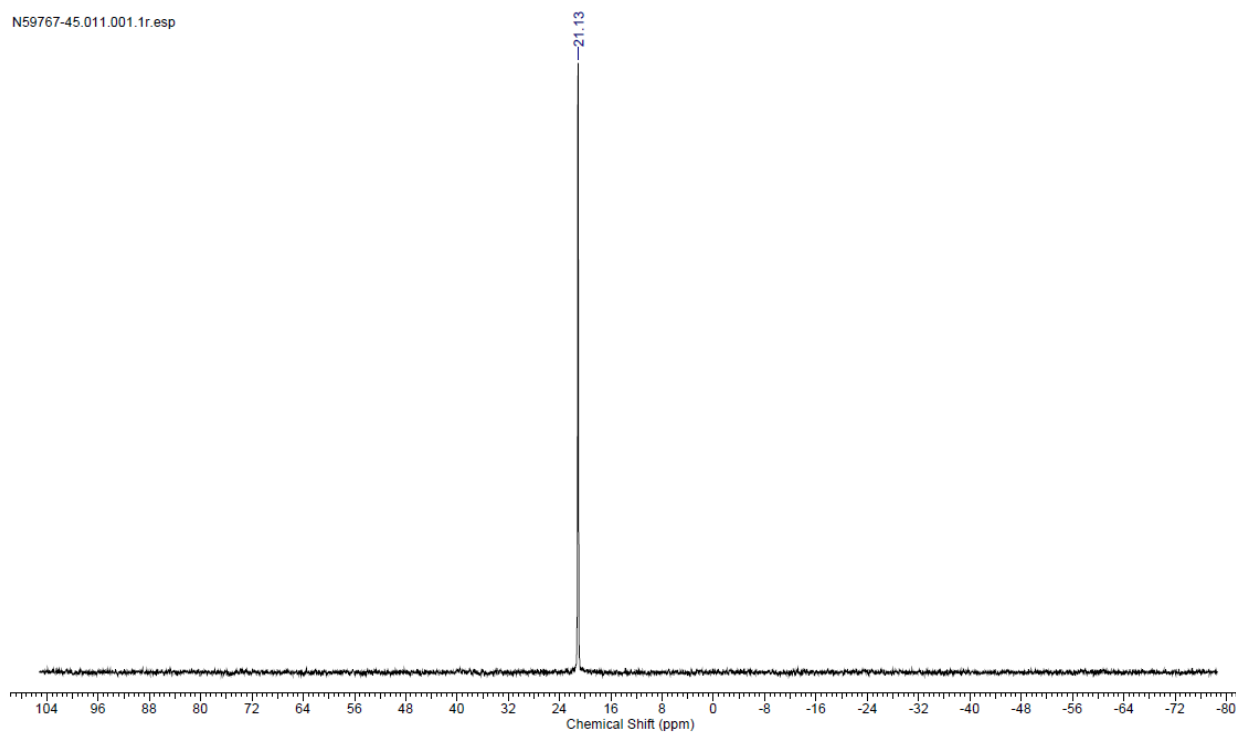


Figure S147. $^{31}\text{P}\{^1\text{H}\}$ NMR spectrum of **11**.

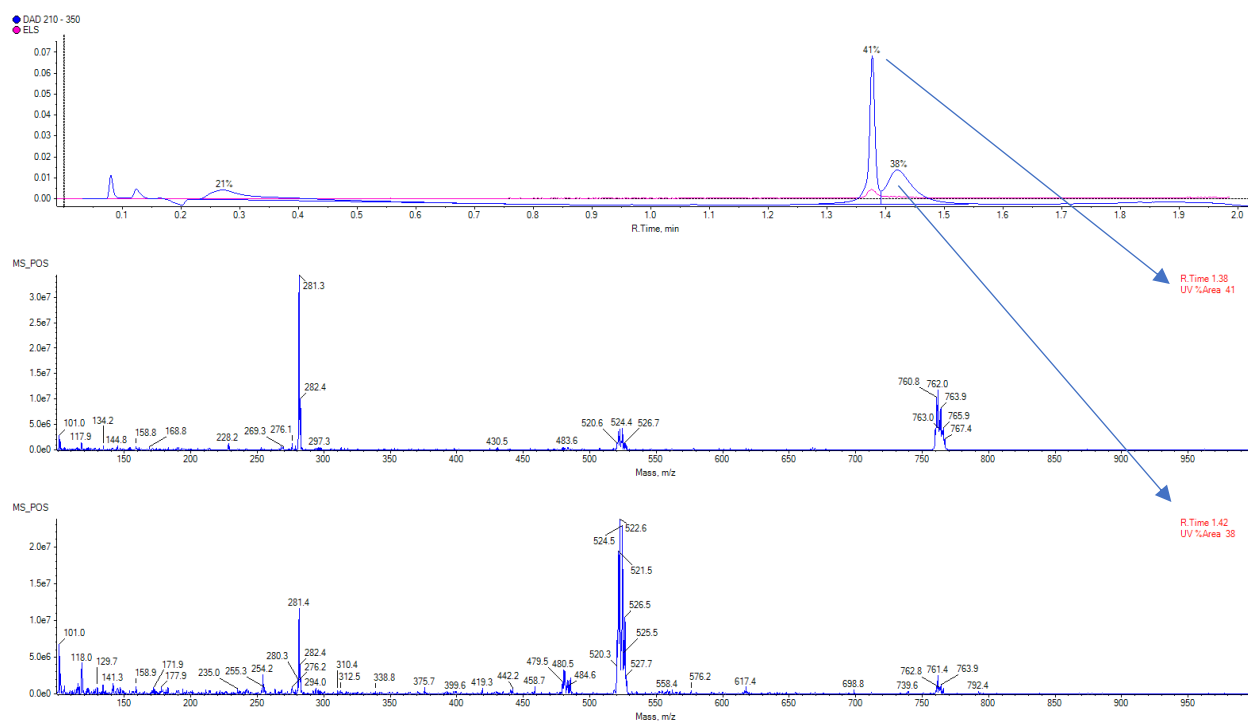


Figure S148. LCMS trace of **11**.

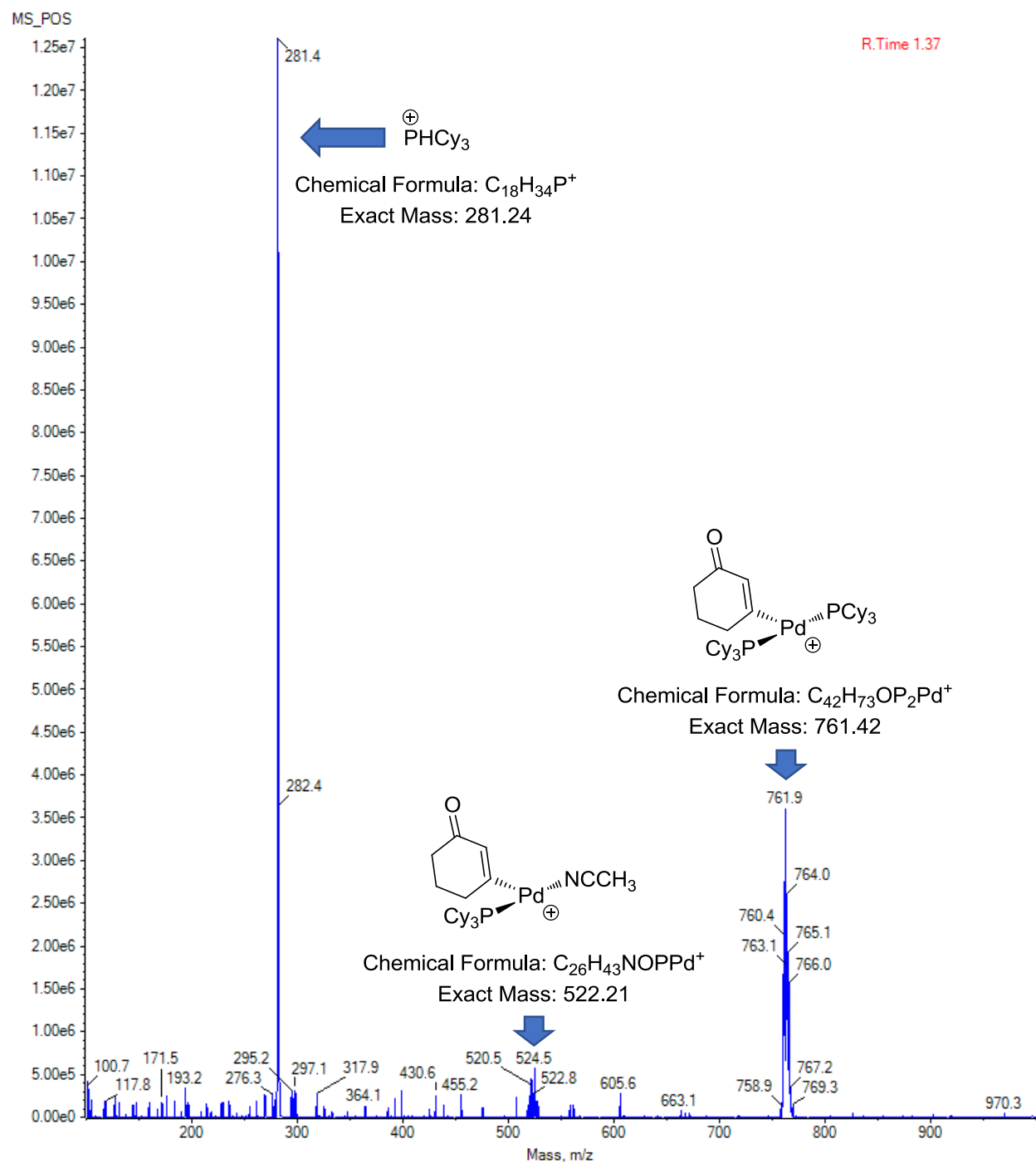


Figure S149. MS of peak at 1.37 min, corresponding to $[\mathbf{11} - \text{Cl}]^+$.

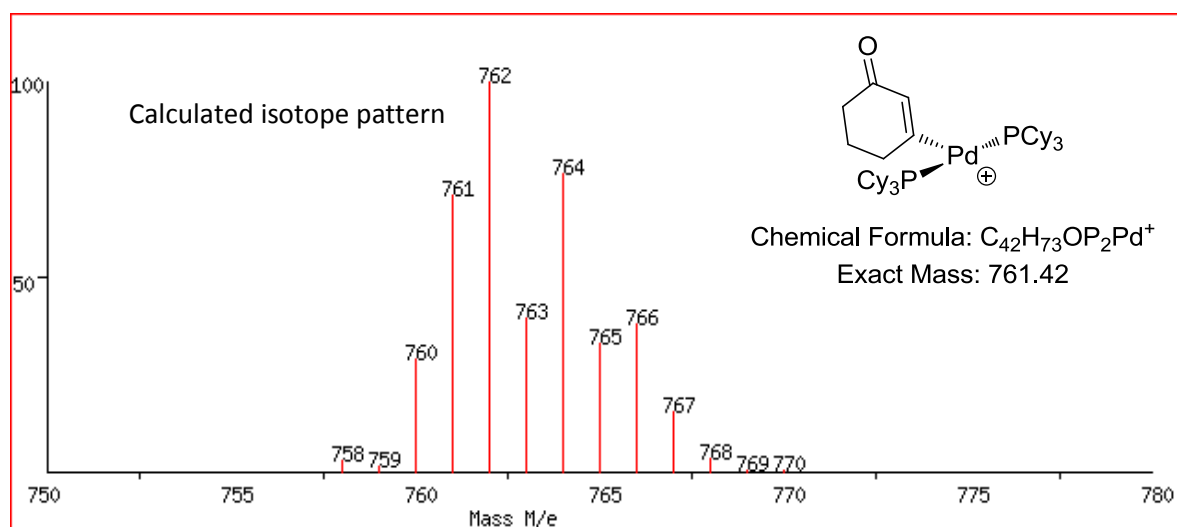
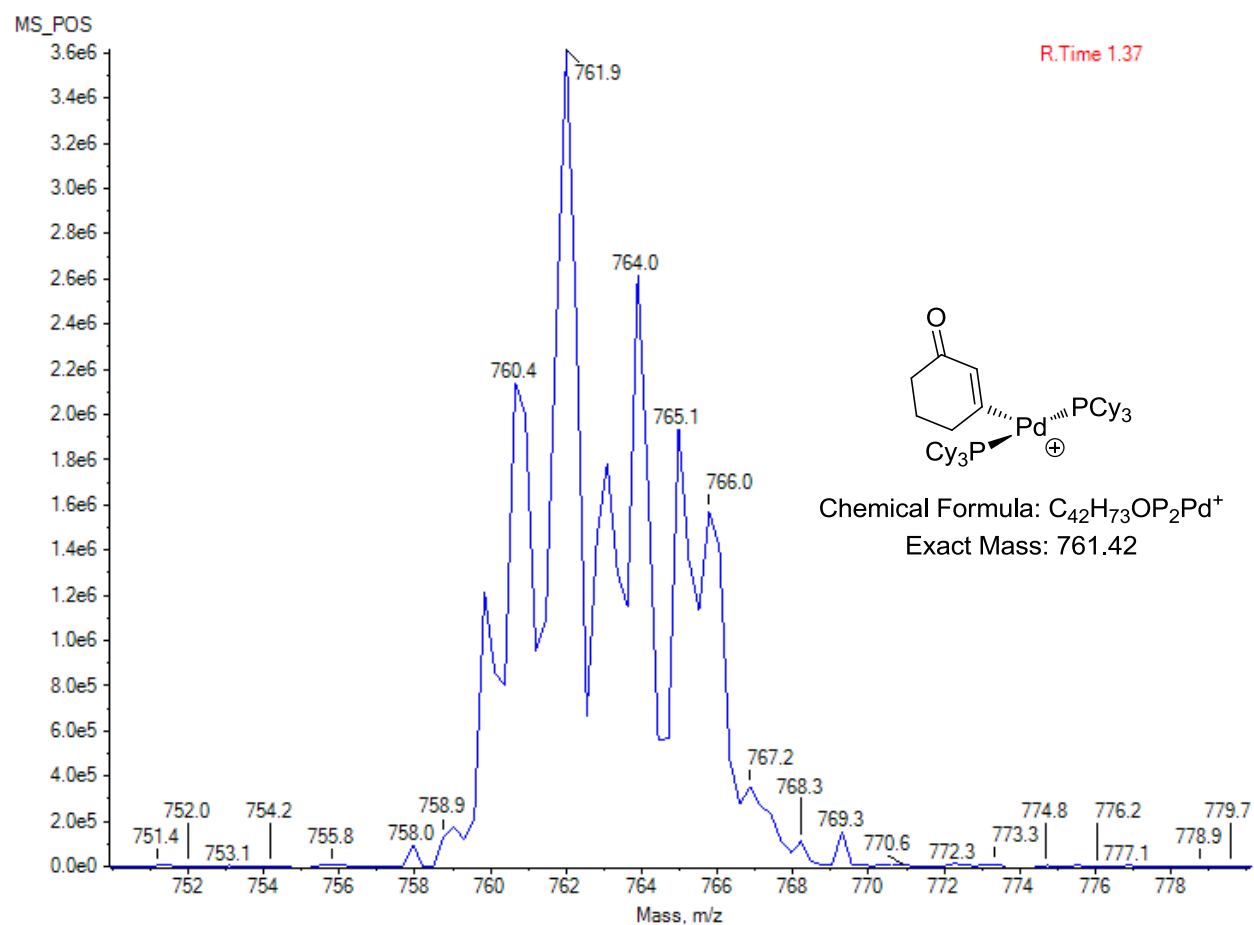


Figure S150. Isotope pattern analysis of experimental and predicted $[\mathbf{11} - \text{Cl}]^+$.

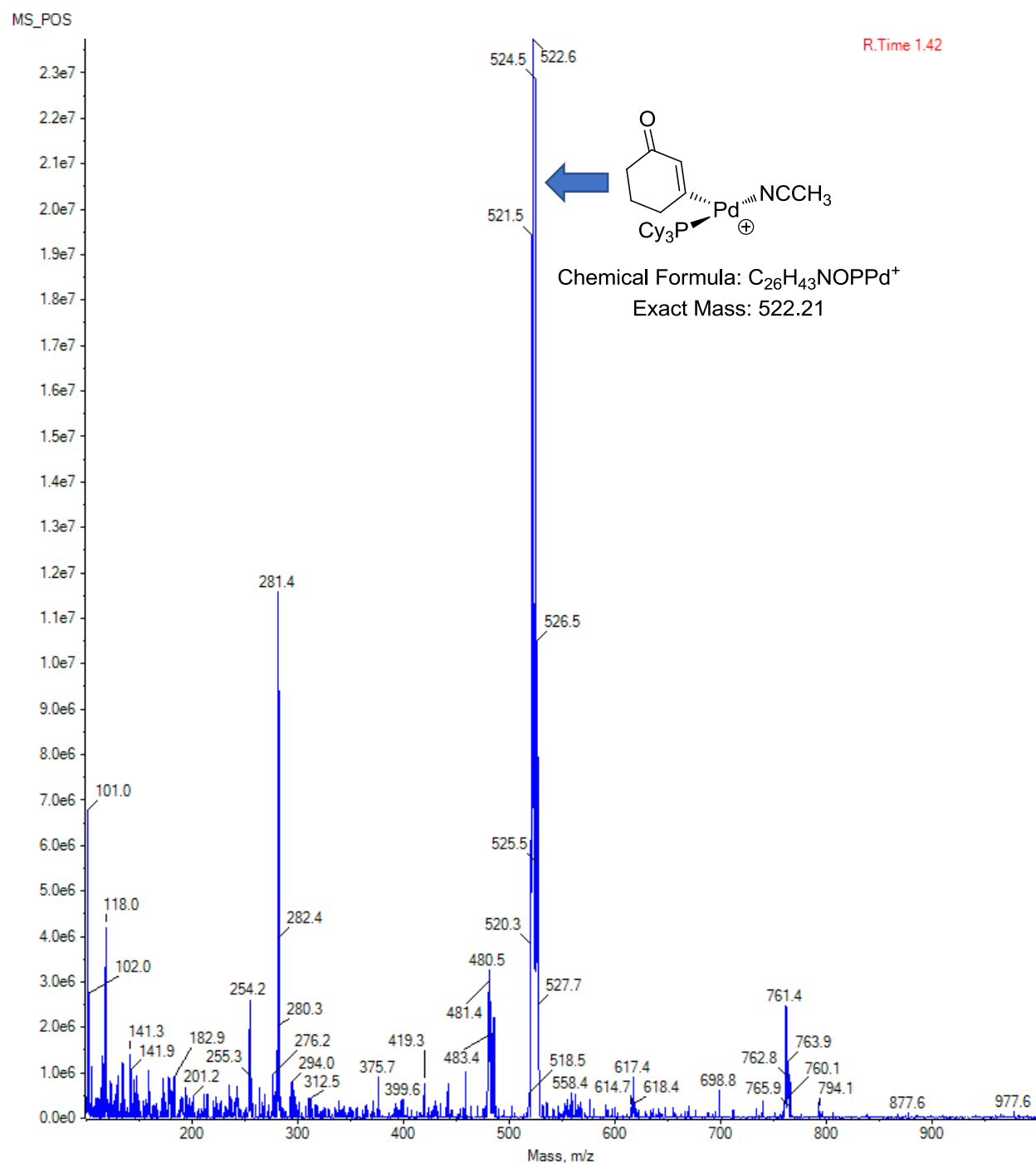


Figure S151. MS of peak at 1.42 min, corresponding to $[11 - Cl - PCy_3 + CH_3CN]^+$.

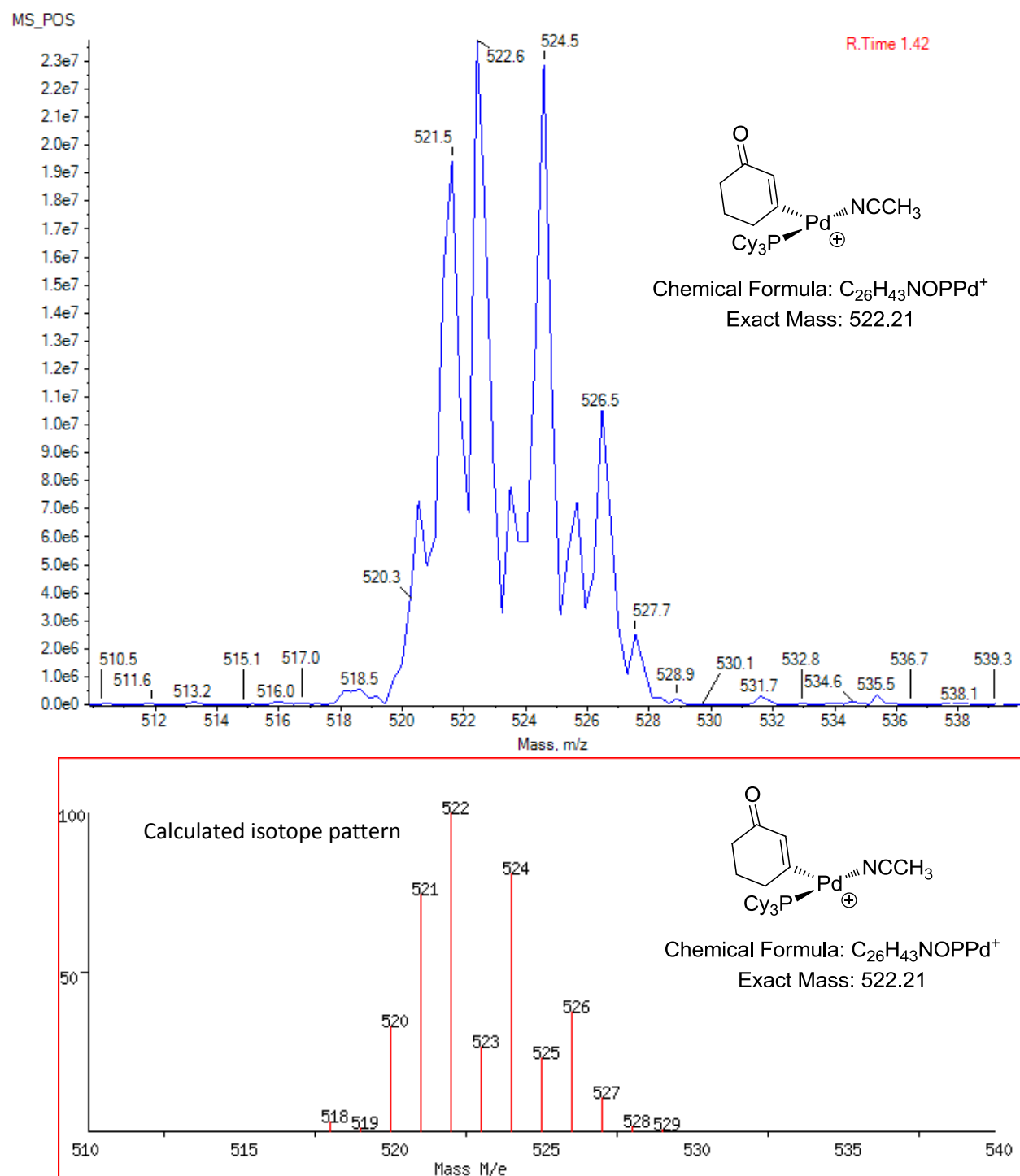


Figure S152. Isotope pattern analysis of experimental and predicted $[11 - Cl - PCy_3 + CH_3CN]^+$.

Characterization Data for 12.

N67804-12.011.001.1r.esp

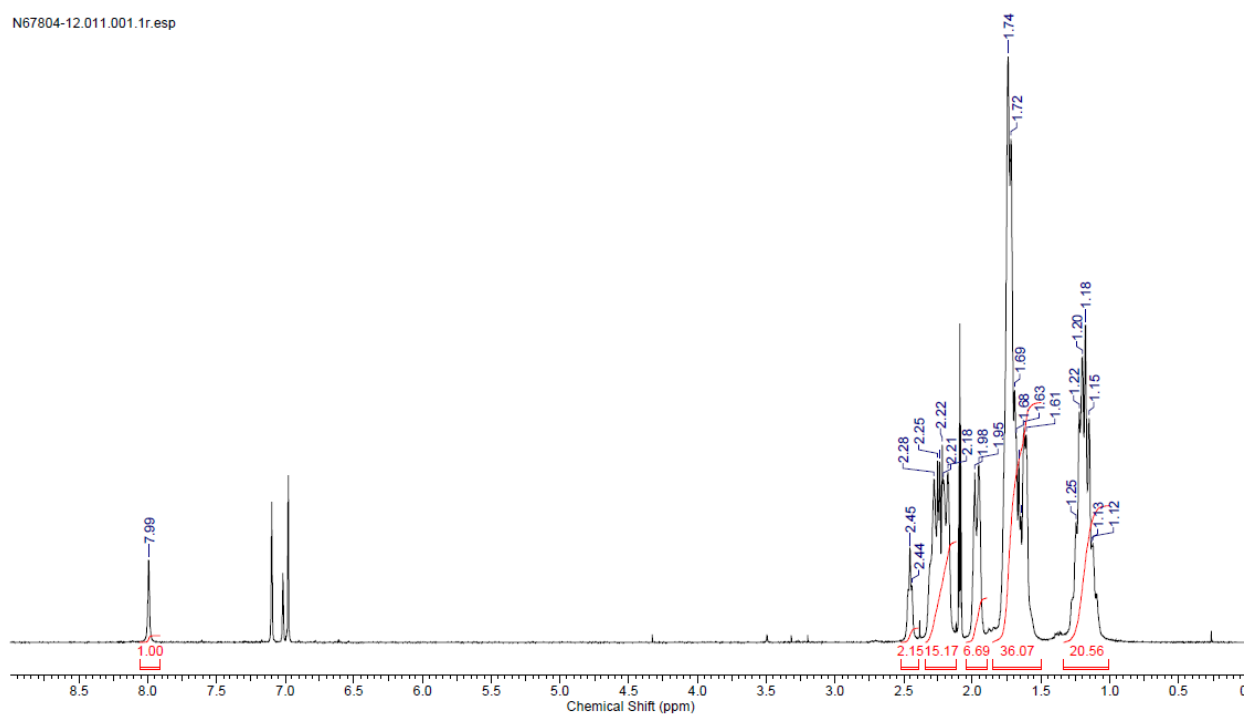


Figure S153. ^1H NMR spectrum of 12.

N67804-12.012.001.1r.esp

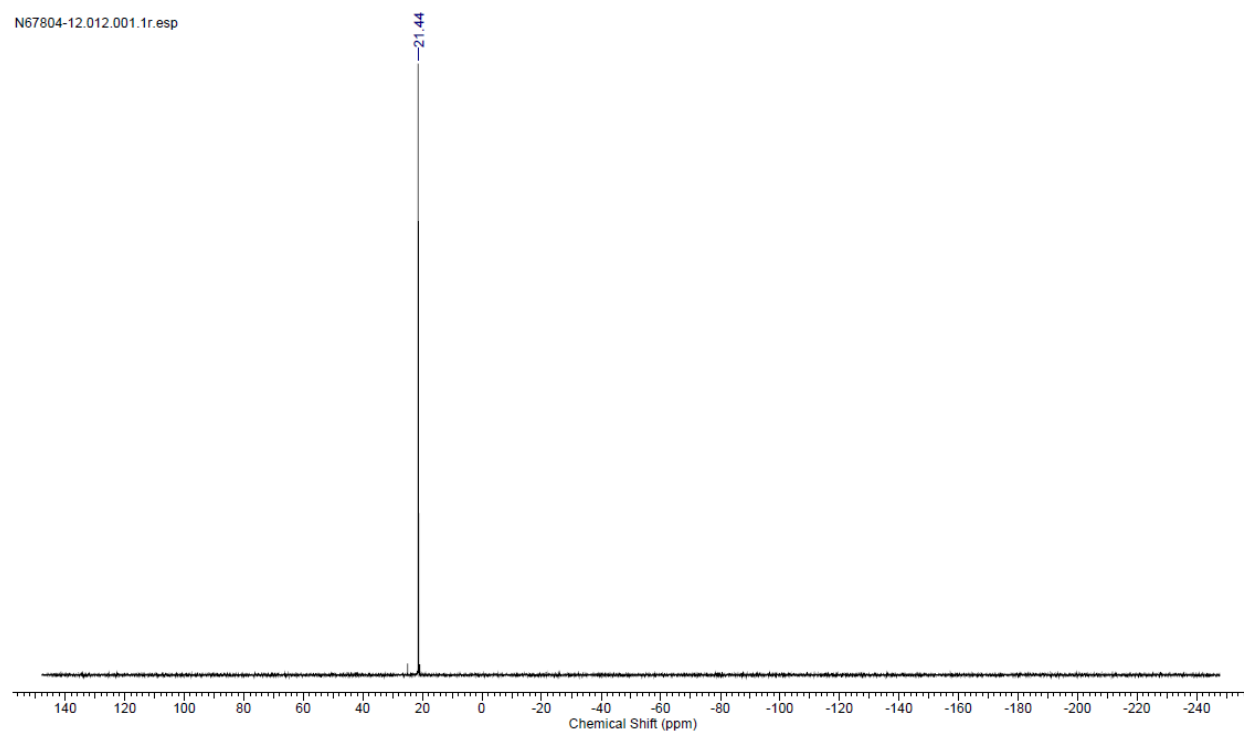


Figure S154. $^{31}\text{P}\{^1\text{H}\}$ NMR spectrum of 12.

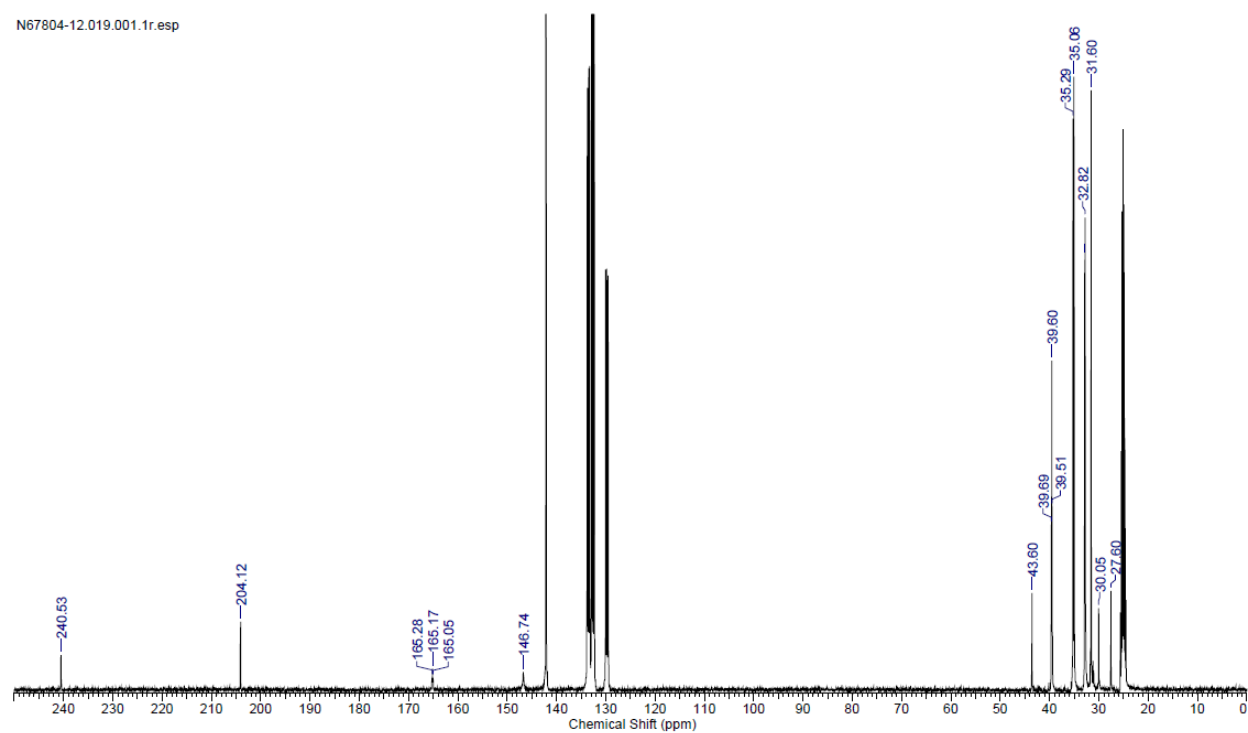


Figure S155. $^{13}\text{C}\{^1\text{H}\}$ NMR spectrum of **12**.

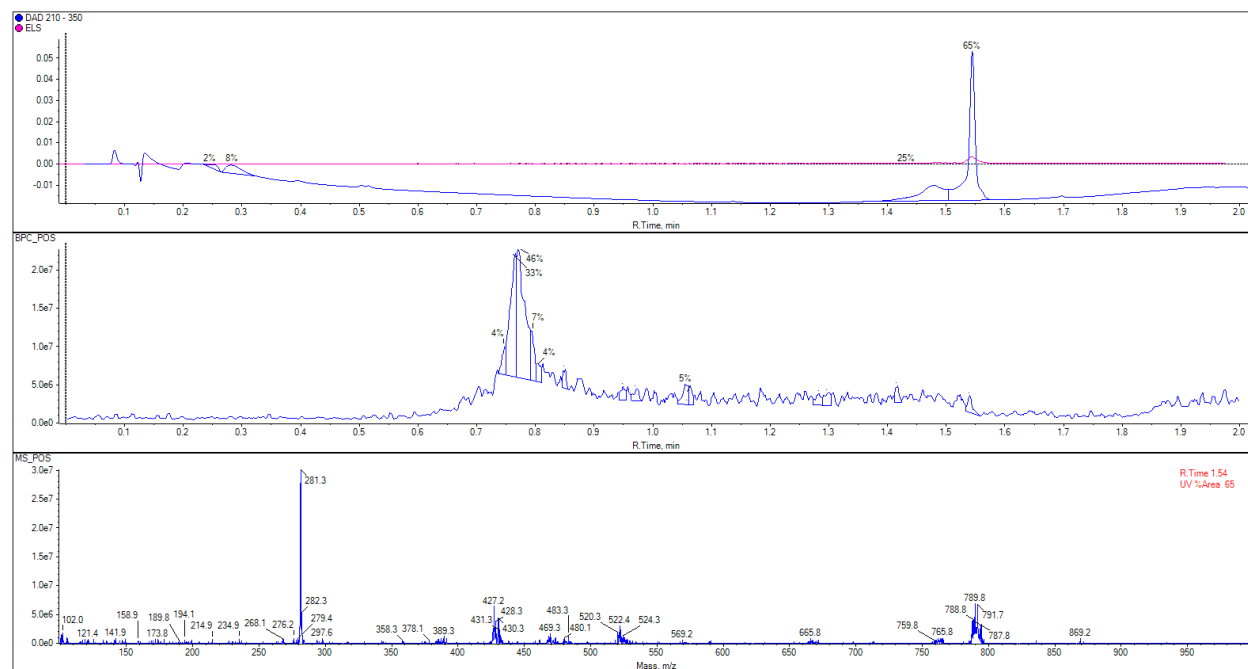


Figure S156. LCMS trace of **12**.

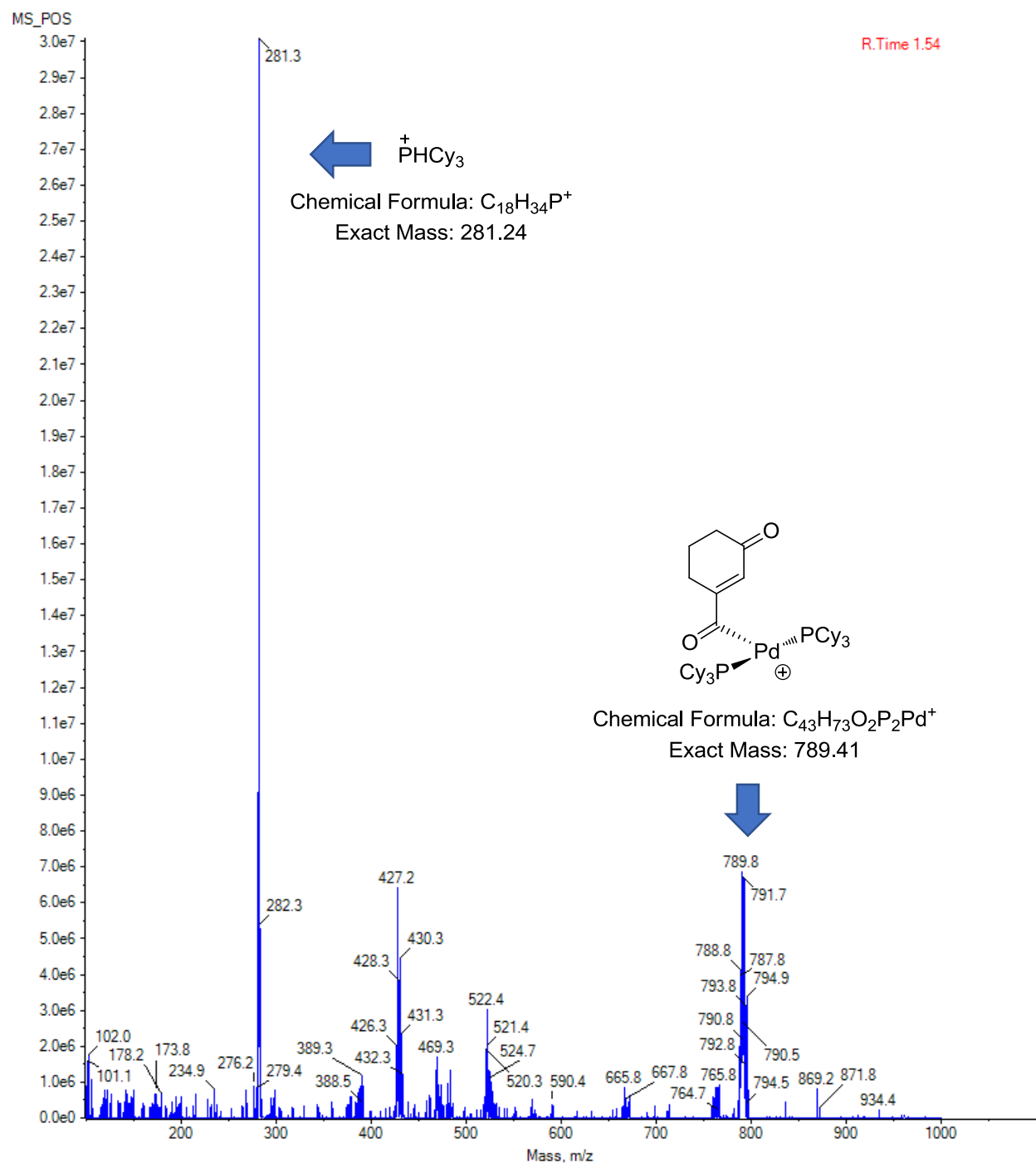


Figure S157. MS of peak at 1.54 min, corresponding to $[\mathbf{12} - \text{Cl}]^+$.

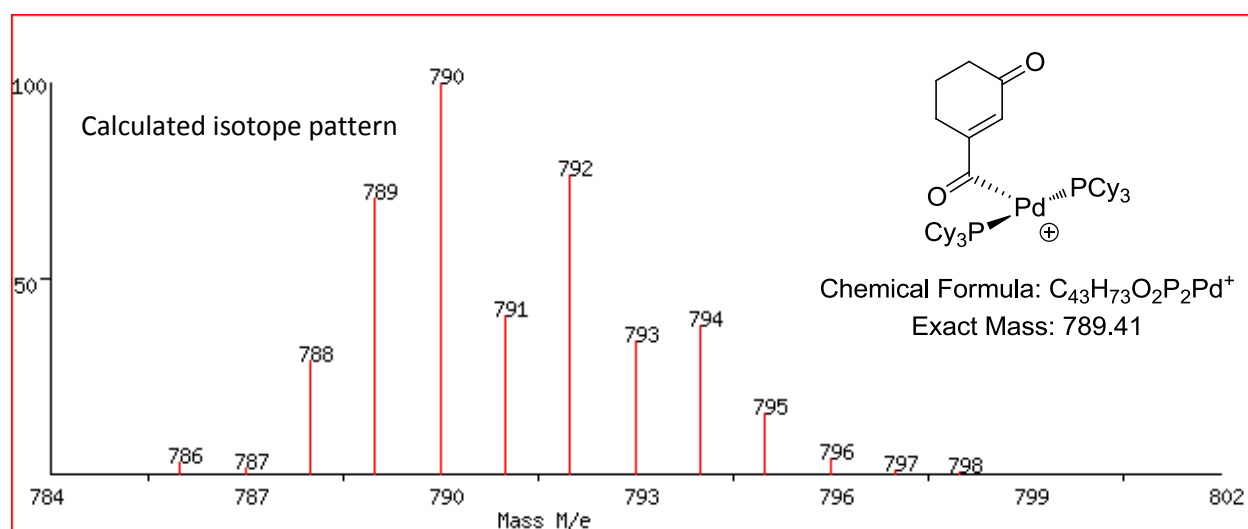
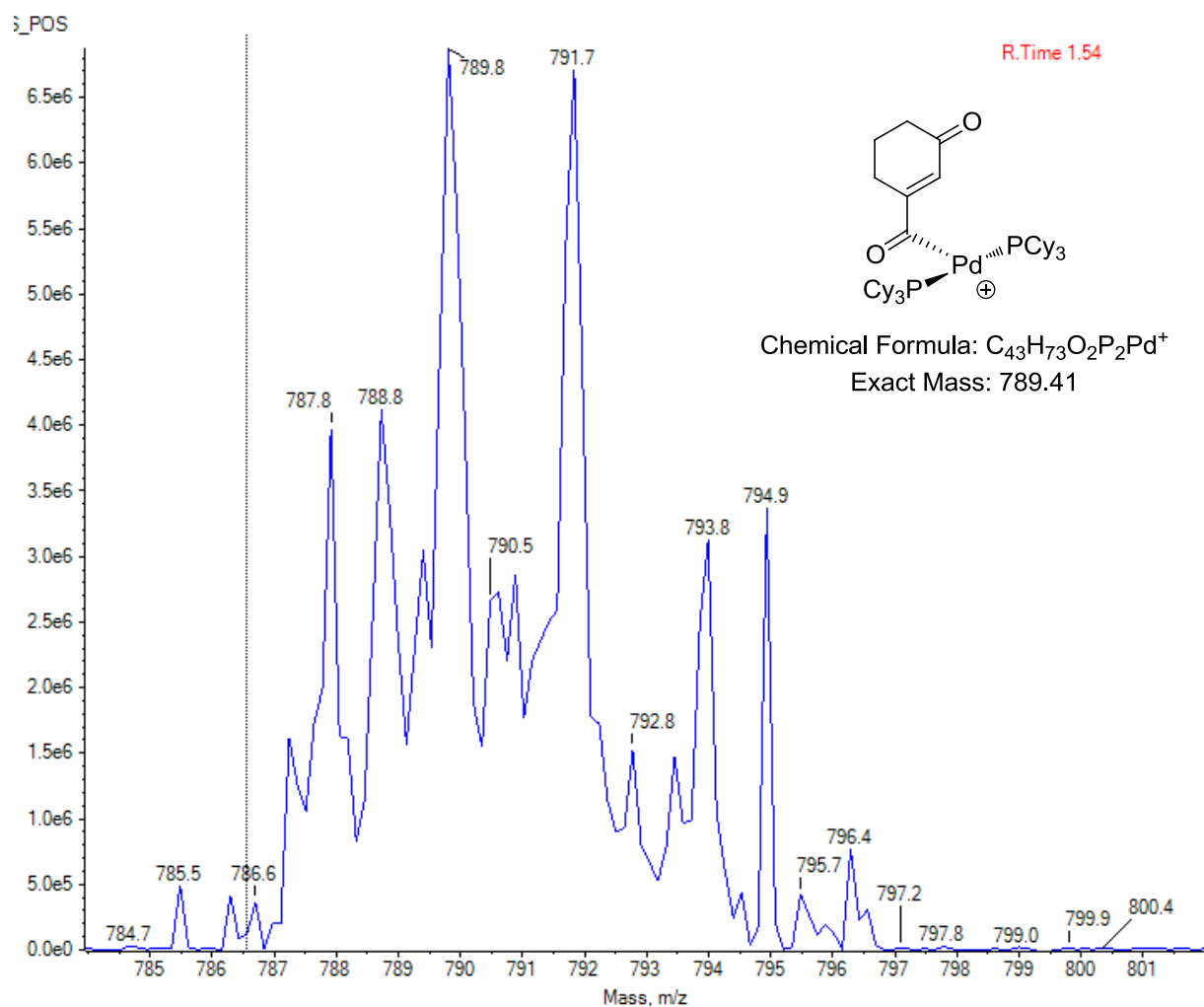


Figure S158. Isotope pattern analysis of experimental and predicted $[12 - Cl]^+$.

V: X-Ray Crystallography

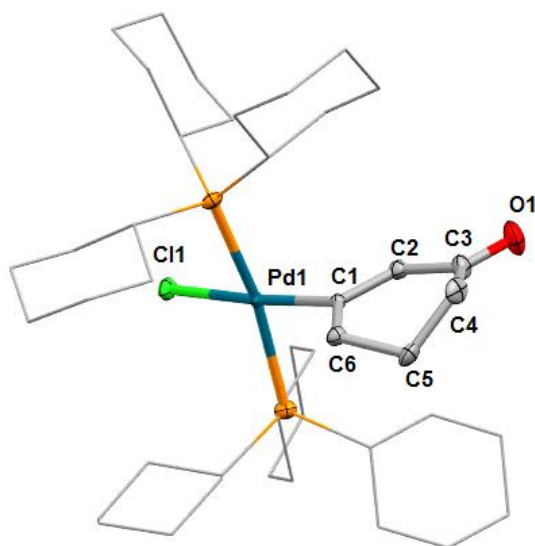


Figure S159. Thermal ellipsoid plot of **11**. Ellipsoids shown at 50% probability. Cyclohexyl rings shown in wireframe, hydrogen atoms and solvent (2-methyl THF) hidden for clarity.

A specimen of $C_{47}H_{83}ClO_2P_2Pd$, approximate dimensions 0.072 mm x 0.140 mm x 0.383 mm, was used for the X-ray crystallographic analysis. The X-ray intensity data were measured.

The integration of the data using an orthorhombic unit cell yielded a total of 12684 reflections to a maximum θ angle of 27.91° (0.76 Å resolution), of which 5101 were independent (average redundancy 2.487, completeness = 99.9%, $R_{int} = 1.32\%$, $R_{sig} = 2.01\%$) and 5072 (99.43%) were greater than $2\sigma(F^2)$. The final cell constants of $a = 14.2986(7)$ Å, $b = 16.8879(8)$ Å, $c = 9.6531(5)$ Å, volume = $2331.0(2)$ Å³, are based upon the refinement of the XYZ-centroids of reflections above $20\sigma(I)$. The calculated minimum and maximum transmission coefficients (based on crystal size) are 0.8140 and 0.9610.

The final anisotropic full-matrix least-squares refinement on F^2 with 275 variables converged at $R1 = 3.73\%$, for the observed data and $wR2 = 9.24\%$ for all data. The goodness-of-fit was 1.262. The largest peak in the final difference electron density synthesis was $0.726\text{ e}^-/\text{\AA}^3$ and the largest hole was $-1.326\text{ e}^-/\text{\AA}^3$ with an RMS deviation of $0.097\text{ e}^-/\text{\AA}^3$. On the basis of the final model, the calculated density was 1.259 g/cm^3 and $F(000)$, 948 e^- .

Table S4. Sample and crystal data for 11.

Identification code	11	
Chemical formula	C ₄₇ H ₈₃ ClO ₂ P ₂ Pd	
Formula weight	883.92 g/mol	
Temperature	100(2) K	
Wavelength	0.71073 Å	
Crystal size	0.072 x 0.140 x 0.383 mm	
Crystal system	orthorhombic	
Space group	P m n 21	
Unit cell dimensions	a = 14.2986(7) Å	α = 90°
	b = 16.8879(8) Å	β = 90°
	c = 9.6531(5) Å	γ = 90°
Volume	2331.0(2) Å ³	
Z	2	
Density (calculated)	1.259 g/cm ³	
Absorption coefficient	0.559 mm ⁻¹	
F(000)	948	

Table S5. Data collection and structure refinement for 11.

Theta range for data collection	1.87 to 27.91°	
Index ranges	-18<=h<=11, -22<=k<=12, -12<=l<=12	
Reflections collected	12684	
Independent reflections	5101 [R(int) = 0.0132]	
Max. and min. transmission	0.9610 and 0.8140	
Refinement method	Full-matrix least-squares on F ²	
Refinement program	SHELXL-2014/7 (Sheldrick, 2014)	
Function minimized	Σ w(F _o ² - F _c ²) ²	
Data / restraints / parameters	5101 / 71 / 275	
Goodness-of-fit on F ²	1.262	
Δ/σ _{max}	0.001	
Final R indices	5072 data; I>2σ(I)	R1 = 0.0373, wR2 = 0.0924
	all data	R1 = 0.0374, wR2 = 0.0924
Weighting scheme	w=1/[σ ² (F _o ²)+6.9683P] where P=(F _o ² +2F _c ²)/3	
Absolute structure parameter	0.09(5)	
Largest diff. peak and hole	0.726 and -1.326 eÅ ⁻³	
R.M.S. deviation from mean	0.097 eÅ ⁻³	

Table S6. Bond lengths (Å) for 11.

Pd1-C1	1.988(7)	Pd1-P1	2.3540(11)
Pd1-P1	2.3540(11)	Pd1-Cl1	2.4147(18)
P1-C19	1.837(6)	P1-C7	1.853(5)
P1-C13	1.859(5)	O1-C3	1.230(10)
C1-C2	1.380(9)	C1-C6	1.508(10)
C2-C3	1.455(10)	C2-H2	0.95
C3-C4	1.525(12)	C4-C5	1.532(13)
C4-H4A	0.99	C4-H4B	0.99
C5-C6	1.556(12)	C5-H5A	0.99
C5-H5B	0.99	C6-H6A	0.99
C6-H6B	0.99	C7-C8	1.528(8)
C7-C12	1.546(8)	C7-H7	1.0
C8-C9	1.535(8)	C8-H8A	0.99
C8-H8B	0.99	C9-C10	1.519(9)
C9-H9A	0.99	C9-H9B	0.99
C10-C11	1.514(9)	C10-H10A	0.99
C10-H10B	0.99	C11-C12	1.531(7)
C11-H11A	0.99	C11-H11B	0.99
C12-H12A	0.99	C12-H12B	0.99
C13-C18	1.537(7)	C13-C14	1.544(7)
C13-H13	1.0	C14-C15	1.528(7)
C14-H14A	0.99	C14-H14B	0.99
C15-C16	1.527(9)	C15-H15A	0.99
C15-H15B	0.99	C16-C17	1.523(9)
C16-H16A	0.99	C16-H16B	0.99
C17-C18	1.525(9)	C17-H17A	0.99
C17-H17B	0.99	C18-H18A	0.99
C18-H18B	0.99	C19-C20	1.536(8)
C19-C24	1.545(7)	C19-H19	1.0
C20-C21	1.535(9)	C20-H20A	0.99
C20-H20B	0.99	C21-C22	1.518(11)
C21-H21A	0.99	C21-H21B	0.99
C22-C23	1.527(9)	C22-H22A	0.99
C22-H22B	0.99	C23-C24	1.529(7)
C23-H23A	0.99	C23-H23B	0.99
C24-H24A	0.99	C24-H24B	0.99
O2-C25	1.364(11)	O2-C28	1.452(11)
C25-C29	1.488(11)	C25-C26	1.539(11)
C25-H25	1.0	C26-C27	1.561(11)
C26-H26B	0.99	C26-H26A	0.99
C27-C28	1.512(11)	C27-H27A	0.99
C27-H27B	0.99	C28-H28A	0.99
C28-H28B	0.99	C29-H29A	0.98

C29-H29B

0.98

C29-H29C

0.98

Table S7. Bond angles (°) for 11.

C1-Pd1-P1	91.31(4)	C1-Pd1-P1	91.31(4)
P1-Pd1-P1	169.71(7)	C1-Pd1-Cl1	172.3(2)
P1-Pd1-Cl1	89.37(4)	P1-Pd1-Cl1	89.37(4)
C19-P1-C7	104.1(2)	C19-P1-C13	109.7(2)
C7-P1-C13	103.6(3)	C19-P1-Pd1	111.37(18)
C7-P1-Pd1	109.70(18)	C13-P1-Pd1	117.33(17)
C2-C1-C6	119.7(6)	C2-C1-Pd1	118.0(6)
C6-C1-Pd1	122.4(5)	C1-C2-C3	123.7(7)
C1-C2-H2	118.1	C3-C2-H2	118.1
O1-C3-C2	121.8(8)	O1-C3-C4	120.8(7)
C2-C3-C4	116.6(7)	C3-C4-C5	110.3(8)
C3-C4-H4A	109.6	C5-C4-H4A	109.6
C3-C4-H4B	109.6	C5-C4-H4B	109.6
H4A-C4-H4B	108.1	C4-C5-C6	109.4(8)
C4-C5-H5A	109.8	C6-C5-H5A	109.8
C4-C5-H5B	109.8	C6-C5-H5B	109.8
H5A-C5-H5B	108.2	C1-C6-C5	113.9(7)
C1-C6-H6A	108.8	C5-C6-H6A	108.8
C1-C6-H6B	108.8	C5-C6-H6B	108.8
H6A-C6-H6B	107.7	C8-C7-C12	109.2(5)
C8-C7-P1	113.7(4)	C12-C7-P1	110.5(4)
C8-C7-H7	107.7	C12-C7-H7	107.7
P1-C7-H7	107.7	C7-C8-C9	111.0(5)
C7-C8-H8A	109.4	C9-C8-H8A	109.4
C7-C8-H8B	109.4	C9-C8-H8B	109.4
H8A-C8-H8B	108.0	C10-C9-C8	110.9(5)
C10-C9-H9A	109.5	C8-C9-H9A	109.5
C10-C9-H9B	109.5	C8-C9-H9B	109.5
H9A-C9-H9B	108.0	C11-C10-C9	112.0(6)
C11-C10-H10A	109.2	C9-C10-H10A	109.2
C11-C10-H10B	109.2	C9-C10-H10B	109.2
H10A-C10-H10B	107.9	C10-C11-C12	110.9(5)
C10-C11-H11A	109.5	C12-C11-H11A	109.5
C10-C11-H11B	109.5	C12-C11-H11B	109.5
H11A-C11-H11B	108.0	C11-C12-C7	111.8(5)
C11-C12-H12A	109.3	C7-C12-H12A	109.3
C11-C12-H12B	109.3	C7-C12-H12B	109.3
H12A-C12-H12B	107.9	C18-C13-C14	109.4(4)
C18-C13-P1	118.5(4)	C14-C13-P1	112.2(4)
C18-C13-H13	105.2	C14-C13-H13	105.2

P1-C13-H13	105.2	C15-C14-C13	111.3(5)
C15-C14-H14A	109.4	C13-C14-H14A	109.4
C15-C14-H14B	109.4	C13-C14-H14B	109.4
H14A-C14-H14B	108.0	C16-C15-C14	111.4(5)
C16-C15-H15A	109.3	C14-C15-H15A	109.3
C16-C15-H15B	109.3	C14-C15-H15B	109.3
H15A-C15-H15B	108.0	C17-C16-C15	111.0(5)
C17-C16-H16A	109.4	C15-C16-H16A	109.4
C17-C16-H16B	109.4	C15-C16-H16B	109.4
H16A-C16-H16B	108.0	C16-C17-C18	111.6(5)
C16-C17-H17A	109.3	C18-C17-H17A	109.3
C16-C17-H17B	109.3	C18-C17-H17B	109.3
H17A-C17-H17B	108.0	C17-C18-C13	110.4(5)
C17-C18-H18A	109.6	C13-C18-H18A	109.6
C17-C18-H18B	109.6	C13-C18-H18B	109.6
H18A-C18-H18B	108.1	C20-C19-C24	110.7(5)
C20-C19-P1	117.2(4)	C24-C19-P1	113.9(4)
C20-C19-H19	104.5	C24-C19-H19	104.5
P1-C19-H19	104.5	C21-C20-C19	109.3(5)
C21-C20-H20A	109.8	C19-C20-H20A	109.8
C21-C20-H20B	109.8	C19-C20-H20B	109.8
H20A-C20-H20B	108.3	C22-C21-C20	112.0(6)
C22-C21-H21A	109.2	C20-C21-H21A	109.2
C22-C21-H21B	109.2	C20-C21-H21B	109.2
H21A-C21-H21B	107.9	C21-C22-C23	112.0(5)
C21-C22-H22A	109.2	C23-C22-H22A	109.2
C21-C22-H22B	109.2	C23-C22-H22B	109.2
H22A-C22-H22B	107.9	C22-C23-C24	111.1(5)
C22-C23-H23A	109.4	C24-C23-H23A	109.4
C22-C23-H23B	109.4	C24-C23-H23B	109.4
H23A-C23-H23B	108.0	C23-C24-C19	110.2(5)
C23-C24-H24A	109.6	C19-C24-H24A	109.6
C23-C24-H24B	109.6	C19-C24-H24B	109.6
H24A-C24-H24B	108.1	C25-O2-C28	111.9(9)
O2-C25-C29	120.2(14)	O2-C25-C26	108.8(9)
C29-C25-C26	109.1(13)	O2-C25-H25	106.0
C29-C25-H25	106.0	C26-C25-H25	106.0
C25-C26-C27	103.4(8)	C25-C26-H26B	111.1
C27-C26-H26B	111.1	C25-C26-H26A	111.1
C27-C26-H26A	111.1	H26B-C26-H26A	109.1
C28-C27-C26	103.3(9)	C28-C27-H27A	111.1
C26-C27-H27A	111.1	C28-C27-H27B	111.1
C26-C27-H27B	111.1	H27A-C27-H27B	109.1
O2-C28-C27	107.7(9)	O2-C28-H28A	110.2

C27-C28-H28A	110.2	O2-C28-H28B	110.2
C27-C28-H28B	110.2	H28A-C28-H28B	108.5
C25-C29-H29A	109.5	C25-C29-H29B	109.5
H29A-C29-H29B	109.5	C25-C29-H29C	109.5
H29A-C29-H29C	109.5	H29B-C29-H29C	109.5

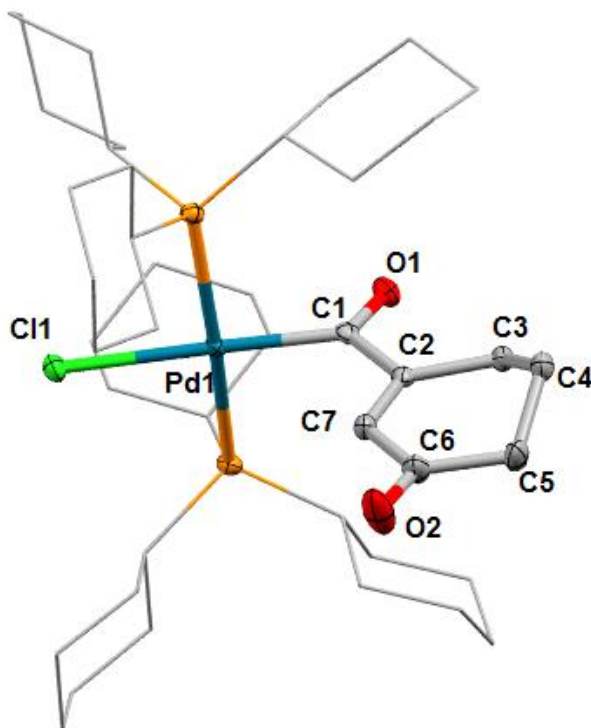


Figure S160. Thermal ellipsoid plot of one of the independent molecules of **12**. Ellipsoids shown at 50% probability. Cyclohexyl rings shown in wireframe, hydrogen atoms and solvent (toluene) hidden for clarity.

A clear intense orange-red block-like specimen of $C_{46.50}H_{77}ClO_2Pd$, approximate dimensions 0.105 mm x 0.144 mm x 0.166 mm, was used for the X-ray crystallographic analysis. The X-ray intensity data were measured.

The total exposure time was 6.62 hours. The frames were integrated with the Bruker SAINT software package using a narrow-frame algorithm. The integration of the data using a triclinic unit cell yielded a total of 79981 reflections to a maximum θ angle of 27.91° ($0.76 \text{ \AA}$ resolution), of which 21196 were independent (average redundancy 3.773, completeness = 99.1%, $R_{\text{int}} = 3.00\%$, $R_{\text{sig}} = 3.03\%$) and 17967 (84.77%) were greater than $2\sigma(F^2)$. The final cell constants of $a = 10.5534(6) \text{ \AA}$, $b = 19.8212(10) \text{ \AA}$, $c = 23.5445(13) \text{ \AA}$, $\alpha = 70.2280(10)^\circ$, $\beta = 82.9580(10)^\circ$, $\gamma = 75.0460(10)^\circ$, volume = $4474.4(4) \text{ \AA}^3$, are based upon the refinement of the XYZ-centroids of 9307 reflections above $20 \sigma(I)$ with $5.018^\circ < 2\theta < 55.82^\circ$. Data were corrected for absorption effects using the Multi-Scan method (SADABS). The ratio of minimum to maximum apparent transmission was 0.947. The calculated minimum and maximum transmission coefficients (based on crystal size) are 0.7063 and 0.7456.

The structure was solved and refined using the Bruker SHELXTL Software Package, using the space group $P-1$, with $Z = 4$ for the formula unit, $C_{46.50}H_{77}ClO_2Pd$. The final anisotropic full-matrix least-squares refinement on F^2 with 947 variables converged at $R1 = 3.11\%$, for the observed data and $wR2 = 7.44\%$ for all data. The goodness-of-fit was 1.024. The largest peak in the final difference electron density synthesis was $1.311 \text{ e}/\text{\AA}^3$ and the largest hole was $-0.486 \text{ e}/\text{\AA}^3$ with an RMS deviation of $0.068 \text{ e}/\text{\AA}^3$. On the basis of the final model, the calculated density was $1.294 \text{ g}/\text{cm}^3$ and $F(000)$, 1860 e^- .

Table S8. Sample and crystal data for 12.

Identification code	12	
Chemical formula	C _{46.50} H ₇₇ ClO ₂ P ₂ Pd	
Formula weight	871.87 g/mol	
Wavelength	0.71073 Å	
Crystal size	0.105 x 0.144 x 0.166 mm	
Crystal habit	clear intense orange-red block	
Crystal system	triclinic	
Space group	P -1	
Unit cell dimensions	a = 10.5534(6) Å	$\alpha = 70.2280(10)^\circ$
	b = 19.8212(10) Å	$\beta = 82.9580(10)^\circ$
	c = 23.5445(13) Å	$\gamma = 75.0460(10)^\circ$
Volume	4474.4(4) Å ³	
Z	4	
Density (calculated)	1.294 g/cm ³	
Absorption coefficient	0.582 mm ⁻¹	
F(000)	1860	

Table S9. Data collection and structure refinement for 12.

Theta range for data collection	1.12 to 27.91°	
Index ranges	-13 ≤ h ≤ 13, -26 ≤ k ≤ 15, -30 ≤ l ≤ 28	
Reflections collected	79981	
Independent reflections	21196 [R(int) = 0.0300]	
Coverage of independent reflections	99.1%	
Absorption correction	Multi-Scan	
Max. and min. transmission	0.7456 and 0.7063	
Structure solution technique	direct methods	
Structure solution program	XT, VERSION 2014/5	
Refinement method	Full-matrix least-squares on F ²	
Refinement program	XL (Sheldrick, 2008)	
Function minimized	$\sum w(F_o^2 - F_c^2)^2$	
Data / restraints / parameters	21196 / 0 / 947	
Goodness-of-fit on F ²	1.024	
$\Delta/\sigma_{\max}$	0.004	
Final R indices	17967 data; $I > 2\sigma(I)$	R1 = 0.0311, wR2 = 0.0707
	all data	R1 = 0.0406, wR2 = 0.0744
Weighting scheme	$w = 1/[\sigma^2(F_o^2) + (0.0310P)^2 + 3.7616P]$ where $P = (F_o^2 + 2F_c^2)/3$	
Largest diff. peak and hole	1.311 and -0.486 eÅ ⁻³	
R.M.S. deviation from mean	0.068 eÅ ⁻³	

Table S10. Bond lengths (Å) for 12.

Pd1-Cl1	2.4302(5)	Pd1-P1	2.3812(5)
Pd1-P2	2.3581(5)	Pd1-C1	1.9827(18)
Pd2-P3	2.3693(5)	Pd2-Cl2	2.4243(5)
Pd2-P4	2.3532(5)	Pd2-C44	1.9752(18)
P1-C20	1.8551(19)	P1-C8	1.8531(19)
P1-C15	1.865(2)	P2-C26	1.8462(19)
P2-C38	1.8605(19)	P2-C32	1.859(2)
P3-C57	1.8423(19)	P3-C63	1.863(2)
P3-C51	1.869(2)	P4-C69	1.847(2)
P4-C81	1.858(2)	P4-C75	1.8629(19)
O1-C1	1.212(2)	O3-C44	1.214(2)
O4-C49	1.216(3)	O2-C6	1.219(3)
C1-C2	1.526(3)	C2-C3	1.508(2)
C2-C7	1.335(3)	C3-H3A	0.99
C3-H3B	0.99	C3-C4	1.522(3)
C44-C45	1.520(3)	C27-H27A	0.99
C27-H27B	0.99	C27-C26	1.536(3)
C27-C28	1.532(3)	C20-H20	1.0
C20-C25	1.536(3)	C20-C21	1.530(3)
C50-H50	0.95	C50-C45	1.336(3)
C50-C49	1.474(3)	C8-H8	1.0
C8-C9	1.536(3)	C8-C13	1.541(3)
C57-H57	1.0	C57-C62	1.534(3)
C57-C58	1.539(3)	C7-H7	0.95
C7-C6	1.474(3)	C62-H62A	0.99
C62-H62B	0.99	C62-C61	1.529(3)
C15-H15	1.0	C15-C16	1.530(3)
C15-C14	1.532(3)	C16-H16A	0.99
C16-H16B	0.99	C16-C17	1.524(3)
C58-H58A	0.99	C58-H58B	0.99
C58-C59	1.525(3)	C26-H26	1.0
C26-C31	1.536(3)	C4-H4A	0.99
C4-H4B	0.99	C4-C5	1.525(3)
C38-H38	1.0	C38-C39	1.537(3)
C38-C43	1.540(3)	C33-H33A	0.99
C33-H33B	0.99	C33-C32	1.543(3)
C33-C34	1.531(3)	C45-C46	1.507(3)
C46-H46A	0.99	C46-H46B	0.99
C46-C47	1.520(3)	C9-H9A	0.99
C9-H9B	0.99	C9-C10	1.526(3)
C25-H25A	0.99	C25-H25B	0.99
C25-C24	1.530(3)	C70-H70A	0.99
C70-H70B	0.99	C70-C69	1.538(3)

C70-C71	1.528(3)	C69-H69	1.0
C69-C74	1.531(3)	C80-H80A	0.99
C80-H80B	0.99	C80-C75	1.533(3)
C80-C79	1.530(3)	C31-H31A	0.99
C31-H31B	0.99	C31-C30	1.529(3)
C61-H61A	0.99	C61-H61B	0.99
C61-C60	1.523(3)	C81-H81	1.0
C81-C82	1.540(3)	C81-C86	1.539(3)
C56-H56A	0.99	C56-H56B	0.99
C56-C51	1.540(3)	C56-C55	1.555(3)
C17-H17A	0.99	C17-H17B	0.99
C17-C18	1.515(3)	C28-H28A	0.99
C28-H28B	0.99	C28-C29	1.522(3)
C30-H30A	0.99	C30-H30B	0.99
C30-C29	1.526(3)	C76-H76A	0.99
C76-H76B	0.99	C76-C75	1.536(3)
C76-C77	1.530(3)	C13-H13A	0.99
C13-H13B	0.99	C13-C12	1.535(3)
C10-H10A	0.99	C10-H10B	0.99
C10-C11	1.519(3)	C21-H21A	0.99
C21-H21B	0.99	C21-C22	1.534(3)
C32-H32	1.0	C32-C37	1.535(3)
C39-H39A	0.99	C39-H39B	0.99
C39-C40	1.532(3)	C43-H43A	0.99
C43-H43B	0.99	C43-C42	1.532(3)
C75-H75	1.0	C59-H59A	0.99
C59-H59B	0.99	C59-C60	1.529(3)
C34-H34A	0.99	C34-H34B	0.99
C34-C35	1.523(3)	C63-H63	1.0
C63-C68	1.508(3)	C63-C64	1.533(3)
C29-H29A	0.99	C29-H29B	0.99
C37-H37A	0.99	C37-H37B	0.99
C37-C36	1.529(3)	C24-H24A	0.99
C24-H24B	0.99	C24-C23	1.525(3)
C12-H12A	0.99	C12-H12B	0.99
C12-C11	1.524(3)	C5-H5A	0.99
C5-H5B	0.99	C5-C6	1.508(3)
C23-H23A	0.99	C23-H23B	0.99
C23-C22	1.517(3)	C22-H22A	0.99
C22-H22B	0.99	C74-H74A	0.99
C74-H74B	0.99	C74-C73	1.527(3)
C49-C48	1.508(3)	C82-H82A	0.99
C82-H82B	0.99	C82-C83	1.527(3)
C60-H60A	0.99	C60-H60B	0.99

C18-H18A	0.99	C18-H18B	0.99
C18-C19	1.519(3)	C51-H51	1.0
C51-C52	1.516(3)	C14-H14A	0.99
C14-H14B	0.99	C14-C19	1.538(3)
C11-H11A	0.99	C11-H11B	0.99
C42-H42A	0.99	C42-H42B	0.99
C42-C41	1.526(3)	C90-H90	0.95
C90-C91	1.376(4)	C90-C89	1.373(4)
C85-H85A	0.99	C85-H85B	0.99
C85-C86	1.531(3)	C85-C84	1.520(3)
C86-H86A	0.99	C86-H86B	0.99
C35-H35A	0.99	C35-H35B	0.99
C35-C36	1.518(3)	C41-H41A	0.99
C41-H41B	0.99	C41-C40	1.518(4)
C47-H47A	0.99	C47-H47B	0.99
C47-C48	1.523(3)	C52-H52A	0.99
C52-H52B	0.99	C52-C53	1.539(3)
C84-H84A	0.99	C84-H84B	0.99
C84-C83	1.527(3)	C77-H77A	0.99
C77-H77B	0.99	C77-C78	1.523(4)
C71-H71A	0.99	C71-H71B	0.99
C71-C72	1.521(4)	C36-H36A	0.99
C36-H36B	0.99	C79-H79A	0.99
C79-H79B	0.99	C79-C78	1.527(3)
C40-H40A	0.99	C40-H40B	0.99
C91-H91	0.95	C91-C92	1.389(3)
C83-H83A	0.99	C83-H83B	0.99
C68-H68A	0.99	C68-H68B	0.99
C68-C67	1.543(3)	C48-H48A	0.99
C48-H48B	0.99	C78-H78A	0.99
C78-H78B	0.99	C53-H53A	0.99
C53-H53B	0.99	C53-C54	1.517(4)
C73-H73A	0.99	C73-H73B	0.99
C73-C72	1.530(4)	C88-H88	0.95
C88-C87	1.388(4)	C88-C89	1.377(4)
C87-H87	0.95	C87-C92	1.388(4)
C19-H19A	0.99	C19-H19B	0.99
C55-H55A	0.99	C55-H55B	0.99
C55-C54	1.498(4)	C89-H89	0.95
C92-C93	1.510(4)	C66-H66A	0.99
C66-H66B	0.99	C66-C67	1.528(4)
C66-C65	1.476(4)	C54-H54A	0.99
C54-H54B	0.99	C67-H67A	0.99
C67-H67B	0.99	C64-H64A	0.99

C64-H64B	0.99	C64-C65	1.536(3)
C65-H65A	0.99	C65-H65B	0.99
C72-H72A	0.99	C72-H72B	0.99
C93-H93A	0.98	C93-H93B	0.98
C93-H93C	0.98		

Table S11. Bond angles (°) for 12.

P1-Pd1-Cl1	86.050(16)	P2-Pd1-Cl1	92.008(16)
P2-Pd1-P1	169.846(18)	C1-Pd1-Cl1	178.02(6)
C1-Pd1-P1	94.26(5)	C1-Pd1-P2	88.03(5)
P3-Pd2-Cl2	87.825(17)	P4-Pd2-P3	171.247(18)
P4-Pd2-Cl2	89.878(18)	C44-Pd2-P3	91.59(6)
C44-Pd2-Cl2	177.64(6)	C44-Pd2-P4	90.36(6)
C20-P1-Pd1	106.15(6)	C20-P1-C15	102.11(9)
C8-P1-Pd1	122.80(6)	C8-P1-C20	106.17(9)
C8-P1-C15	106.81(9)	C15-P1-Pd1	110.81(6)
C26-P2-Pd1	114.21(6)	C26-P2-C38	109.05(9)
C26-P2-C32	103.89(9)	C38-P2-Pd1	116.30(6)
C32-P2-Pd1	107.35(6)	C32-P2-C38	104.84(9)
C57-P3-Pd2	104.81(6)	C57-P3-C63	105.48(9)
C57-P3-C51	105.48(9)	C63-P3-Pd2	113.19(7)
C63-P3-C51	100.04(10)	C51-P3-Pd2	126.14(8)
C69-P4-Pd2	112.40(7)	C69-P4-C81	104.16(9)
C69-P4-C75	109.40(9)	C81-P4-Pd2	108.95(7)
C81-P4-C75	104.28(9)	C75-P4-Pd2	116.60(7)
O1-C1-Pd1	124.17(15)	O1-C1-C2	117.59(16)
C2-C1-Pd1	118.24(13)	C3-C2-C1	116.88(16)
C7-C2-C1	121.08(16)	C7-C2-C3	122.01(17)
C2-C3-H3A	109.4	C2-C3-H3B	109.4
C2-C3-C4	111.08(16)	H3A-C3-H3B	108.0
C4-C3-H3A	109.4	C4-C3-H3B	109.4
O3-C44-Pd2	121.65(14)	O3-C44-C45	117.52(16)
C45-C44-Pd2	120.83(13)	H27A-C27-H27B	108.0
C26-C27-H27A	109.4	C26-C27-H27B	109.4
C28-C27-H27A	109.4	C28-C27-H27B	109.4
C28-C27-C26	111.19(16)	P1-C20-H20	105.1
C25-C20-P1	113.40(13)	C25-C20-H20	105.1
C21-C20-P1	117.15(14)	C21-C20-H20	105.1
C21-C20-C25	109.88(16)	C45-C50-H50	118.8
C45-C50-C49	122.42(17)	C49-C50-H50	118.8
P1-C8-H8	107.5	C9-C8-P1	111.01(13)
C9-C8-H8	107.5	C9-C8-C13	111.50(16)
C13-C8-P1	111.51(13)	C13-C8-H8	107.5

P3-C57-H57	104.8	C62-C57-P3	117.29(13)
C62-C57-H57	104.8	C62-C57-C58	109.78(16)
C58-C57-P3	113.99(13)	C58-C57-H57	104.8
C2-C7-H7	118.6	C2-C7-C6	122.79(17)
C6-C7-H7	118.6	C57-C62-H62A	109.9
C57-C62-H62B	109.9	H62A-C62-H62B	108.3
C61-C62-C57	109.11(16)	C61-C62-H62A	109.9
C61-C62-H62B	109.9	P1-C15-H15	105.1
C16-C15-P1	117.30(14)	C16-C15-H15	105.1
C16-C15-C14	109.92(17)	C14-C15-P1	113.12(14)
C14-C15-H15	105.1	C15-C16-H16A	109.3
C15-C16-H16B	109.3	H16A-C16-H16B	108.0
C17-C16-C15	111.65(17)	C17-C16-H16A	109.3
C17-C16-H16B	109.3	C57-C58-H58A	109.8
C57-C58-H58B	109.8	H58A-C58-H58B	108.3
C59-C58-C57	109.33(16)	C59-C58-H58A	109.8
C59-C58-H58B	109.8	P2-C26-H26	105.3
C27-C26-P2	115.13(13)	C27-C26-H26	105.3
C27-C26-C31	111.00(16)	C31-C26-P2	113.75(13)
C31-C26-H26	105.3	C3-C4-H4A	109.5
C3-C4-H4B	109.5	C3-C4-C5	110.85(17)
H4A-C4-H4B	108.1	C5-C4-H4A	109.5
C5-C4-H4B	109.5	P2-C38-H38	105.0
C39-C38-P2	118.52(14)	C39-C38-H38	105.0
C39-C38-C43	109.34(16)	C43-C38-P2	112.82(13)
C43-C38-H38	105.0	H33A-C33-H33B	107.9
C32-C33-H33A	109.2	C32-C33-H33B	109.2
C34-C33-H33A	109.2	C34-C33-H33B	109.2
C34-C33-C32	111.95(17)	C50-C45-C44	121.27(17)
C50-C45-C46	121.90(17)	C46-C45-C44	116.82(16)
C45-C46-H46A	109.2	C45-C46-H46B	109.2
C45-C46-C47	111.84(17)	H46A-C46-H46B	107.9
C47-C46-H46A	109.2	C47-C46-H46B	109.2
C8-C9-H9A	109.1	C8-C9-H9B	109.1
H9A-C9-H9B	107.8	C10-C9-C8	112.49(17)
C10-C9-H9A	109.1	C10-C9-H9B	109.1
C20-C25-H25A	109.7	C20-C25-H25B	109.7
H25A-C25-H25B	108.2	C24-C25-C20	109.99(17)
C24-C25-H25A	109.7	C24-C25-H25B	109.7
H70A-C70-H70B	108.1	C69-C70-H70A	109.6
C69-C70-H70B	109.6	C71-C70-H70A	109.6
C71-C70-H70B	109.6	C71-C70-C69	110.34(17)
P4-C69-H69	104.9	C70-C69-P4	113.81(14)
C70-C69-H69	104.9	C74-C69-P4	116.27(14)

C74-C69-C70	110.82(17)	C74-C69-H69	104.9
H80A-C80-H80B	108.0	C75-C80-H80A	109.4
C75-C80-H80B	109.4	C79-C80-H80A	109.4
C79-C80-H80B	109.4	C79-C80-C75	111.17(18)
C26-C31-H31A	109.7	C26-C31-H31B	109.7
H31A-C31-H31B	108.2	C30-C31-C26	110.05(16)
C30-C31-H31A	109.7	C30-C31-H31B	109.7
C62-C61-H61A	109.3	C62-C61-H61B	109.3
H61A-C61-H61B	107.9	C60-C61-C62	111.78(17)
C60-C61-H61A	109.3	C60-C61-H61B	109.3
P4-C81-H81	107.8	C82-C81-P4	110.58(14)
C82-C81-H81	107.8	C86-C81-P4	112.53(14)
C86-C81-H81	107.8	C86-C81-C82	110.02(17)
H56A-C56-H56B	108.2	C51-C56-H56A	109.7
C51-C56-H56B	109.7	C51-C56-C55	109.92(19)
C55-C56-H56A	109.7	C55-C56-H56B	109.7
C16-C17-H17A	109.3	C16-C17-H17B	109.3
H17A-C17-H17B	108.0	C18-C17-C16	111.51(18)
C18-C17-H17A	109.3	C18-C17-H17B	109.3
C27-C28-H28A	109.3	C27-C28-H28B	109.3
H28A-C28-H28B	108.0	C29-C28-C27	111.61(17)
C29-C28-H28A	109.3	C29-C28-H28B	109.3
C31-C30-H30A	109.4	C31-C30-H30B	109.4
H30A-C30-H30B	108.0	C29-C30-C31	111.34(17)
C29-C30-H30A	109.4	C29-C30-H30B	109.4
H76A-C76-H76B	108.2	C75-C76-H76A	109.6
C75-C76-H76B	109.6	C77-C76-H76A	109.6
C77-C76-H76B	109.6	C77-C76-C75	110.09(18)
C8-C13-H13A	109.2	C8-C13-H13B	109.2
H13A-C13-H13B	107.9	C12-C13-C8	112.10(17)
C12-C13-H13A	109.2	C12-C13-H13B	109.2
C9-C10-H10A	109.5	C9-C10-H10B	109.5
H10A-C10-H10B	108.1	C11-C10-C9	110.84(17)
C11-C10-H10A	109.5	C11-C10-H10B	109.5
C20-C21-H21A	109.7	C20-C21-H21B	109.7
C20-C21-C22	109.92(18)	H21A-C21-H21B	108.2
C22-C21-H21A	109.7	C22-C21-H21B	109.7
P2-C32-H32	107.9	C33-C32-P2	111.79(13)
C33-C32-H32	107.9	C37-C32-P2	110.36(13)
C37-C32-C33	110.69(16)	C37-C32-H32	107.9
C38-C39-H39A	109.9	C38-C39-H39B	109.9
H39A-C39-H39B	108.3	C40-C39-C38	109.13(18)
C40-C39-H39A	109.9	C40-C39-H39B	109.9
C38-C43-H43A	109.5	C38-C43-H43B	109.5

H43A-C43-H43B	108.1	C42-C43-C38	110.66(18)
C42-C43-H43A	109.5	C42-C43-H43B	109.5
P4-C75-H75	105.6	C80-C75-P4	111.51(13)
C80-C75-C76	109.64(17)	C80-C75-H75	105.6
C76-C75-P4	117.97(14)	C76-C75-H75	105.6
C58-C59-H59A	109.3	C58-C59-H59B	109.3
C58-C59-C60	111.81(17)	H59A-C59-H59B	107.9
C60-C59-H59A	109.3	C60-C59-H59B	109.3
C33-C34-H34A	109.2	C33-C34-H34B	109.2
H34A-C34-H34B	107.9	C35-C34-C33	111.90(17)
C35-C34-H34A	109.2	C35-C34-H34B	109.2
P3-C63-H63	106.1	C68-C63-P3	117.66(16)
C68-C63-H63	106.1	C68-C63-C64	109.84(19)
C64-C63-P3	110.18(14)	C64-C63-H63	106.1
C28-C29-C30	111.19(17)	C28-C29-H29A	109.4
C28-C29-H29B	109.4	C30-C29-H29A	109.4
C30-C29-H29B	109.4	H29A-C29-H29B	108.0
C32-C37-H37A	109.3	C32-C37-H37B	109.3
H37A-C37-H37B	108.0	C36-C37-C32	111.54(17)
C36-C37-H37A	109.3	C36-C37-H37B	109.3
C25-C24-H24A	109.3	C25-C24-H24B	109.3
H24A-C24-H24B	108.0	C23-C24-C25	111.64(18)
C23-C24-H24A	109.3	C23-C24-H24B	109.3
C13-C12-H12A	109.3	C13-C12-H12B	109.3
H12A-C12-H12B	107.9	C11-C12-C13	111.72(17)
C11-C12-H12A	109.3	C11-C12-H12B	109.3
C4-C5-H5A	109.2	C4-C5-H5B	109.2
H5A-C5-H5B	107.9	C6-C5-C4	111.97(16)
C6-C5-H5A	109.2	C6-C5-H5B	109.2
C24-C23-H23A	109.5	C24-C23-H23B	109.5
H23A-C23-H23B	108.1	C22-C23-C24	110.69(18)
C22-C23-H23A	109.5	C22-C23-H23B	109.5
C21-C22-H22A	109.1	C21-C22-H22B	109.1
C23-C22-C21	112.46(17)	C23-C22-H22A	109.1
C23-C22-H22B	109.1	H22A-C22-H22B	107.8
C69-C74-H74A	109.5	C69-C74-H74B	109.5
H74A-C74-H74B	108.1	C73-C74-C69	110.69(18)
C73-C74-H74A	109.5	C73-C74-H74B	109.5
O4-C49-C50	121.06(18)	O4-C49-C48	121.74(19)
C50-C49-C48	117.17(18)	C81-C82-H82A	109.4
C81-C82-H82B	109.4	H82A-C82-H82B	108.0
C83-C82-C81	111.27(18)	C83-C82-H82A	109.4
C83-C82-H82B	109.4	C61-C60-C59	111.42(17)
C61-C60-H60A	109.3	C61-C60-H60B	109.3

C59-C60-H60A	109.3	C59-C60-H60B	109.3
H60A-C60-H60B	108.0	C17-C18-H18A	109.5
C17-C18-H18B	109.5	C17-C18-C19	110.9(2)
H18A-C18-H18B	108.0	C19-C18-H18A	109.5
C19-C18-H18B	109.5	P3-C51-H51	106.1
C56-C51-P3	112.91(15)	C56-C51-H51	106.1
C52-C51-P3	113.27(15)	C52-C51-C56	111.75(18)
C52-C51-H51	106.1	C15-C14-H14A	109.5
C15-C14-H14B	109.5	C15-C14-C19	110.61(18)
H14A-C14-H14B	108.1	C19-C14-H14A	109.5
C19-C14-H14B	109.5	C10-C11-C12	109.98(18)
C10-C11-H11A	109.7	C10-C11-H11B	109.7
C12-C11-H11A	109.7	C12-C11-H11B	109.7
H11A-C11-H11B	108.2	C43-C42-H42A	109.5
C43-C42-H42B	109.5	H42A-C42-H42B	108.1
C41-C42-C43	110.87(18)	C41-C42-H42A	109.5
C41-C42-H42B	109.5	C91-C90-H90	119.6
C89-C90-H90	119.6	C89-C90-C91	120.7(3)
H85A-C85-H85B	108.0	C86-C85-H85A	109.3
C86-C85-H85B	109.3	C84-C85-H85A	109.3
C84-C85-H85B	109.3	C84-C85-C86	111.61(18)
C81-C86-H86A	109.4	C81-C86-H86B	109.4
C85-C86-C81	111.39(18)	C85-C86-H86A	109.4
C85-C86-H86B	109.4	H86A-C86-H86B	108.0
C34-C35-H35A	109.7	C34-C35-H35B	109.7
H35A-C35-H35B	108.2	C36-C35-C34	110.01(18)
C36-C35-H35A	109.7	C36-C35-H35B	109.7
O2-C6-C7	120.77(18)	O2-C6-C5	122.52(19)
C7-C6-C5	116.70(18)	C42-C41-H41A	109.3
C42-C41-H41B	109.3	H41A-C41-H41B	108.0
C40-C41-C42	111.60(18)	C40-C41-H41A	109.3
C40-C41-H41B	109.3	C46-C47-H47A	109.4
C46-C47-H47B	109.4	C46-C47-C48	110.96(19)
H47A-C47-H47B	108.0	C48-C47-H47A	109.4
C48-C47-H47B	109.4	C51-C52-H52A	109.4
C51-C52-H52B	109.4	C51-C52-C53	111.3(2)
H52A-C52-H52B	108.0	C53-C52-H52A	109.4
C53-C52-H52B	109.4	C85-C84-H84A	109.5
C85-C84-H84B	109.5	C85-C84-C83	110.8(2)
H84A-C84-H84B	108.1	C83-C84-H84A	109.5
C83-C84-H84B	109.5	C76-C77-H77A	109.2
C76-C77-H77B	109.2	H77A-C77-H77B	107.9
C78-C77-C76	112.2(2)	C78-C77-H77A	109.2
C78-C77-H77B	109.2	C70-C71-H71A	109.4

C70-C71-H71B	109.4	H71A-C71-H71B	108.0
C72-C71-C70	111.1(2)	C72-C71-H71A	109.4
C72-C71-H71B	109.4	C37-C36-H36A	109.4
C37-C36-H36B	109.4	C35-C36-C37	111.12(17)
C35-C36-H36A	109.4	C35-C36-H36B	109.4
H36A-C36-H36B	108.0	C80-C79-H79A	109.6
C80-C79-H79B	109.6	H79A-C79-H79B	108.1
C78-C79-C80	110.13(18)	C78-C79-H79A	109.6
C78-C79-H79B	109.6	C39-C40-H40A	109.1
C39-C40-H40B	109.1	C41-C40-C39	112.47(19)
C41-C40-H40A	109.1	C41-C40-H40B	109.1
H40A-C40-H40B	107.8	C90-C91-H91	119.4
C90-C91-C92	121.2(2)	C92-C91-H91	119.4
C82-C83-H83A	109.4	C82-C83-H83B	109.4
C84-C83-C82	111.15(19)	C84-C83-H83A	109.4
C84-C83-H83B	109.4	H83A-C83-H83B	108.0
C63-C68-H68A	109.7	C63-C68-H68B	109.7
C63-C68-C67	110.0(2)	H68A-C68-H68B	108.2
C67-C68-H68A	109.7	C67-C68-H68B	109.7
C49-C48-C47	111.77(18)	C49-C48-H48A	109.3
C49-C48-H48B	109.3	C47-C48-H48A	109.3
C47-C48-H48B	109.3	H48A-C48-H48B	107.9
C77-C78-C79	111.32(19)	C77-C78-H78A	109.4
C77-C78-H78B	109.4	C79-C78-H78A	109.4
C79-C78-H78B	109.4	H78A-C78-H78B	108.0
C52-C53-H53A	109.3	C52-C53-H53B	109.3
H53A-C53-H53B	108.0	C54-C53-C52	111.5(2)
C54-C53-H53A	109.3	C54-C53-H53B	109.3
C74-C73-H73A	109.4	C74-C73-H73B	109.4
C74-C73-C72	111.05(19)	H73A-C73-H73B	108.0
C72-C73-H73A	109.4	C72-C73-H73B	109.4
C87-C88-H88	119.8	C89-C88-H88	119.8
C89-C88-C87	120.5(3)	C88-C87-H87	119.6
C88-C87-C92	120.9(3)	C92-C87-H87	119.6
C18-C19-C14	112.4(2)	C18-C19-H19A	109.1
C18-C19-H19B	109.1	C14-C19-H19A	109.1
C14-C19-H19B	109.1	H19A-C19-H19B	107.9
C56-C55-H55A	109.2	C56-C55-H55B	109.2
H55A-C55-H55B	107.9	C54-C55-C56	112.2(2)
C54-C55-H55A	109.2	C54-C55-H55B	109.2
C90-C89-C88	119.0(3)	C90-C89-H89	120.5
C88-C89-H89	120.5	C91-C92-C93	121.0(2)
C87-C92-C91	117.6(3)	C87-C92-C93	121.3(3)
H66A-C66-H66B	108.0	C67-C66-H66A	109.5

C67-C66-H66B	109.5	C65-C66-H66A	109.5
C65-C66-H66B	109.5	C65-C66-C67	110.9(2)
C53-C54-H54A	109.6	C53-C54-H54B	109.6
C55-C54-C53	110.5(2)	C55-C54-H54A	109.6
C55-C54-H54B	109.6	H54A-C54-H54B	108.1
C68-C67-H67A	109.6	C68-C67-H67B	109.6
C66-C67-C68	110.4(2)	C66-C67-H67A	109.6
C66-C67-H67B	109.6	H67A-C67-H67B	108.1
C63-C64-H64A	109.4	C63-C64-H64B	109.4
C63-C64-C65	111.13(18)	H64A-C64-H64B	108.0
C65-C64-H64A	109.4	C65-C64-H64B	109.4
C66-C65-C64	111.3(2)	C66-C65-H65A	109.4
C66-C65-H65B	109.4	C64-C65-H65A	109.4
C64-C65-H65B	109.4	H65A-C65-H65B	108.0
C71-C72-C73	111.3(2)	C71-C72-H72A	109.4
C71-C72-H72B	109.4	C73-C72-H72A	109.4
C73-C72-H72B	109.4	H72A-C72-H72B	108.0
C92-C93-H93A	109.5	C92-C93-H93B	109.5
C92-C93-H93C	109.5	H93A-C93-H93B	109.5
H93A-C93-H93C	109.5	H93B-C93-H93C	109.5

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