

# Facile synthesis of amides via acceptorless dehydrogenative coupling of aryl epoxides and amines

Yaoyu Liang, Jie Luo, David Milstein\*

*Department of Molecular Chemistry and Materials Science, Weizmann Institute of Science,  
Rehovot, 76100, Israel*

*E-mail: david.milstein@weizmann.ac.il*

## Table of Contents

1. General considerations .....	1
2. Conditions evaluation.....	2
3. General procedures for amidation reaction and characterization data of amides ..	3
4. Mechanistic studies .....	11
5. References .....	26
6. NMR spectra of amides.....	28

## 1. General considerations

All the catalytic experiments were carried out under an atmosphere of purified nitrogen in a Vacuum Atmosphere glovebox equipped with a MO 40-2 inert gas purifier or using standard Schlenk techniques. Toluene, benzene, dioxane, and tetrahydrofuran (THF) were refluxed over sodium/benzophenone, distilled under argon or nitrogen atmosphere, and stored over activated 3Å molecular sieves (MS). Other solvents were used after degassing with nitrogen. Deuterated benzene was degassed with nitrogen and stored in the glovebox over 3Å MS. NMR spectra were recorded on Bruker AVANCE III (300 MHz) or AVANCE III HD (500 MHz) spectrometers and are reported in ppm ( $\delta$ ).  $^1\text{H}$  NMR spectra are referred to the TMS signal ( $\delta = 0$  ppm) or  $\text{CHCl}_3$  ( $\delta = 7.26$  ppm), and  $^{13}\text{C}$  NMR spectra are referred to the residual solvent signal ( $\delta = 77.16$  ppm).  $^{31}\text{P}\{^1\text{H}\}$  NMR chemical shifts are referenced with respect to an external solution of 85% phosphoric acid in  $\text{D}_2\text{O}$ . NMR spectroscopy abbreviations: s, singlet; d, doublet; t, triplet; q, quartet; m, multiplet. GC-MS analyses were carried out on HP 6890/5973 (MS detector) instruments equipped with a 30 m column (Restek 5MS, 0.32 mm internal diameter) with a 5% phenylmethylsilicone coating (0.25 mm) with He as carrier gas.

Analytical TLC was performed on Merck silica gel 60 F254 plates and visualized under 254 nm UV light. Column chromatography was performed on 200-300 mesh silica gel. Complexes **Ru-1**,<sup>1</sup> **Ru-2**,<sup>2</sup> **Ru-3**,<sup>3</sup> **Ru-4**,<sup>3</sup> **Mn-1**,<sup>4</sup> and **Co-1**<sup>5</sup> were prepared according to the literature procedures. Epoxide **1a** and **1f** were commercially available and used after purifying by flash silica gel column chromatography, and other epoxides were prepared according to the literature procedures.<sup>6,7</sup> All the amines were commercially available and used after degassing with nitrogen and stored in the glovebox over 3Å MS.

## 2. Conditions evaluation

**Table S1. Conditions evaluation for amidation of epoxide **1a** and amine **2a**<sup>a</sup>**

Reaction scheme: Epoxide **1a** (Ph-epoxide) + Amine **2a** (*n*Pr<sub>2</sub>NH)  $\xrightarrow[\text{solvent, temp, time}]{\text{cat. (1 mol\%), } ^t\text{BuOK (1.2 mol\%)}}$  Product **3a** (Ph-CH<sub>2</sub>-C(=O)-N(*n*Pr)<sub>2</sub>) + H<sub>2</sub> or Product **3a'** (Ph-CH(OH)-CH<sub>2</sub>-N(*n*Pr)<sub>2</sub>)

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**Ru-1**

**Ru-2**

**Ru-3**

**Ru-4**

**Mn-1**

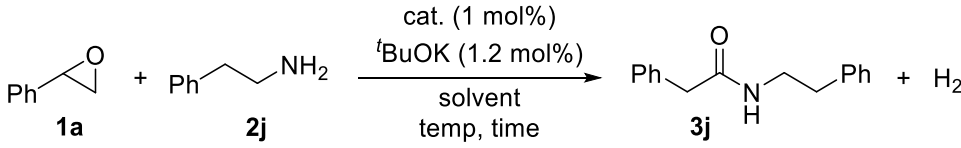
**Co-1**

entry	cat.	solvent	temp (°C)	time (h)	yield (%) <sup>b</sup> <b>3a/3a'</b>
1	<b>Ru-1</b>	toluene	120	12	nd/3
2	<b>Ru-2</b>	toluene	120	12	nd/6
3	<b>Ru-3</b>	toluene	120	12	42/3
4	<b>Ru-4</b>	toluene	120	12	30/5
5	<b>Mn-1</b>	toluene	120	12	nd/86
6 <sup>c</sup>	<b>Co-1</b>	toluene	120	12	nd/72
7	<b>Ru-3</b>	toluene	135	12	61/4
8	<b>Ru-3</b>	toluene	150	12	91/4
9 <sup>d</sup>	<b>Ru-3</b>	toluene	150	12	nd/96
10 <sup>e</sup>	<b>Ru-3</b>	toluene	150	12	nd/77
11	<b>Ru-3</b>	xylene	150	12	81/4
12	<b>Ru-3</b>	PhCl	150	12	12/15
13	<b>Ru-3</b>	benzene	150	12	52/11
14	<b>Ru-3</b>	dioxane	150	12	83/8
15	<b>Ru-3</b>	DMF	150	12	nd/12
16 <sup>f</sup>	<b>Ru-3</b>	toluene	150	12	nd/3
17	<b>Ru-3</b>	toluene	150	24	91/4
18	<b>Ru-3</b>	toluene	150	36	91/4

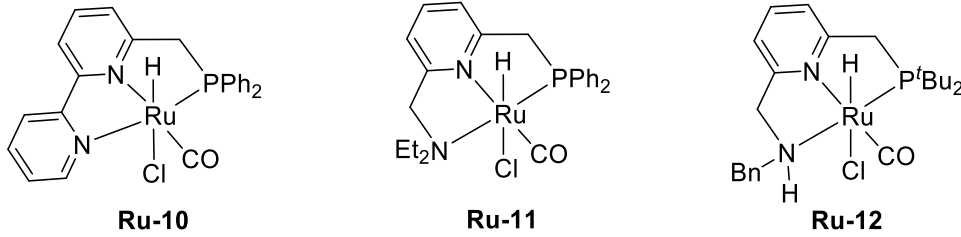
<sup>a</sup>Conditions: **1a** (0.5 mmol), **2a** (0.5 mmol), cat. (1 mol%), <sup>t</sup>BuOK (1.2 mol%), solvent (1 mL).

<sup>b</sup>NMR yield using mesitylene as the internal standard. <sup>c</sup>1 mol% NaBEt<sub>3</sub>H was added. <sup>d</sup>With 1 mol% Zn(OTf)<sub>2</sub>. <sup>e</sup>With 1 mol% BF<sub>3</sub>·Et<sub>2</sub>O. <sup>f</sup>Without <sup>t</sup>BuOK. nd = not detected.

**Table S2. Conditions evaluation for amidation of epoxide 1a and amine 2j<sup>a</sup>**



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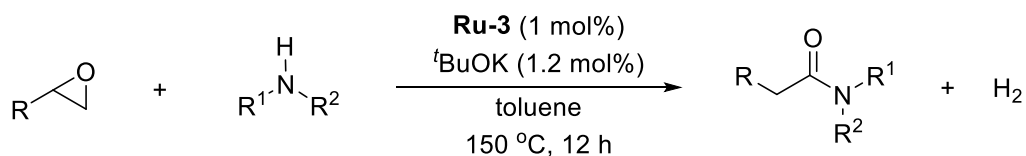


entry	cat.	solvent	temp (°C)	time (h)	yield (%) <sup>b</sup>
1	<b>Ru-3</b>	toluene	150	12	nd
2	<b>Ru-1</b>	toluene	150	12	71 (66)
3	<b>Ru-2</b>	toluene	150	12	nd
4	<b>Ru-10</b>	toluene	150	12	nd
5	<b>Ru-11</b>	toluene	150	12	<5
6	<b>Ru-12</b>	toluene	150	12	24
7	<b>Ru-1</b>	mesitylene	150	12	67
8 <sup>c</sup>	<b>Ru-1</b>	mesitylene	150	12	55
9	<b>Ru-1</b>	toluene	135	12	42
10	<b>Ru-1</b>	toluene	150	36	71

<sup>a</sup>Conditions: **1a** (0.5 mmol), **2j** (0.5 mmol), cat. (1 mol%), <sup>t</sup>BuOK (1.2 mol%), solvent (1 mL).

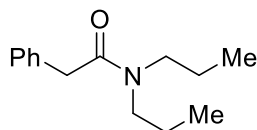
<sup>b</sup>NMR yield using mesitylene or benzyl benzoate as the internal standard, isolated yields in parentheses. <sup>c</sup>Under open system. nd = not detected.

### 3. General procedures for the amidation reaction and characterization data of amide products

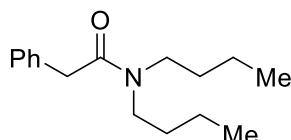


In a N<sub>2</sub> glovebox, **Ru-3** (2.4 mg, 0.005 mmol), <sup>t</sup>BuOK (0.7 mg, 0.006 mmol), and toluene (1 mL) were added into the Schlenk flask. The mixture was stirred at room temperature for 20 min. Epoxides (0.5 mmol) and amines (0.5 mmol) were added into the flask in succession. The flask was sealed and taken out of the glovebox, and the resulting mixture was heated at 150 °C. After heating for 12 h, the reaction was cooled

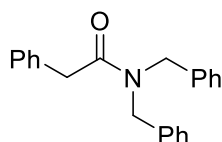
to room temperature. 0.5 M HCl (5 mL) was added to the flask and the mixture was extracted with CH<sub>2</sub>Cl<sub>2</sub> three times. The combined organic layers were dried over Na<sub>2</sub>SO<sub>4</sub>, filtered, and concentrated under reduced pressure. The residue was purified by column chromatography using a short flash silica gel column to yield the corresponding amide.



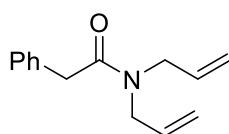
**2-Phenyl-*N,N*-dipropylacetamide (3a).** Purified by column chromatography using a short flash silica gel column (eluent: hexane/EtOAc = hexane to 10:1 v/v) to afford **3a** as a colorless oil (91% yield). <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>) δ 7.34 – 7.03 (m, 5H), 3.62 (s, 2H), 3.21 (t, *J* = 7.7 Hz, 2H), 3.10 (t, *J* = 7.7 Hz, 2H), 1.57 – 1.35 (m, 4H), 0.79 (t, *J* = 7.4 Hz, 6H). <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>) δ 170.69, 135.65, 128.76, 128.65, 126.71, 49.99, 47.59, 41.04, 22.26, 20.88, 11.47, 11.27. The <sup>1</sup>H NMR and <sup>13</sup>C NMR characterization data matched the literature data.<sup>8</sup>



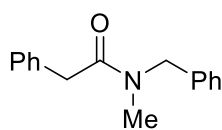
***N,N*-Dibutyl-2-phenylacetamide (3b).** Purified by column chromatography using a short flash silica gel column (eluent: hexane/EtOAc = hexane to 10:1 v/v) to afford **3b** as a colorless oil (95% yield). <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>) δ 7.33 – 7.12 (m, 5H), 3.62 (s, 2H), 3.24 (t, *J* = 7.8 Hz, 2H), 3.13 (t, *J* = 7.8 Hz, 2H), 1.51 – 1.31 (m, 4H), 1.29 – 1.11 (m, 4H), 0.84 (t, *J* = 7.4, 6H). <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>) δ 170.58, 135.70, 128.80, 128.70, 126.74, 48.18, 45.81, 41.11, 31.22, 29.83, 20.36, 20.19, 13.99, 13.93. The <sup>1</sup>H NMR and <sup>13</sup>C NMR characterization data matched the literature data.<sup>9</sup>



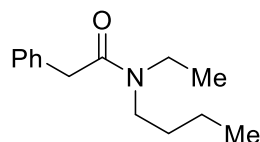
***N,N*-Dibenzyl-2-phenylacetamide (3c)**. Purified by column chromatography using a short flash silica gel column (eluent: hexane/EtOAc = hexane to 10:1 v/v) to afford **3c** as a colorless oil (84% yield). <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>) δ 7.31 – 7.14 (m, 11H), 7.13 – 7.07 (m, 2H), 7.01 (d, *J* = 6.9 Hz, 2H), 4.53 (s, 2H), 4.34 (s, 2H), 3.71 (s, 2H). <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>) δ 171.74, 137.32, 136.43, 135.05, 129.06, 128.90, 128.80, 128.66, 128.39, 127.76, 127.50, 126.99, 126.51, 50.26, 48.30, 41.06. The <sup>1</sup>H NMR and <sup>13</sup>C NMR characterization data matched the literature data.<sup>8</sup>



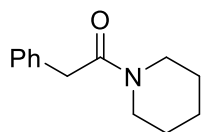
***N,N*-Diallyl-2-phenylacetamide (3d)**. Purified by column chromatography using a short flash silica gel column (eluent: hexane/EtOAc = hexane to 10:1 v/v) to afford **3d** as a colorless oil (62% yield). <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>) δ 7.27 – 7.06 (m, 5H), 5.78 – 5.46 (m, 2H), 5.15 – 4.90 (m, 4H), 3.90 (d, *J* = 5.8 Hz, 2H), 3.75 (d, *J* = 4.6 Hz, 2H), 3.60 (s, 2H). <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>) δ 170.80, 135.02, 132.96, 132.72, 128.62, 128.48, 126.61, 117.12, 116.62, 49.26, 47.69, 40.56. The <sup>1</sup>H NMR and <sup>13</sup>C NMR characterization data matched the literature data.<sup>10</sup>



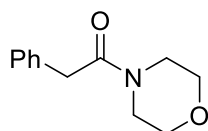
***N*-Benzyl-*N*-methyl-2-phenylacetamide (3e)**. Purified by column chromatography using a short flash silica gel column (eluent: hexane/EtOAc = hexane to 10:1 v/v) to afford **3e** as a colorless oil (78% yield). <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>), the major isomer: δ 7.40 – 6.91 (m, 10H), 4.54 (s, 2H), 3.72 (s, 2H), 2.83 (s, 3H). <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>), a mixture of two isomers: δ 171.66, 171.32, 137.36, 136.55, 135.19, 135.03, 129.04, 128.94, 128.82, 128.69, 128.18, 127.78, 127.49, 126.93, 126.50, 53.76, 51.10, 41.29, 40.95, 35.34, 34.16. The <sup>1</sup>H NMR and <sup>13</sup>C NMR characterization data matched the literature data.<sup>11</sup>



***N*-Butyl-*N*-ethyl-2-phenylacetamide (3f).** Purified by column chromatography using a short flash silica gel column (eluent: hexane/EtOAc = hexane to 10:1 v/v) to afford **3f** as a colorless oil (95% yield).  $^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ ), mixture of two isomers:  $\delta$  7.35 – 7.09 (m, 5H), 3.63 (s, 2H), 3.32 (q,  $J = 7.2$  Hz, 1H), 3.27 – 3.18 (m, 2H), 3.16 – 3.08 (m, 1H), 1.50 – 1.30 (m, 2H), 1.28 – 1.12 (m, 3H), 1.03 (q,  $J = 7.2$  Hz, 3H), 0.84 (td,  $J = 7.2, 3.4$  Hz, 3H).  $^{13}\text{C}$  NMR (75 MHz,  $\text{CDCl}_3$ ), mixture of two isomers:  $\delta$  170.46, 170.40, 135.64, 129.15, 128.81, 128.75, 128.71, 128.48, 126.75, 47.86, 45.30, 42.78, 41.11, 40.99, 40.76, 31.26, 29.92, 20.36, 20.18, 14.24, 13.99, 13.93, 12.94. GC-MS  $m/z$  calcd. for  $\text{C}_{14}\text{H}_{21}\text{NO}$   $[\text{M}]^+$ : 219.2, found: 219.1.

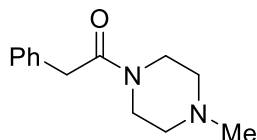


**2-Phenyl-1-(piperidin-1-yl)ethan-1-one (3g).** Purified by column chromatography using a short flash silica gel column (eluent: hexane/EtOAc = hexane to 10:1 v/v) to afford **3g** as a colorless oil (71% yield).  $^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ )  $\delta$  7.34 – 7.07 (m, 5H), 3.65 (s, 2H), 3.48 (t,  $J = 7.8$  Hz, 2H), 3.28 (t,  $J = 7.8$  Hz, 2H), 1.57 – 1.34 (m, 4H), 1.36 – 1.16 (m, 2H).  $^{13}\text{C}$  NMR (75 MHz,  $\text{CDCl}_3$ )  $\delta$  169.21, 135.39, 128.61, 128.54, 126.59, 47.22, 42.83, 41.11, 26.12, 25.46, 24.38. The  $^1\text{H}$  NMR and  $^{13}\text{C}$  NMR characterization data matched the literature data.<sup>8</sup>

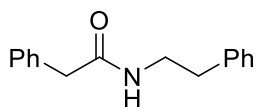


**1-Morpholino-2-phenylethan-1-one (3h).** Purified by column chromatography using a short flash silica gel column (eluent: hexane/EtOAc = hexane to 5:1 v/v) to afford **3h** as a colorless oil (80% yield).  $^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ )  $\delta$  7.28 – 7.21 (m, 2H), 7.16 (t,  $J = 6.1$  Hz, 3H), 3.65 (s, 2H), 3.55 (s, 4H), 3.44 – 3.29 (m, 4H).  $^{13}\text{C}$  NMR (75

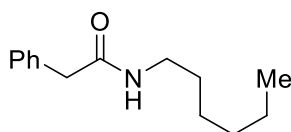
MHz, CDCl<sub>3</sub>)  $\delta$  169.58, 134.77, 128.76, 128.50, 126.86, 66.73, 66.40, 46.46, 42.09, 40.78. The <sup>1</sup>H NMR and <sup>13</sup>C NMR characterization data matched the literature data.<sup>8</sup>



**1-(4-Methylpiperazin-1-yl)-2-phenylethan-1-one (3i).** Purified by column chromatography using a short flash silica gel column (eluent: hexane/EtOAc = hexane to 3:1 v/v) to afford **3i** as a colorless oil (83% yield). <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>)  $\delta$  7.25 – 7.17 (m, 2H), 7.16 – 7.09 (m, 3H), 3.62 (s, 2H), 3.55 (t,  $J$  = 5.1 Hz, 2H), 3.34 (t,  $J$  = 5.1 Hz, 2H), 2.23 (t,  $J$  = 5.1 Hz, 2H), 2.13 (s, 3H), 2.09 (t,  $J$  = 5.1 Hz, 2H). <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>)  $\delta$  169.11, 134.81, 128.43, 128.34, 126.50, 54.60, 54.30, 45.70, 41.38, 40.64. The <sup>1</sup>H NMR and <sup>13</sup>C NMR characterization data matched the literature data.<sup>12</sup>



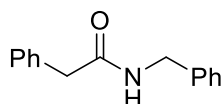
**N-Phenethyl-2-phenylacetamide (3j).** Purified by column chromatography using a short flash silica gel column (eluent: hexane/EtOAc = hexane to 10:1 v/v) to afford **3j** as a colorless oil (66% yield). <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>)  $\delta$  7.36 – 7.13 (m, 8H), 7.05 – 6.97 (m, 2H), 5.38 (s, 1H), 3.53 (s, 2H), 3.46 (dd,  $J$  = 12.9, 6.8 Hz, 2H), 2.72 (t,  $J$  = 6.8 Hz, 2H). <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>)  $\delta$  171.05, 138.78, 134.87, 129.59, 129.15, 128.82, 128.71, 127.47, 126.56, 44.00, 40.81, 35.59. The <sup>1</sup>H NMR and <sup>13</sup>C NMR characterization data matched the literature data.<sup>13</sup>



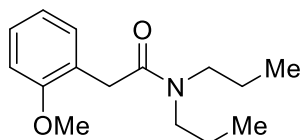
**N-Hexyl-2-phenylacetamide (3k).** Purified by column chromatography using a short flash silica gel column (eluent: hexane/EtOAc = hexane to 10:1 v/v) to afford **3k** as a



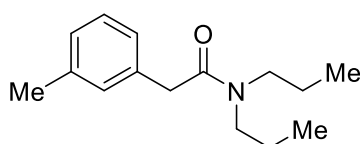
colorless oil (44% yield).  $^1\text{H}$  NMR (500 MHz,  $\text{CDCl}_3$ )  $\delta$  7.26 – 7.21 (m, 2H), 7.17 (t,  $J = 6.7$  Hz, 3H), 6.01 (s, 1H), 3.43 (s, 2H), 3.08 (dd,  $J = 13.3, 6.7$  Hz, 2H), 1.36 – 1.28 (m, 2H), 1.19 – 1.08 (m, 6H), 0.77 (t,  $J = 6.9$  Hz, 3H).  $^{13}\text{C}$  NMR (126 MHz,  $\text{CDCl}_3$ )  $\delta$  171.03, 135.24, 129.25, 128.76, 127.05, 43.61, 39.65, 31.35, 29.33, 26.42, 22.45, 13.92. The  $^1\text{H}$  NMR and  $^{13}\text{C}$  NMR characterization data matched the literature data.<sup>8</sup>



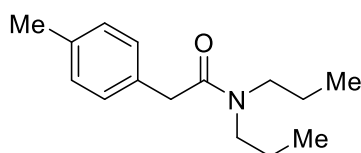
***N*-Benzyl-2-phenylacetamide (3l)**. Purified by recrystallization to afford **3l** as a white solid (51% yield).  $^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ )  $\delta$  7.42 – 7.26 (m, 8H), 7.20 (d,  $J = 7.6$  Hz, 2H), 5.89 (s, 1H), 4.42 (d,  $J = 5.7$  Hz, 2H), 3.64 (s, 2H).  $^{13}\text{C}$  NMR (75 MHz,  $\text{CDCl}_3$ )  $\delta$  171.02, 138.22, 134.88, 129.54, 129.13, 128.74, 127.57, 127.51, 127.48, 43.86, 43.65. The  $^1\text{H}$  NMR and  $^{13}\text{C}$  NMR characterization data matched the literature data.<sup>8</sup>



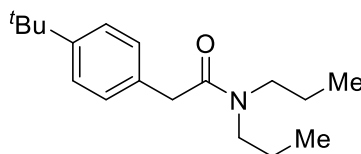
**2-(2-Methoxyphenyl)-*N,N*-dipropylacetamide (3m)**. Purified by column chromatography using a short flash silica gel column (eluent: hexane/EtOAc = hexane to 10:1 v/v) to afford **3m** as a colorless oil (89% yield).  $^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ )  $\delta$  7.30 – 7.20 (m, 2H), 6.93 (t,  $J = 7.5$  Hz, 1H), 6.88 (d,  $J = 8.1$  Hz, 1H), 3.84 (s, 3H), 3.69 (s, 2H), 3.36 – 3.27 (m, 2H), 3.26 – 3.13 (m, 2H), 1.66 – 1.48 (m, 4H), 0.90 (t,  $J = 7.4$  Hz, 6H).  $^{13}\text{C}$  NMR (75 MHz,  $\text{CDCl}_3$ )  $\delta$  171.28, 156.84, 130.23, 128.02, 124.51, 120.78, 110.33, 55.41, 49.96, 47.72, 34.60, 22.30, 20.99, 11.52, 11.34. GC-MS  $m/z$  calcd. for  $\text{C}_{15}\text{H}_{23}\text{NO}_2$   $[\text{M}]^+$ : 249.2, found: 249.2.



***N,N*-Dipropyl-2-(*m*-tolyl)acetamide (3n).** Purified by column chromatography using a short flash silica gel column (eluent: hexane/EtOAc = hexane to 10:1 v/v) to afford **3n** as a colorless oil (92% yield). <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>) δ 7.22 – 7.13 (m, 1H), 7.07 (s, 1H), 7.03 (d, *J* = 7.5 Hz, 2H), 3.65 (s, 2H), 3.32 – 3.24 (m, 2H), 3.21 – 3.11 (m, 2H), 2.31 (s, 3H), 1.62 – 1.40 (m, 4H), 0.86 (td, *J* = 7.4, 3.1 Hz, 6H). <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>) δ 170.73, 138.19, 135.46, 129.44, 128.46, 127.39, 125.72, 49.92, 47.51, 40.95, 22.19, 21.40, 20.82, 11.41, 11.21. GC-MS *m/z* calcd. for C<sub>15</sub>H<sub>23</sub>NO [M]<sup>+</sup>: 233.2, found: 233.2.

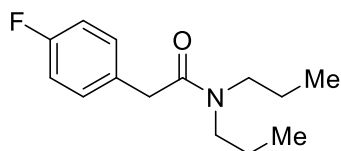


***N,N*-Dipropyl-2-(*p*-tolyl)acetamide (3o).** Purified by column chromatography using a short flash silica gel column (eluent: hexane/EtOAc = hexane to 10:1 v/v) to afford **3o** as a colorless oil (90% yield). <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>) δ 7.16 – 7.06 (m, 4H), 3.64 (s, 2H), 3.29 – 3.23 (m, 2H), 3.18 – 3.10 (m, 2H), 2.29 (s, 3H), 1.61 – 1.41 (m, 4H), 0.85 (t, *J* = 7.4 Hz, 6H). <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>) δ 170.74, 136.06, 132.42, 129.21, 128.48, 49.83, 47.44, 40.52, 22.15, 20.98, 20.77, 11.35, 11.16. GC-MS *m/z* calcd. for C<sub>15</sub>H<sub>23</sub>NO [M]<sup>+</sup>: 233.2, found: 233.2.

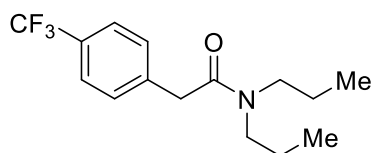


**2-(4-(*tert*-Butyl)phenyl)-*N,N*-dipropylacetamide (3p).** Purified by column chromatography using a short flash silica gel column (eluent: hexane/EtOAc = hexane to 10:1 v/v) to afford **3p** as a colorless oil (83% yield). <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>) δ 7.32 (d, *J* = 8.2 Hz, 2H), 7.17 (d, *J* = 8.2 Hz, 2H), 3.66 (s, 2H), 3.34 – 3.25 (m, 2H), 3.23 – 3.13 (m, 2H), 1.62 – 1.44 (m, 4H), 1.30 (s, 9H), 0.87 (t, *J* = 6.7 Hz, 6H). <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>) δ 170.97, 149.56, 132.58, 128.50, 125.62, 50.09, 47.75,

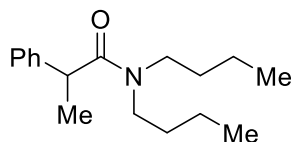
40.44, 34.53, 31.47, 22.35, 20.99, 11.55, 11.33. GC-MS  $m/z$  calcd. for  $C_{18}H_{29}NO$   $[M]^+$ : 275.2, found: 275.1.



**2-(4-Fluorophenyl)-*N,N*-dipropylacetamide (3q).** Purified by column chromatography using a short flash silica gel column (eluent: hexane/EtOAc = hexane to 10:1 v/v) to afford **3q** as a colorless oil (80% yield).  $^1H$  NMR (300 MHz,  $CDCl_3$ )  $\delta$  7.20 (dd,  $J = 8.3, 5.5$  Hz, 2H), 7.01 – 6.93 (m, 2H), 3.65 (s, 2H), 3.31 – 3.24 (m, 2H), 3.22 – 3.12 (m, 2H), 1.62 – 1.45 (m, 4H), 0.87 (td,  $J = 7.3, 5.3$  Hz, 6H).  $^{13}C$  NMR (75 MHz,  $CDCl_3$ )  $\delta$  170.54, 161.84 (d,  $J = 244.7$  Hz), 131.35 (d,  $J = 3.2$  Hz), 130.42 (d,  $J = 7.9$  Hz), 115.48 (d,  $J = 21.3$  Hz), 50.03, 47.73, 39.96, 22.35, 20.93, 11.49, 11.33.  $^{19}F$  NMR (282 MHz,  $CDCl_3$ )  $\delta$  -116.47. GC-MS  $m/z$  calcd. for  $C_{14}H_{20}FNO$   $[M]^+$ : 237.2, found: 237.1.



***N,N*-Dipropyl-2-(4-(trifluoromethyl)phenyl)acetamide (3r).** Purified by a short flash silica gel column chromatography (eluent: hexane/EtOAc = hexane to 10:1 v/v) to afford **3r** as a colorless oil (85% yield).  $^1H$  NMR (300 MHz,  $CDCl_3$ )  $\delta$  7.56 (d,  $J = 8.1$  Hz, 2H), 7.36 (d,  $J = 8.1$  Hz, 2H), 3.74 (s, 2H), 3.33 – 3.25 (m, 2H), 3.23 – 3.13 (m, 2H), 1.64 – 1.47 (m, 4H), 0.92 – 0.84 (m, 6H).  $^{13}C$  NMR (75 MHz,  $CDCl_3$ )  $\delta$  169.81, 139.77, 129.81 (q,  $J = 32.5$  Hz), 129.41, 125.57 (q,  $J = 3.8$  Hz), 124.33 (q,  $J = 271.8$  Hz), 50.10, 47.86, 40.47, 22.42, 20.96, 11.49, 11.33.  $^{19}F$  NMR (282 MHz,  $CDCl_3$ )  $\delta$  -63.47. GC-MS  $m/z$  calcd. for  $C_{15}H_{20}F_3NO$   $[M]^+$ : 287.2, found: 287.1.

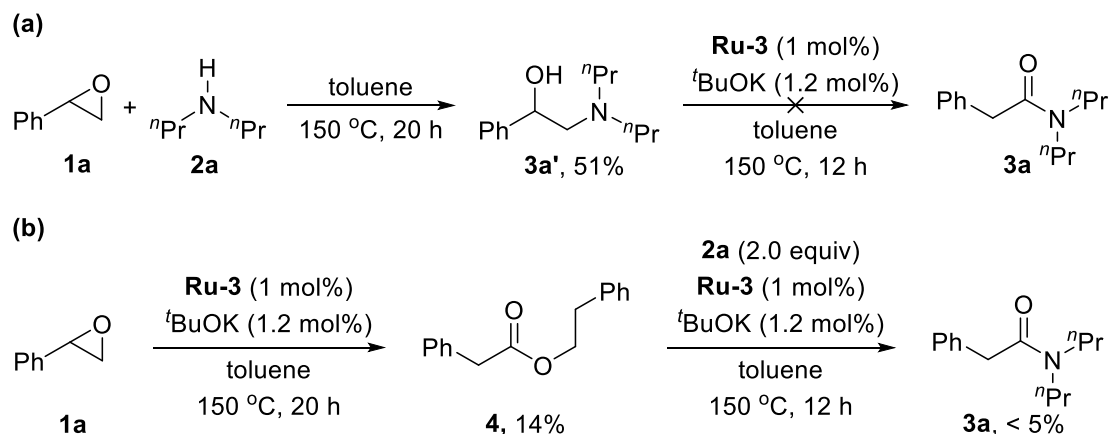


***N,N*-Dibutyl-2-phenylpropanamide (3s)**. Purified by column chromatography using a short flash silica gel column (eluent: hexane/EtOAc = hexane to 10:1 v/v) to afford **3s** as a colorless oil (65% yield).  $^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ )  $\delta$  7.27 – 7.09 (m, 5H), 3.75 (q,  $J$  = 6.8 Hz, 1H), 3.47 – 3.33 (m, 1H), 3.25 – 3.11 (m, 1H), 3.10 – 2.98 (m, 1H), 2.96 – 2.81 (m, 1H), 1.49 – 1.29 (m, 6H), 1.26 – 1.07 (m, 5H), 0.86 – 0.74 (m, 6H).  $^{13}\text{C}$  NMR (75 MHz,  $\text{CDCl}_3$ )  $\delta$  173.12, 142.54, 128.80, 127.31, 126.70, 47.43, 45.93, 43.25, 31.20, 29.70, 21.06, 20.29, 20.14, 13.92, 13.87. The  $^1\text{H}$  NMR and  $^{13}\text{C}$  NMR characterization data matched the literature data.<sup>14</sup>

## 4. Mechanistic studies

### 4.1 Formation of **3a'** and **4**

To get insight into the reaction mechanism, some control experiments were carried out as shown below:



(a) Upon treatment of epoxide **1a** with amine **2a** in the absence of **Ru-3**, 51% of amino alcohol **3a'** was obtained after 20 h at 150 °C. However, **3a'** did not transform into the amide under the standard conditions. The result indicated that **3a'** was not an intermediate in formation of amide **3a**.

(b) Epoxide **1a** slowly converted into ester **4** catalyzed by **Ru-3** and  $t\text{BuOK}$  in the absence of amine. 14% yield was obtained when the reaction proceeded for 20 h at

150 °C. Ester **4** hardly converted to amide **3a** under the standard conditions. These results demonstrated that the ester **4** was not an intermediate either.

The correlation between reaction time and yields of **3a**, **3a'**, and **4** was drawn in Figure S1 to investigate why amide **3a** was generated as the major product instead of **3a'** or **4**. As shown in the figure, the formation of **3a** was rapid under the standard conditions, and the reaction was finished in about 8 to 10 h (blue curve). In contrast, the formation of **3a'** in the absence of catalyst and the formation of **4** in the absence of amine were both slower than the formation of amide **3a** at the same temperature. Only a trace amount of **3a'** and **4** were observed after 10 h (red and black curves). Thus, almost all of the epoxides would quickly convert into amides.

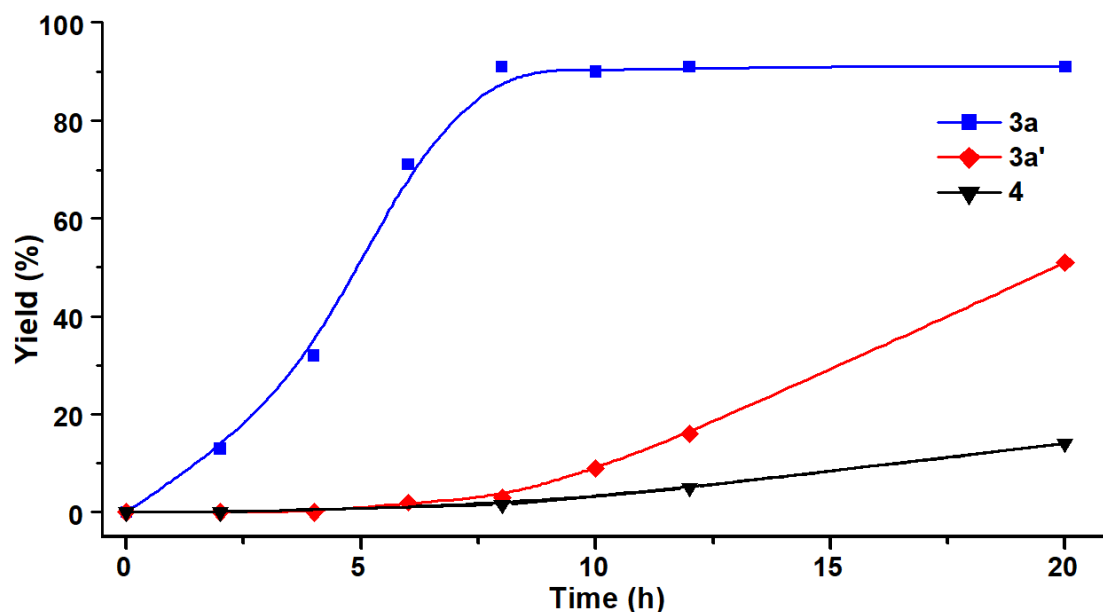


Figure S1. Correlation between yields and reaction time

**Procedure for conducting the experiment of the blue curve:** In a N<sub>2</sub> glovebox, **Ru-3** (2.4 mg, 0.005 mmol), <sup>t</sup>BuOK (0.7 mg, 0.006 mmol), and toluene (1 mL) were added into the Schlenk flask. The mixture was stirred at room temperature for 20 min. Epoxide **1a** (60.1 mg, 0.5 mmol) and amine **2a** (50.6 mg, 0.5 mmol) were added into the flask in succession. The flask was sealed and taken out of the glovebox, and the resultant mixture was heated at 150 °C. After heating for the given time, the reaction was cooled to room temperature and the solvent was evaporated in vacuo. The residue

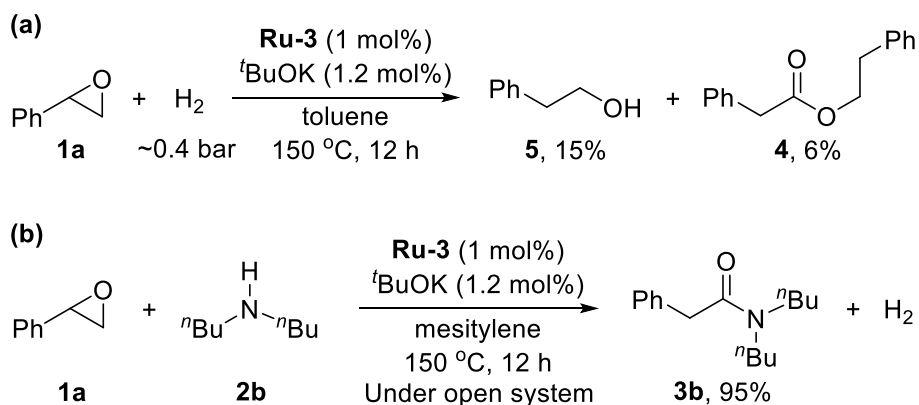
was transferred to an NMR tube to determine the yield of **3a** using mesitylene as an internal standard.

**Procedure for conducting the experiment of the red curve:** In a N<sub>2</sub> glovebox, toluene (1 mL), epoxide **1a** (60.1 mg, 0.5 mmol), and amine **2a** (50.6 mg, 0.5 mmol) were added to the Schlenk flask. The flask was sealed and taken out of the glovebox, and the resultant mixture was heated at 150 °C. After heating for the given time, the reaction was cooled to room temperature and the solvent was removed in vacuo. The residue was transferred to an NMR tube to determine the yield of **3a'** using mesitylene as an internal standard.

**Procedure for conducting the experiment of the black curve:** In a N<sub>2</sub> glovebox, **Ru-3** (2.4 mg, 0.005 mmol), <sup>t</sup>BuOK (0.7 mg, 0.006 mmol), and toluene (1 mL) were added to the Schlenk flask. The mixture was stirred at room temperature for 20 min. Epoxide **1a** (60.1 mg, 0.5 mmol) was added into the flask. The flask was sealed and taken out of the glovebox, and the resultant mixture was heated at 150 °C. After heating for the given time, the reaction was cooled to room temperature and removed the solvent. The residue was transferred to an NMR tube to determine the yield of **4** using mesitylene as an internal standard.

#### **4.2 The possibility of alcohol as an intermediate in the generation of amides**

The dehydrogenative coupling of alcohols and amines could potentially generate amides under the catalysis of ruthenium pincer complexes. Epoxides can possibly be hydrogenated to primary alcohols by hydrogen generated in the developed reaction. To investigate if the alcohol can be generated as an intermediate, two control experiments were conducted as shown below:



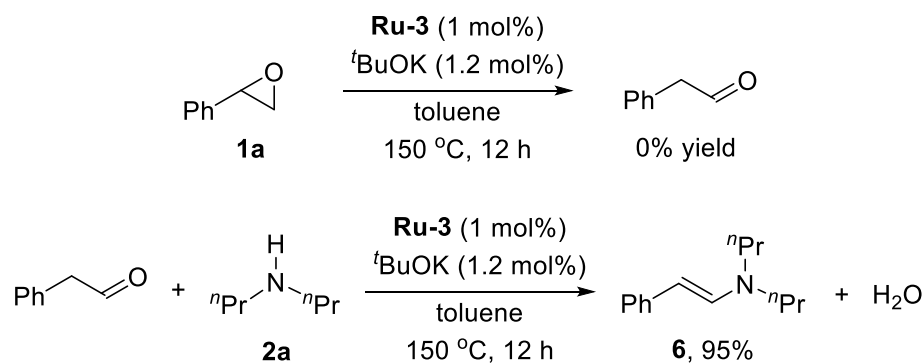
(a) The developed amidation reaction can generate 1.0 equivalent of H<sub>2</sub>. Therefore ~0.4 bar (using a 90 mL Fischer-Porter tube, the gas is more than 1 equivalent to **1a**) of hydrogen gas was added to the epoxide **1a** under the standard conditions. It was found that only 15% of primary alcohol **5** along with 6% of ester **4** were produced. This result suggested that the hydrogen gas generated from the amidation reaction was inefficient for converting the epoxide into primary alcohol.

(b) Next, the amidation reaction was carried out in an open system with nitrogen flow, since the open system could remove the generated hydrogen gas. It was found that 95% of amide was obtained. The result demonstrated that the developed amidation reaction can proceed without the participation of hydrogen gas.

The above experiments revealed that the primary alcohol **5** was not an intermediate in the generation of amide **3a**.

### 4.3 The possibility of generating free aldehyde as an intermediate

The Meinwald rearrangement of epoxides is a well-known procedure for converting epoxides into aldehydes, which is another possible intermediate for the generation of an amide under the current catalytic system. Control experiments were carried out to check this possibility.



Under the standard reaction conditions, epoxide **1a** could not convert to phenylacetaldehyde, as shown in the first experiment. When phenylacetaldehyde was employed as an alternative substrate under the standard conditions, enamine **6** was generated as the major product (see the crude  $^1\text{H}$  NMR below).

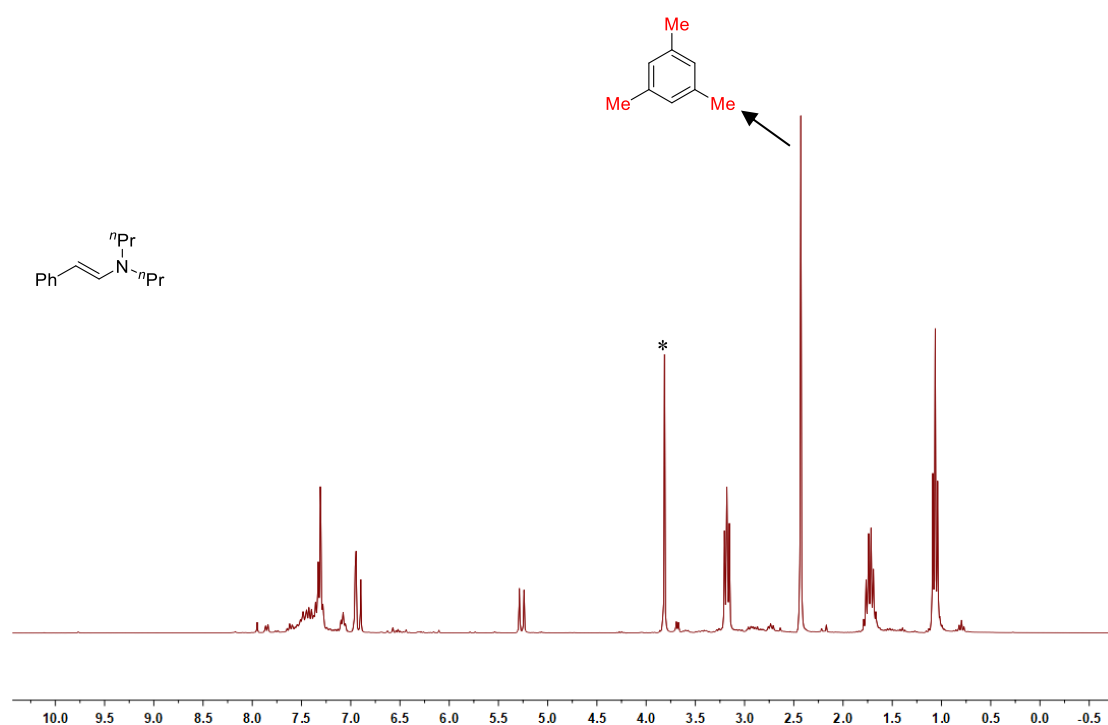


Figure S2. Crude  $^1\text{H}$  NMR spectrum of enamine formation in  $\text{CDCl}_3$

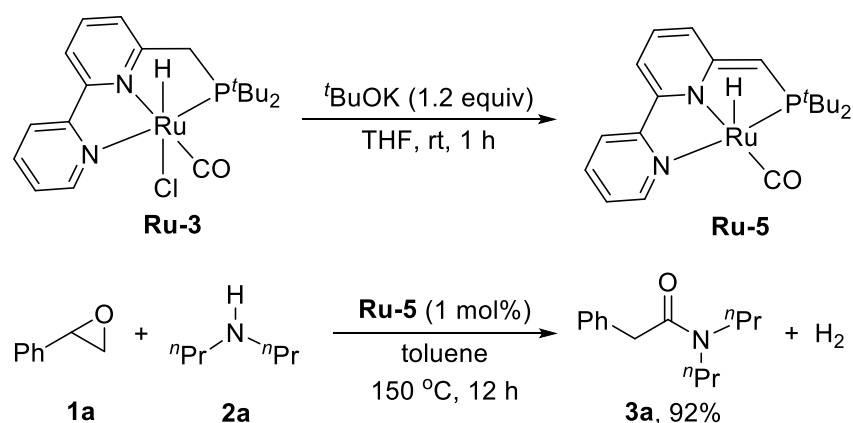
Note: mesitylene was used as the internal standard. \* unidentified impurity

The above results indicate that the amidation reaction does not generate the free aldehyde as the intermediate.

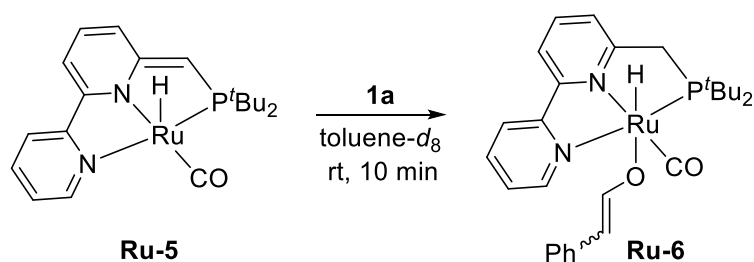


#### 4.4 The reaction intermediates and epoxide activation pathway

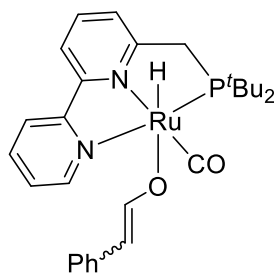
To determine the catalytically active species, **Ru-3** was combined with  $t\text{BuOK}$  (1.2 equiv) in a THF solution at room temperature. After 1 h, the dark green solution was filtered through a small piece of cotton. The solution was concentrated to get the dearomatized complex **Ru-5**. Using **Ru-5** as the catalyst for the reaction of epoxide **1a** with amine **2a** resulted in 92% yield of the amide **3a**. This result indicates that **Ru-5** is the actual catalyst for this amidation reaction.



Next, **Ru-5** was combined with epoxide **1a** in  $\text{toluene-}d_8$  in a 1:3 ratio at room temperature to explore the activation process. NMR spectra revealed the formation of new complexes, which were identified by  $^{31}\text{P}$  NMR and  $^1\text{H}$  NMR as two isomers (Z and E) of **Ru-6** in a 1:2 ratio with an enolate coordinated to the aromatic ruthenium complex.



**Procedure for generating Ru-6:** In a  $\text{N}_2$  glovebox, **Ru-5** (8.9 mg, 0.02 mmol) was added to an NMR tube and dissolved by  $\text{toluene-}d_8$ . **1a** (7.2 mg, 0.06 mmol) was added to the solution. The NMR tube was sealed and then rotated at room temperature for about 10 min to produce **Ru-6**.



NMR data for the major configuration of **Ru-6**:

$^1\text{H}$  NMR (500 MHz, toluene- $d_8$ )  $\delta$  8.78 (br, 1H, PyH), 7.74 (d,  $J = 5.1$  Hz, 1H, OCHCHPh), 7.48 (d,  $J = 7.4$  Hz, 2H, PhH), 7.44 – 7.35 (m, 1H, PyH), 7.30 (d,  $J = 7.0$  Hz, 1H, PyH), 7.21 (d,  $J = 7.0$  Hz, 1H, PyH), 7.10 – 7.02 (m, 2H, PyH, overlapping with excess styrene oxide), 6.83 (t,  $J = 7.2$  Hz, 1H, PhH), 6.76 (d,  $J = 7.4$  Hz, 2H, PhH), 6.36 (br, 1H, PyH), 4.79 (d,  $J = 5.1$  Hz, 1H, OCHCHPh), 3.29 (dd,  $J = 15.9, 8.9$  Hz, 1H, PyCHHP), 3.00 (dd,  $J = 15.9, 9.2$  Hz, 1H, PyCHHP), 1.32 (d,  $J = 12.8$  Hz, 9H, PC(CH $_3$ ) $_3$ ), 1.16 (d,  $J = 12.8$  Hz, 9H, PC(CH $_3$ ) $_3$ ), -15.35 (d,  $J = 24.2$  Hz, 1H, Ru-H).

$^{13}\text{C}$  NMR (126 MHz, toluene- $d_8$ )  $\delta$  208.12 (d,  $J = 14.7$  Hz, RuCO), 165.07 (s, OCHCHPh), 161.91 (s, PyC), 156.44 (s, PyC), 152.45 (s, PyC), 143.65 (s, PyC), 138.57 (s, PhC), 136.83 (s, PyC), 135.99 (s, PyC), 129.18 (s, PhC), 128.53 (s, PyC), 127.37 (s, PyC), 125.48 (s, PhC), 122.41 (s, PyC), 121.89 (d,  $J = 9.0$  Hz, PyC), 119.85 (s, PhC), 99.28 (s, OCHCHPh), 37.50 (d,  $J = 13.9$  Hz, PC(CH $_3$ )), 37.25 (d,  $J = 11.5$  Hz, PyCH $_2$ P), 37.12 (d,  $J = 11.5$  Hz, PyCH $_2$ P), 35.24 (d,  $J = 23.2$  Hz, PC(CH $_3$ )), 29.67 (d,  $J = 4.2$  Hz, PC(CH $_3$ ) $_3$ ), 29.35 (d,  $J = 3.3$  Hz, PC(CH $_3$ ) $_3$ ).

$^{31}\text{P}$  NMR (202 MHz, toluene- $d_8$ )  $\delta$  105.23 (s).

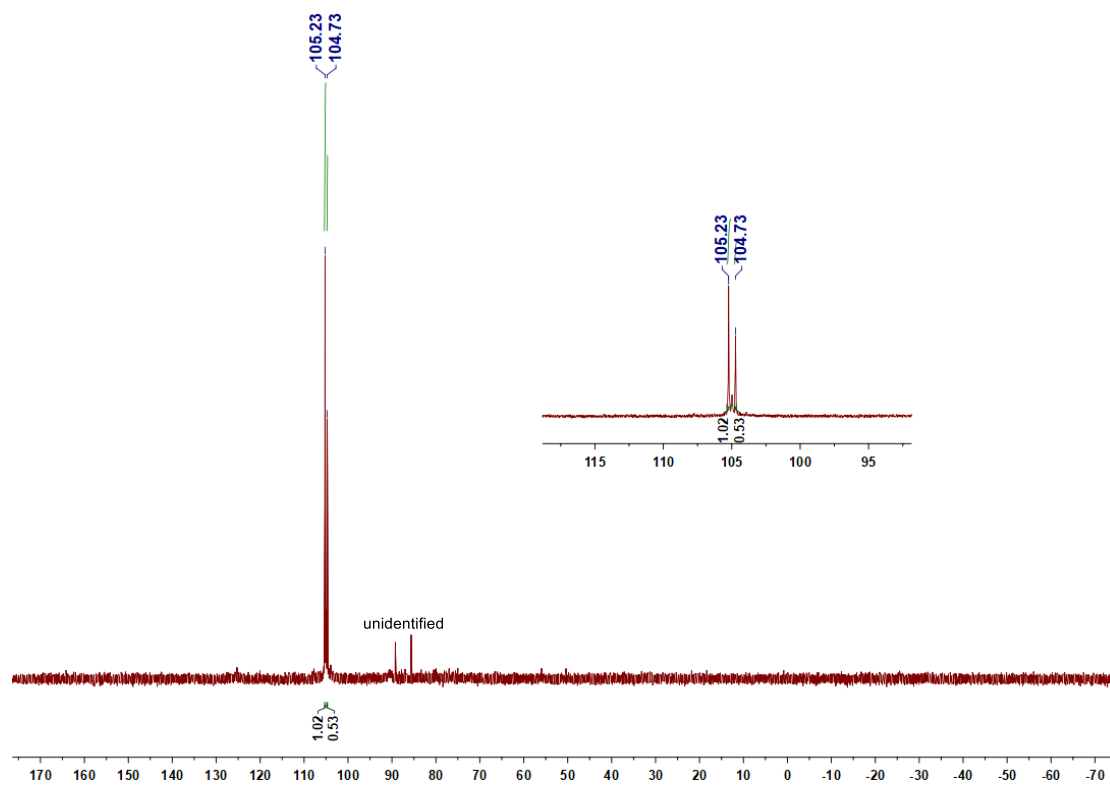


Figure S3.  $^{31}\text{P}$  NMR spectrum of **Ru-6** in toluene- $d_8$

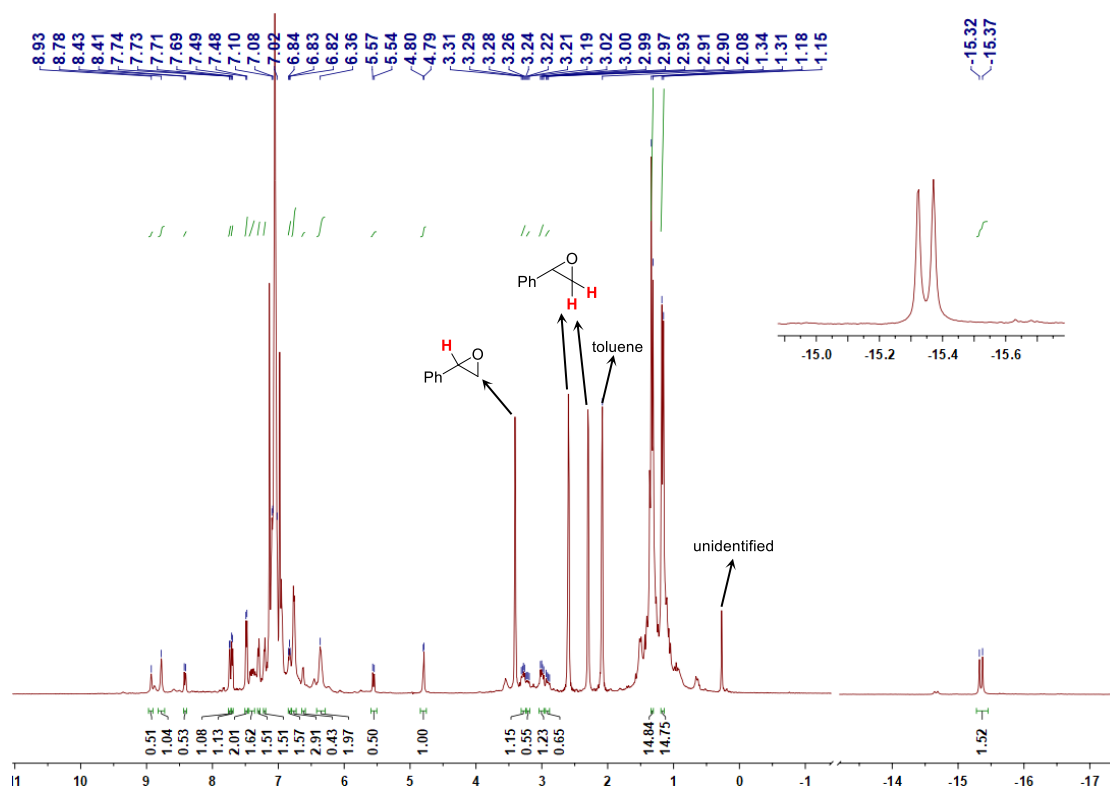


Figure S4.  $^1\text{H}$  NMR spectrum of **Ru-6** in toluene- $d_8$

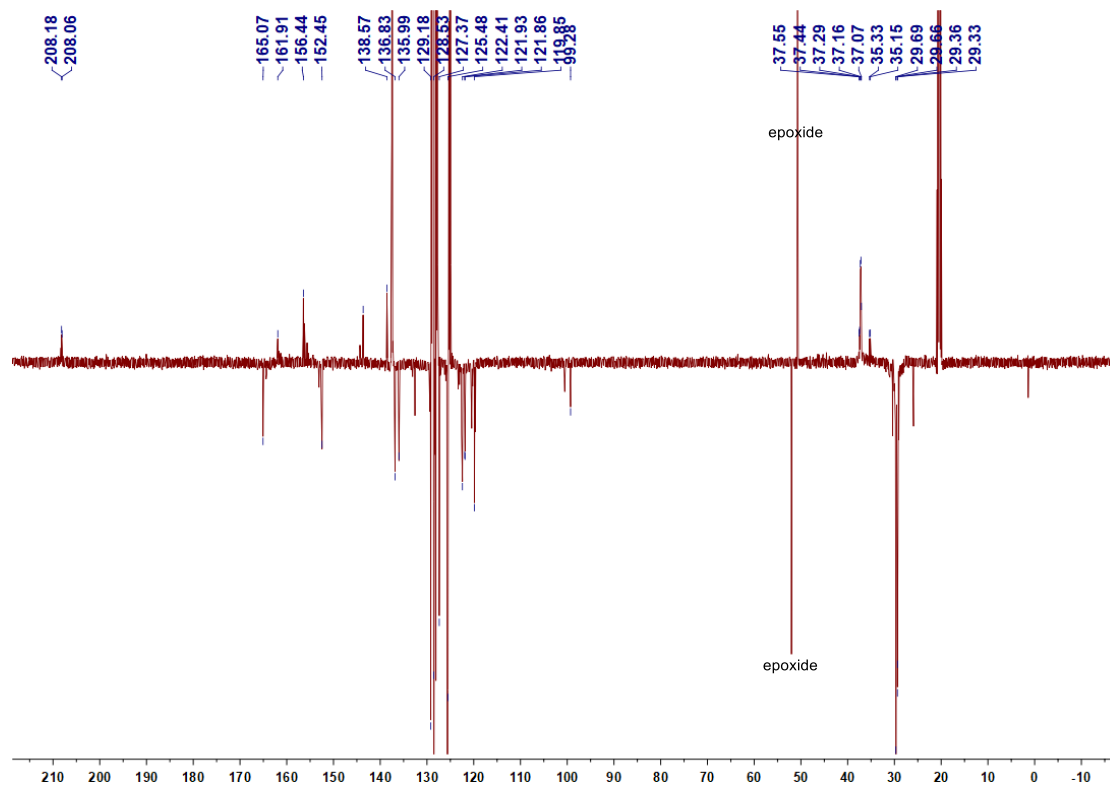


Figure S5.  $^{13}\text{C}$ -DEPTQ NMR spectrum of **Ru-6** in toluene- $d_8$

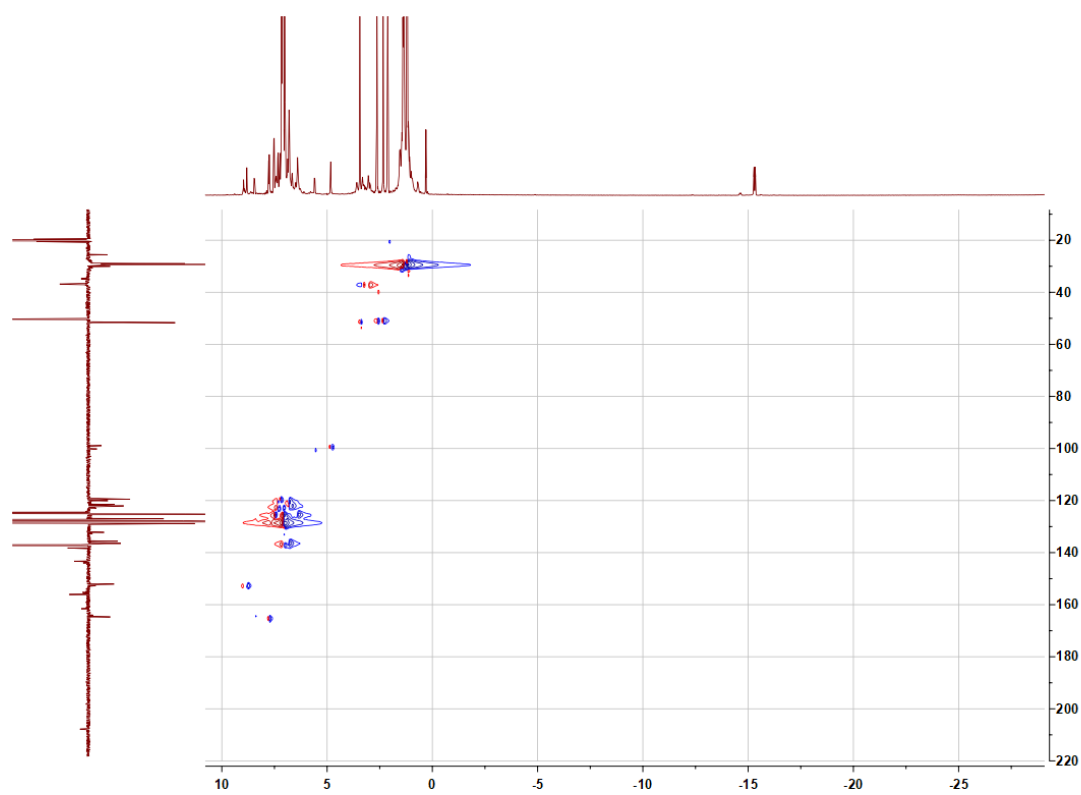


Figure S6. HSQC spectrum of **Ru-6** in toluene- $d_8$

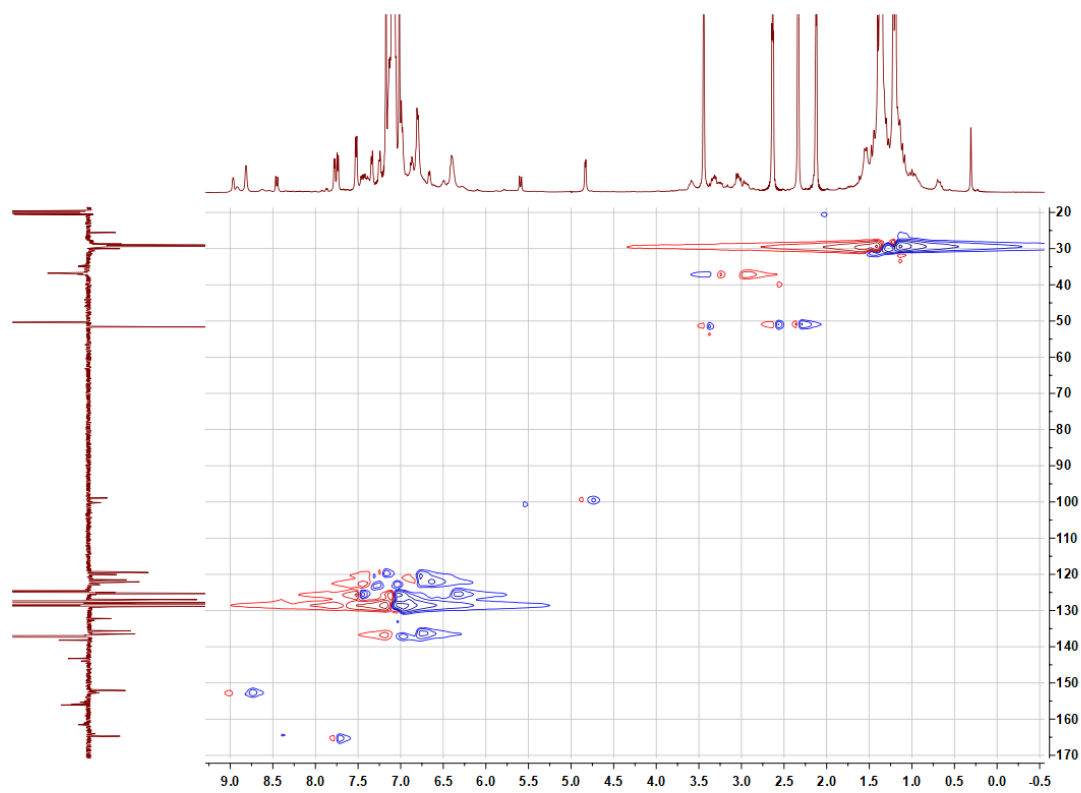


Figure S7. HSQC spectrum (zoom in) of **Ru-6** in toluene- $d_8$

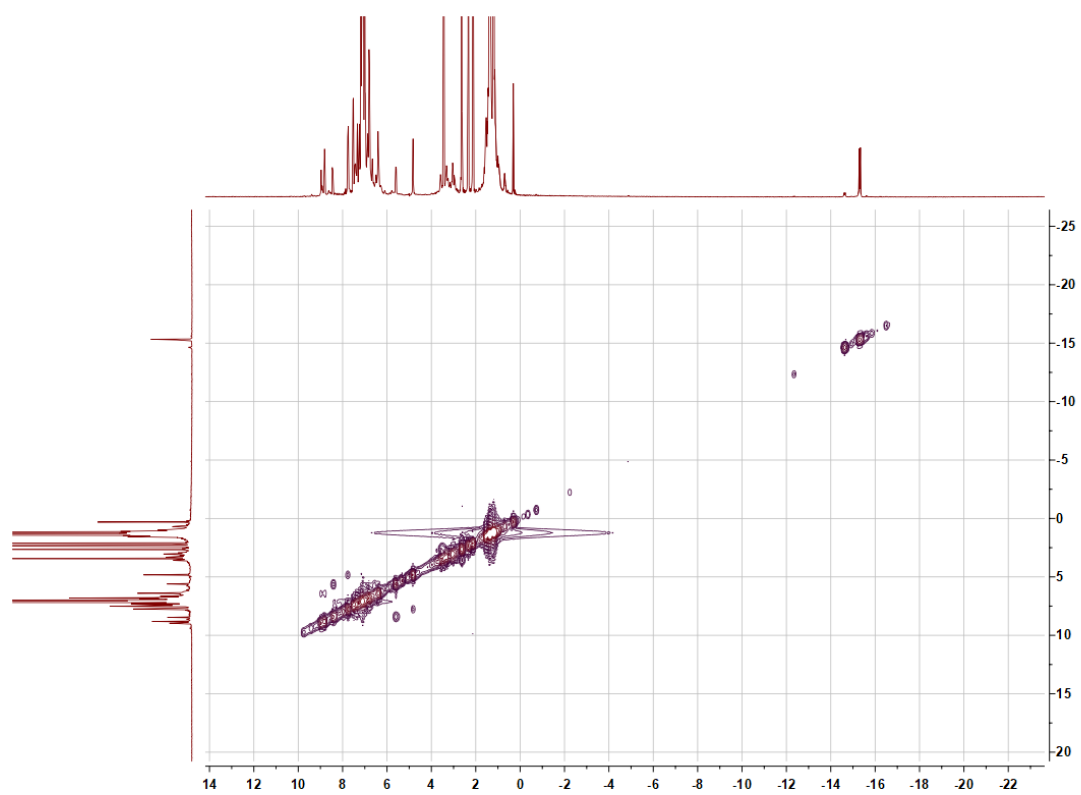


Figure S8. H-H COSY spectrum of **Ru-6** in toluene- $d_8$

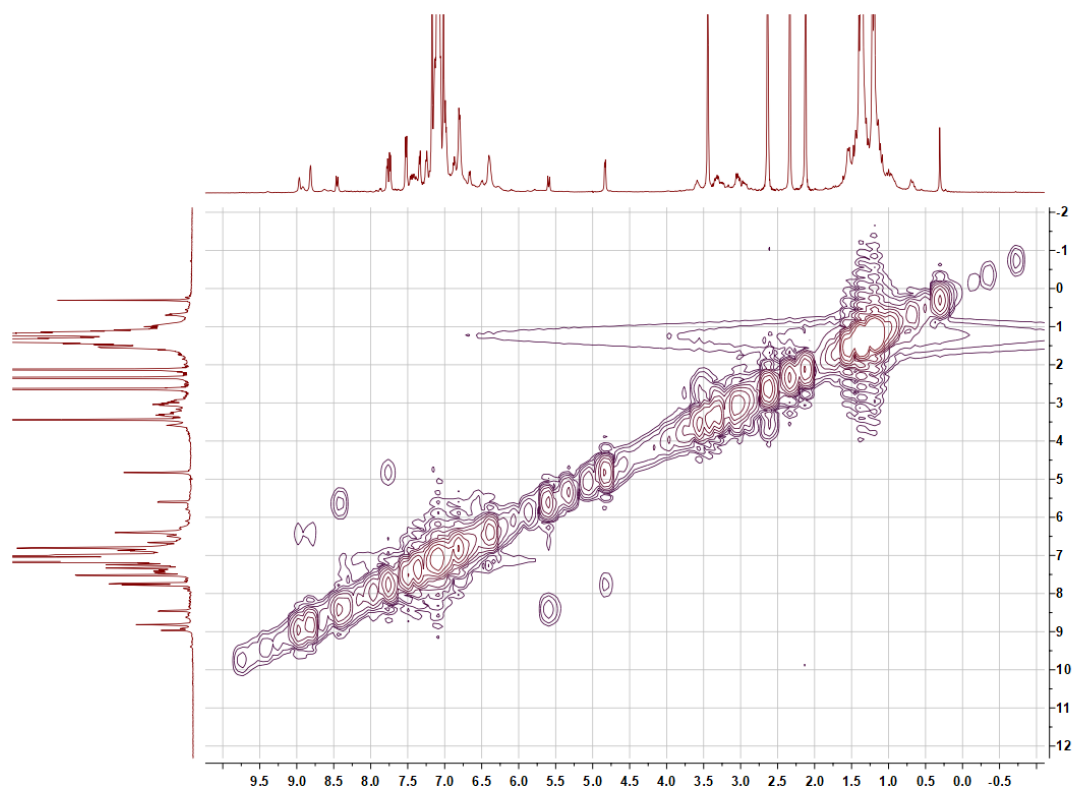
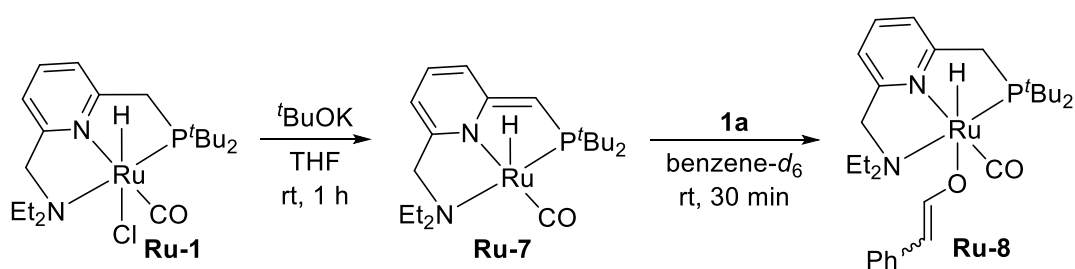


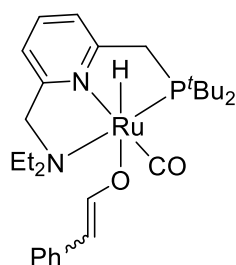
Figure S9. H-H COSY spectrum (zoom in) of **Ru-6** in toluene- $d_8$

The combination of **Ru-1** and  $t$ BuOK in THF solution also generated the well-known dearomatized complex **Ru-7**.<sup>1</sup> A new complex **Ru-8** was formed when **Ru-7** was reacted with epoxide **1a** in deuterated benzene at room temperature. The Ru-enolate intermediate **Ru-8** demonstrated the activation pathway of the epoxide.



**Procedure for generating Ru-8:** In a  $N_2$  glovebox, **Ru-1** (9.8 mg, 0.02 mmol) and  $t$ BuOK (2.2 mg, 0.02 mmol) were added into a vial. THF (2 mL) was added and stirred at room temperature for 1 h. The solvent was removed, and the residue was redissolved in pentane. The mixture was filtered through a piece of cotton. The solution was concentrated to afford the dearomatized complex **Ru-7**. Next, benzene- $d_6$  and **1a** were added to the vial containing **Ru-7**, and the solution was

stirred at room temperature for about 30 min to produce **Ru-8**. The solution was transferred to the NMR tube for analysis.



NMR data for the major configuration of **Ru-8**:

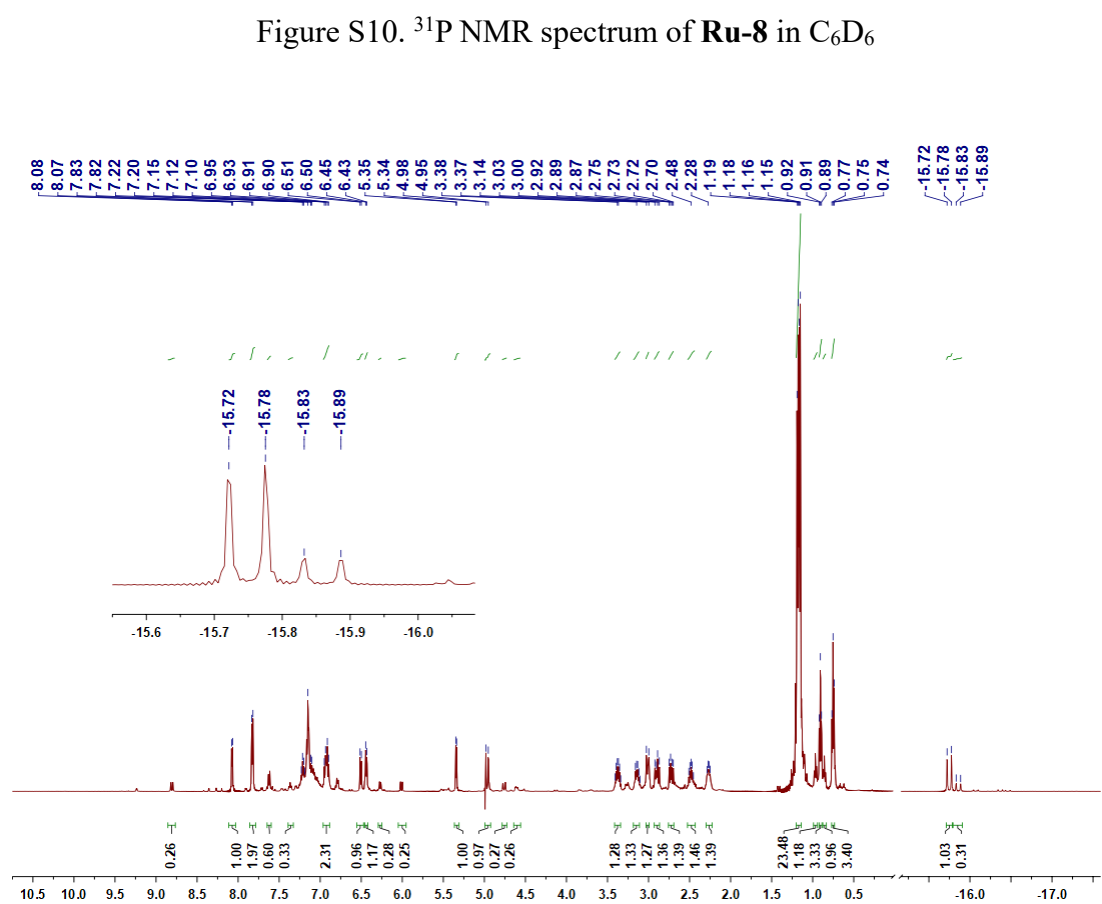
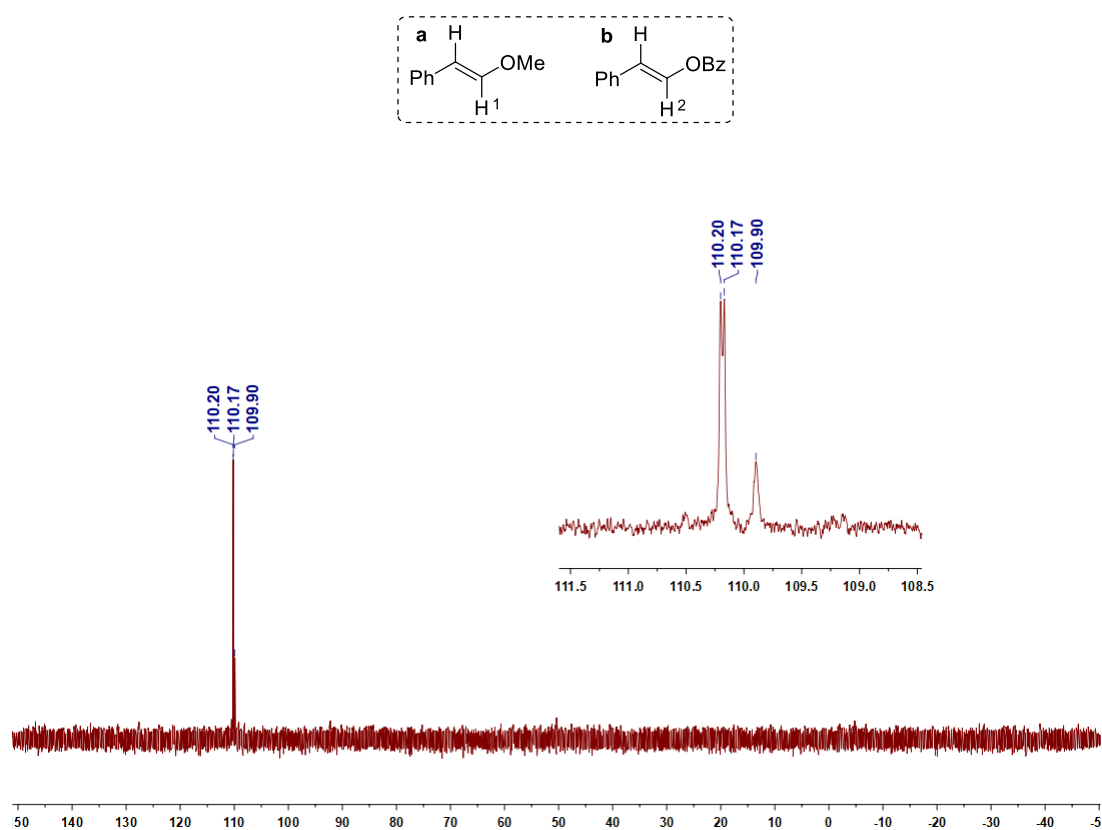
$^1\text{H}$  NMR (500 MHz,  $\text{C}_6\text{D}_6$ )  $\delta$  8.07 (d,  $J = 6.0$  Hz, 1H, OCHCHPh), 7.83 (d,  $J = 7.4$  Hz, 2H, PhH), 7.23 – 7.10 (m, 2H, PhH, overlapping with residual benzene), 6.95 – 6.90 (m, 2H, PhH and PyH), 6.51 (d,  $J = 7.9$  Hz, 1H, PyH), 6.44 (d,  $J = 7.1$  Hz, 1H, PyH), 5.34 (d,  $J = 6.0$  Hz, 1H, OCHCHPh), 4.97 (d,  $J = 14.6$  Hz, 1H, PyCHHN), 3.41 – 3.34 (m, 1H, NCHHCH<sub>3</sub>), 3.17 – 3.10 (m, 1H, NCHHCH<sub>3</sub>), 3.01 (d,  $J = 14.6$  Hz, 1H, PyCHHN), 2.90 (dd,  $J = 16.4, 10.2$  Hz, 1H, PyCHHP), 2.72 (dd,  $J = 16.4, 8.4$  Hz, 1H, PyCHHP), 2.53 – 2.43 (m, 1H, NCHHCH<sub>3</sub>), 2.27 (dd,  $J = 11.5, 5.7$  Hz, 1H, NCHHCH<sub>3</sub>), 1.18 (d,  $J = 7.2$  Hz, 9H, PC(CH<sub>3</sub>)<sub>3</sub>), 1.16 (d,  $J = 7.2$  Hz, 9H, PC(CH<sub>3</sub>)<sub>3</sub>), 0.91 (t,  $J = 6.6$  Hz, 3H, NCH<sub>2</sub>CH<sub>3</sub>), 0.75 (t,  $J = 6.6$  Hz, 3H, NCH<sub>2</sub>CH<sub>3</sub>), -15.75 (d,  $J = 26.9$  Hz, 1H, RuH).

$^{13}\text{C}$  NMR (126 MHz,  $\text{C}_6\text{D}_6$ )  $\delta$  208.74 (d,  $J = 16.6$  Hz, RuCO), 166.25 (s, OCHCHPh), 161.70 (d,  $J = 4.1$  Hz, PyC), 161.59 (s, PyC), 144.00 (s, PhC), 136.59 (s, PyC), 127.96 (s, PhC), 125.53 (s, PhC), 120.38 (s, PhC), 119.81 (d,  $J = 9.2$  Hz, PyC), 118.68 (s, PyC), 99.94 (s, OCHCHPh), 64.43 (s, PyCH<sub>2</sub>N), 53.89 (s, NCH<sub>2</sub>CH<sub>3</sub>), 50.30 (s, NCH<sub>2</sub>CH<sub>3</sub>), 37.59 (d,  $J = 12.4$  Hz, PC(CH<sub>3</sub>)), 37.40 (d,  $J = 19.5$  Hz, PyCH<sub>2</sub>P), 34.53 (d,  $J = 22.9$  Hz, PC(CH<sub>3</sub>)), 30.36 (d,  $J = 3.0$  Hz, PC(CH<sub>3</sub>)<sub>3</sub>), 29.33 (d,  $J = 4.3$  Hz, PC(CH<sub>3</sub>)<sub>3</sub>), 10.68 (s, NCH<sub>2</sub>CH<sub>3</sub>), 8.77 (s, NCH<sub>2</sub>CH<sub>3</sub>).

$^{31}\text{P}$  NMR (202 MHz,  $\text{C}_6\text{D}_6$ )  $\delta$  110.19 (d,  $J = 6.4$  Hz).

It should be mentioned that the proton chemical shift of the methyne group (CH) connected to the ORu appears at the low field (8.07 ppm), in the range characteristic of corresponding enol ethers. For example, the chemical shift of H<sup>1</sup> on compound **a** below is 7.05 ppm, and H<sup>2</sup> on compound **b** is 8.10 ppm, according to the

literature.<sup>15,16</sup>





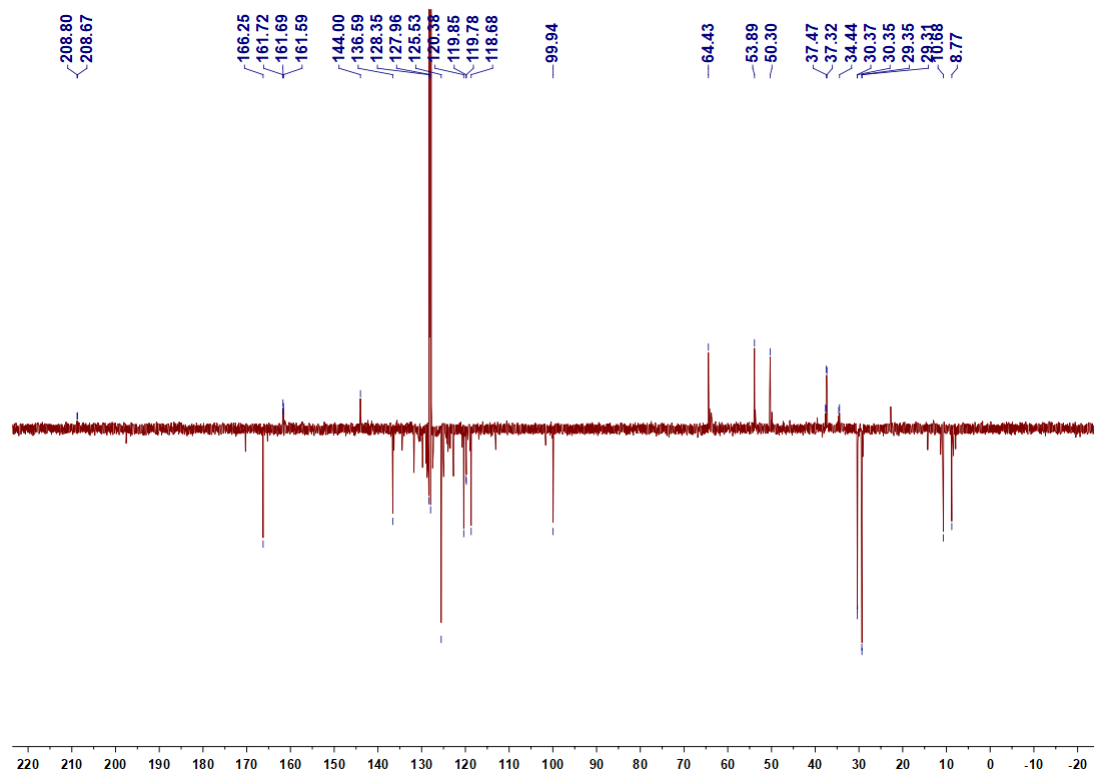


Figure S12.  $^{13}\text{C}$ -DEPTQ NMR spectrum of **Ru-8** in  $\text{C}_6\text{D}_6$

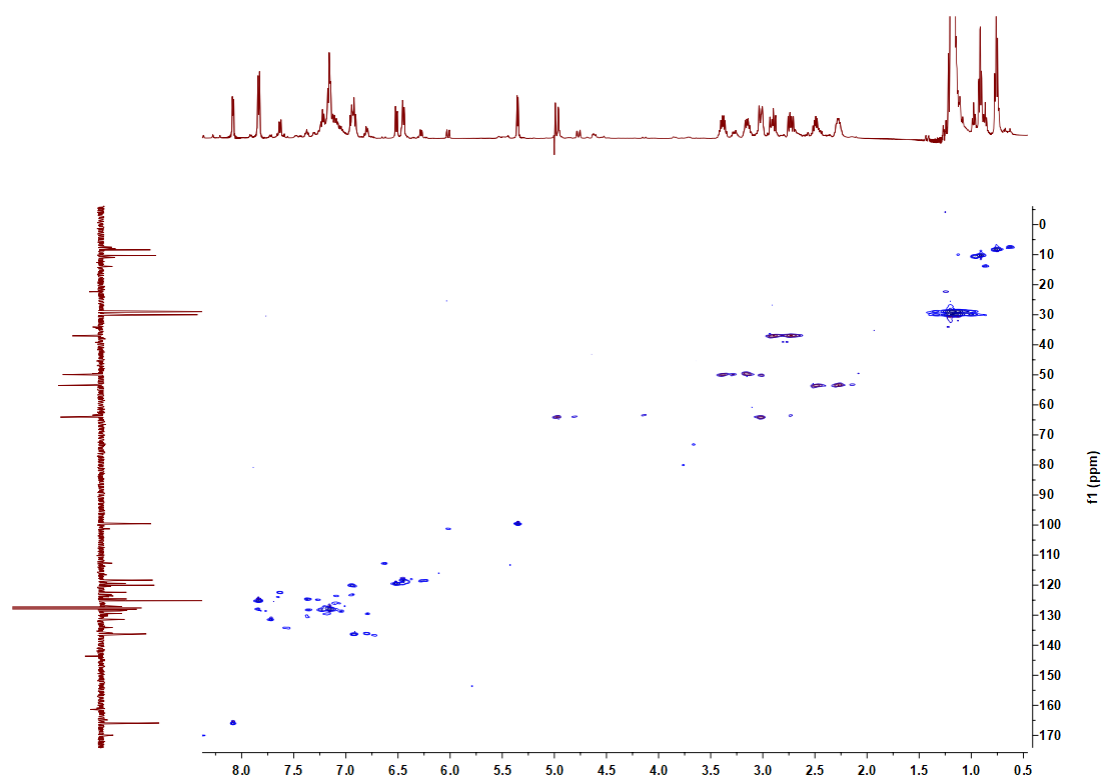


Figure S13. HSQC spectrum of **Ru-8** in  $\text{C}_6\text{D}_6$

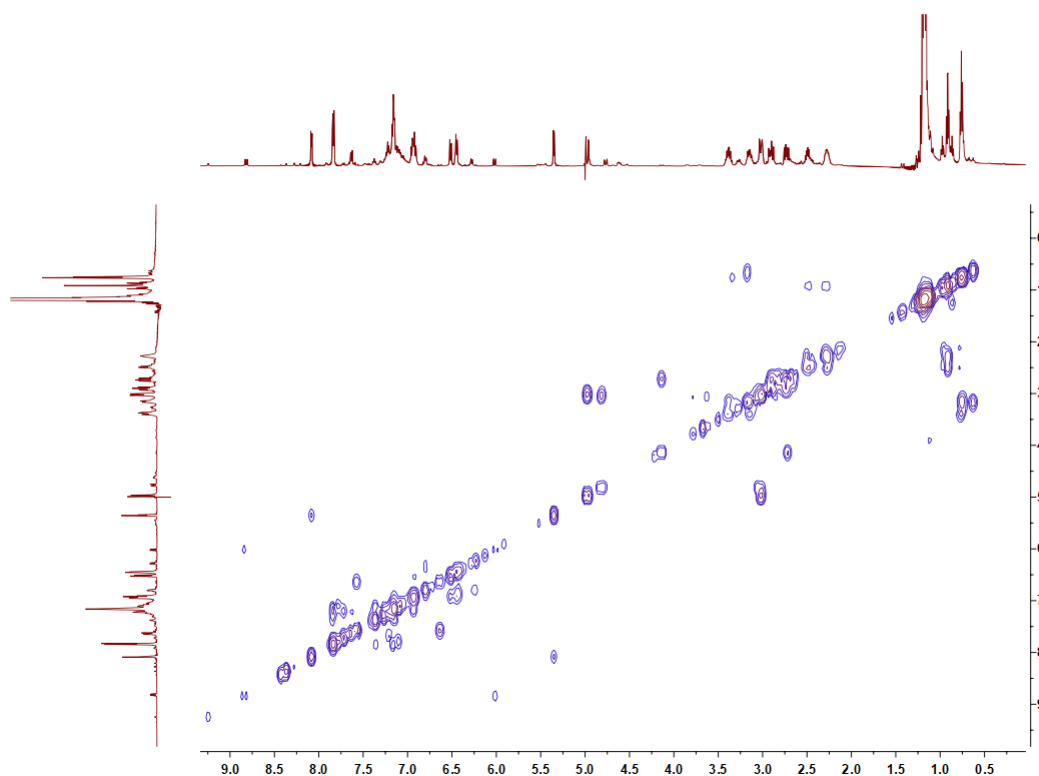
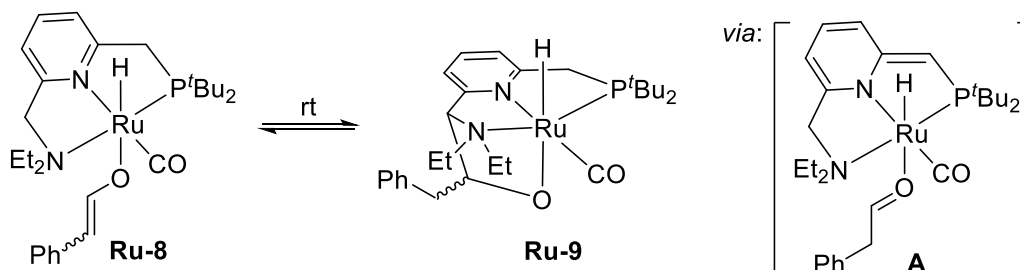


Figure S14. H-H COSY spectrum of **Ru-8** in  $C_6D_6$

**Ru-8** was unstable at room temperature, and part of it slowly converted to another new complex reaching a chemical equilibrium. On the basis of the chemical shifts of the  $^{31}P$  NMR and  $^1H$  NMR, we propose that the enolate on **Ru-8** isomerizes to an aldehyde intermediate **A**, via a keto-enol equilibrium, which rapidly converted to **Ru-9** via electrophilic attack of the aldehyde on the side arm of intermediate **A**.



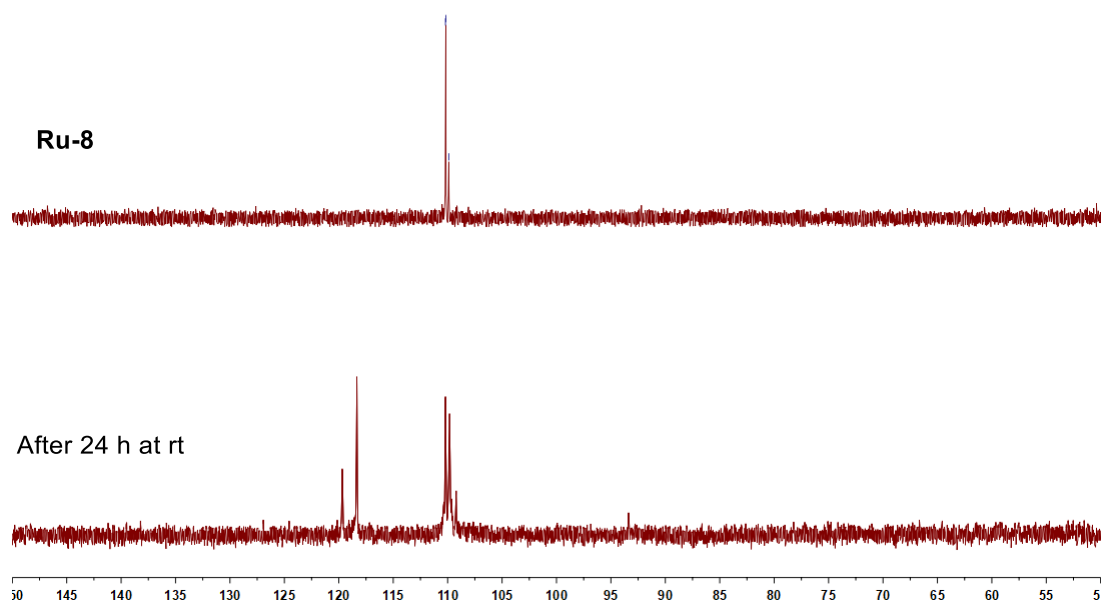


Figure S15.  $^{31}\text{P}$  NMR spectrum of the chemical equilibrium in  $\text{C}_6\text{D}_6$

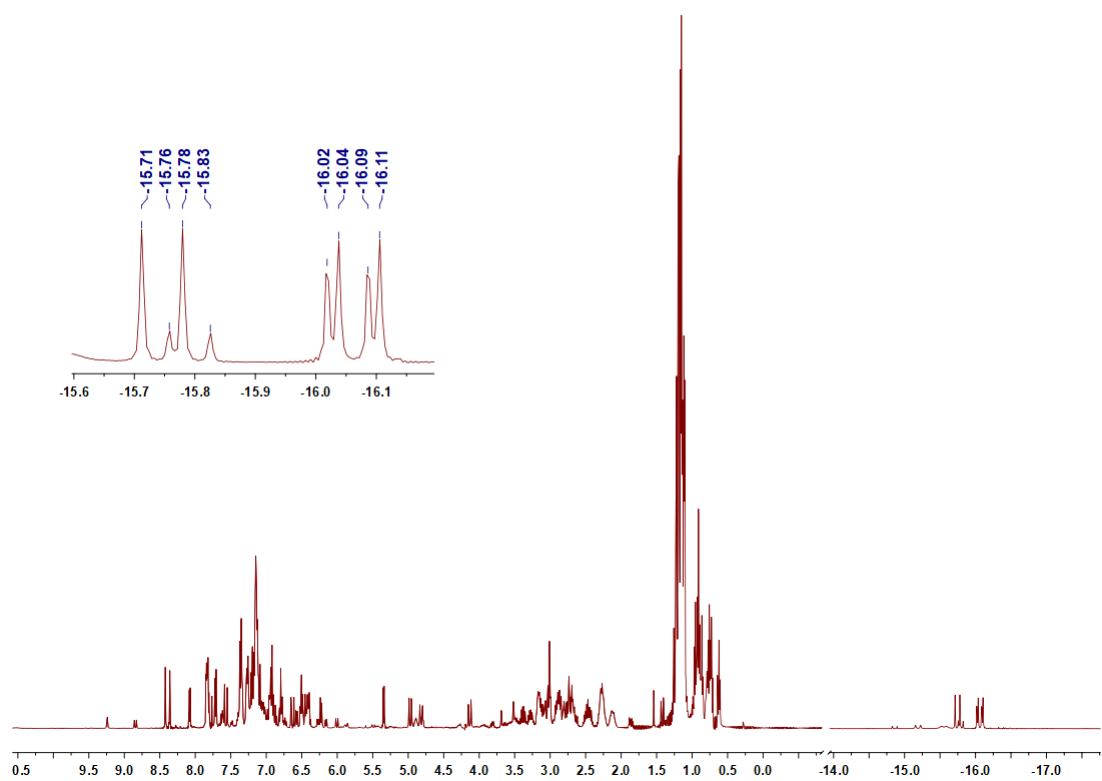


Figure S16.  $^1\text{H}$  NMR spectrum of the chemical equilibrium in  $\text{C}_6\text{D}_6$

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## 6. NMR spectra of amides

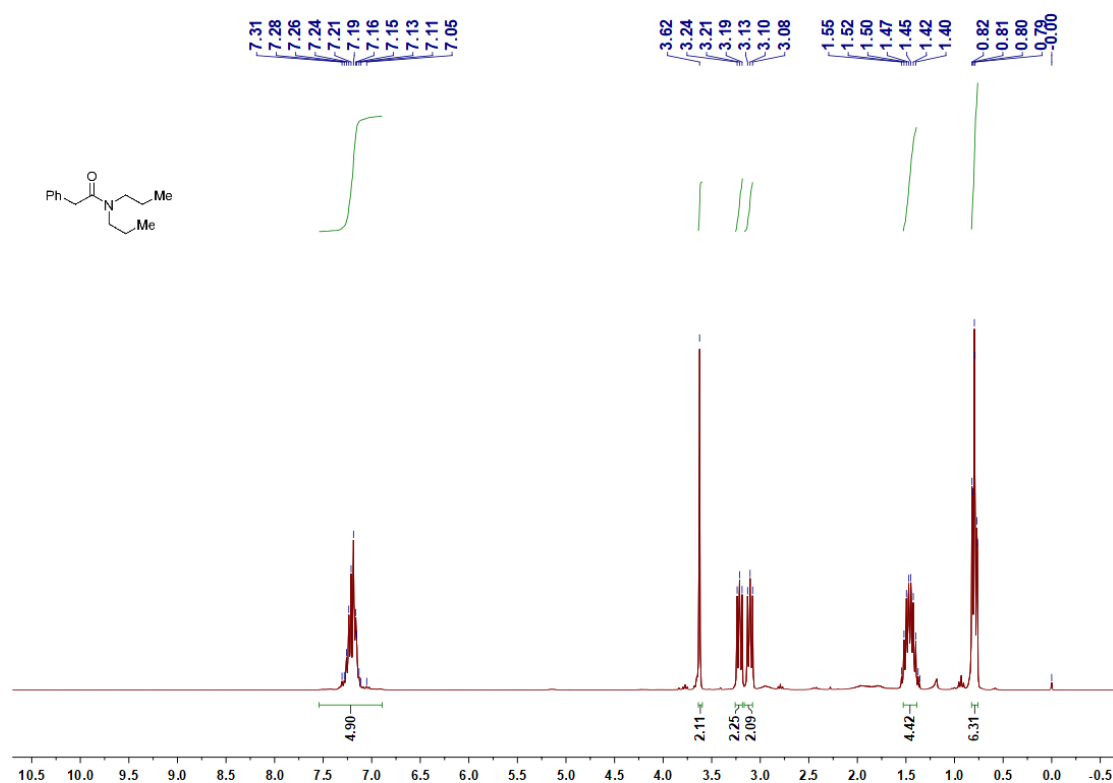


Figure S17. <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>) spectrum of compound 3a

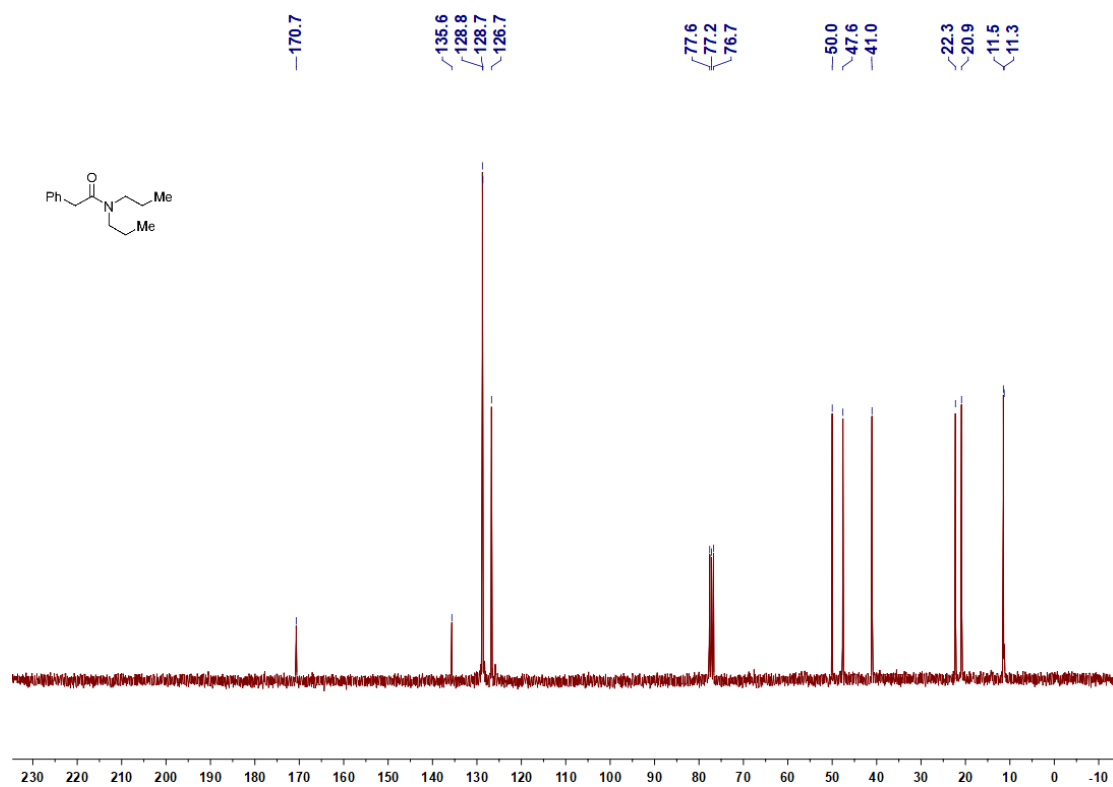


Figure S18. <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>) spectrum of compound 3a

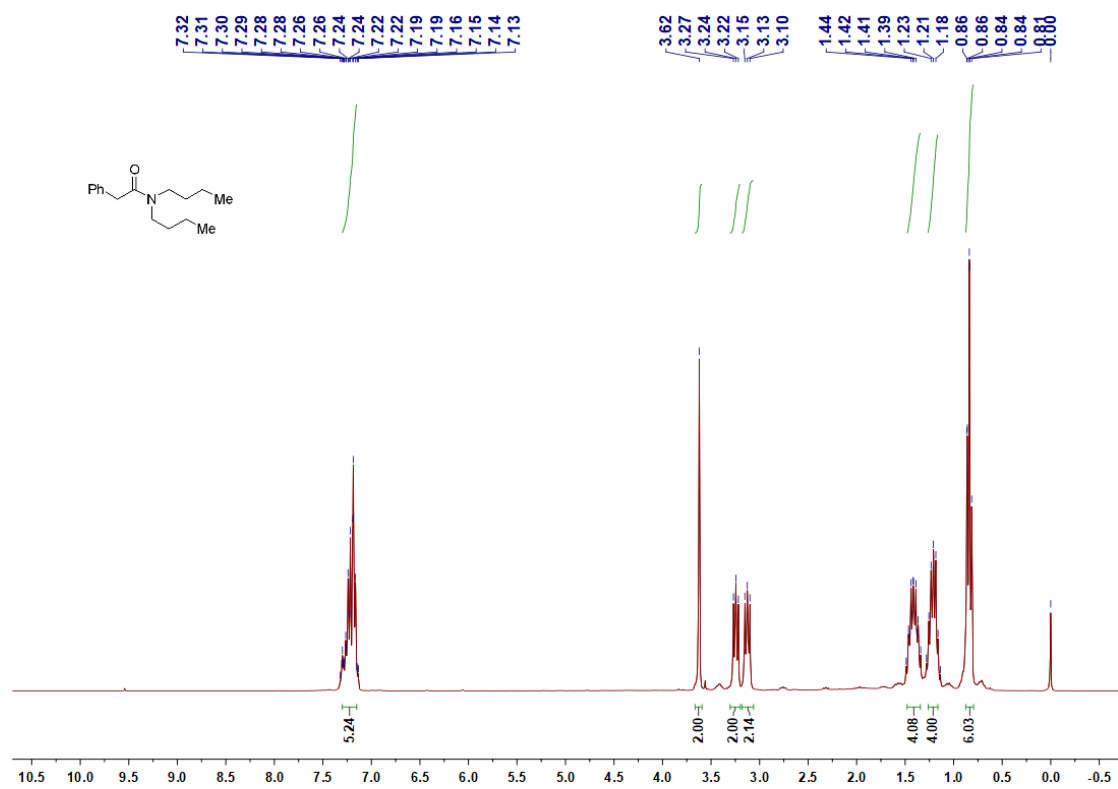


Figure S19. <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>) spectrum of compound **3b**

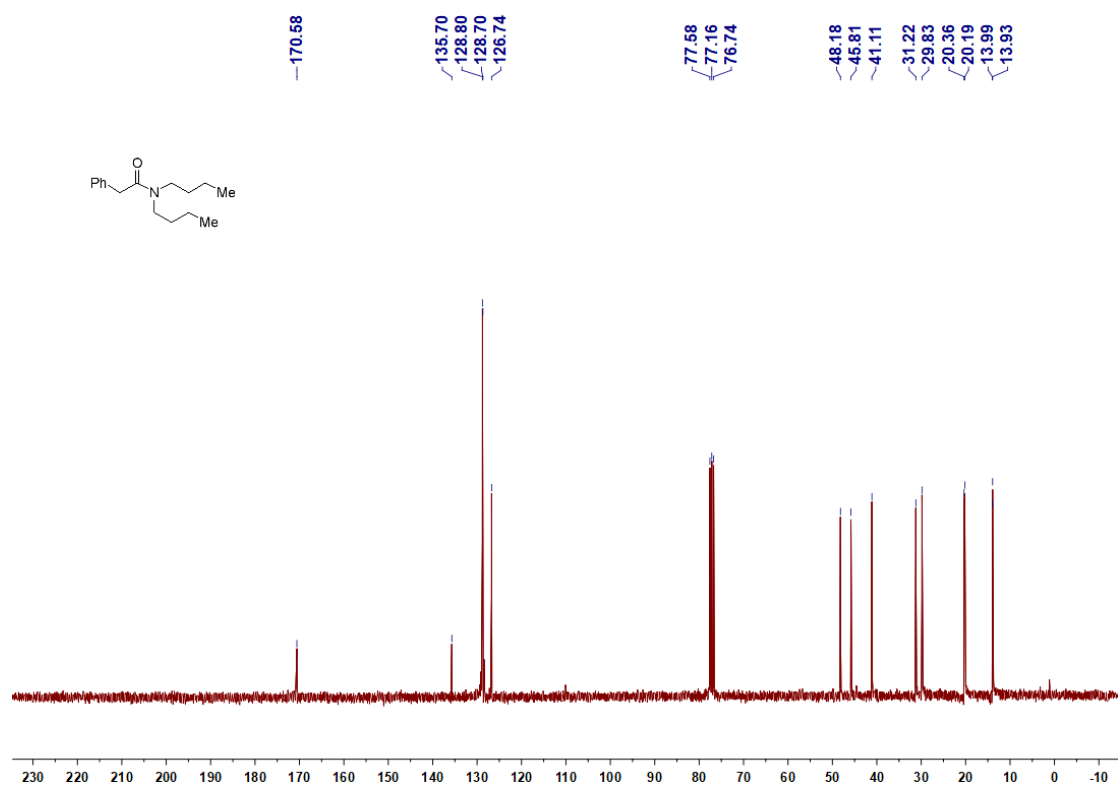


Figure S20. <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>) spectrum of compound **3b**

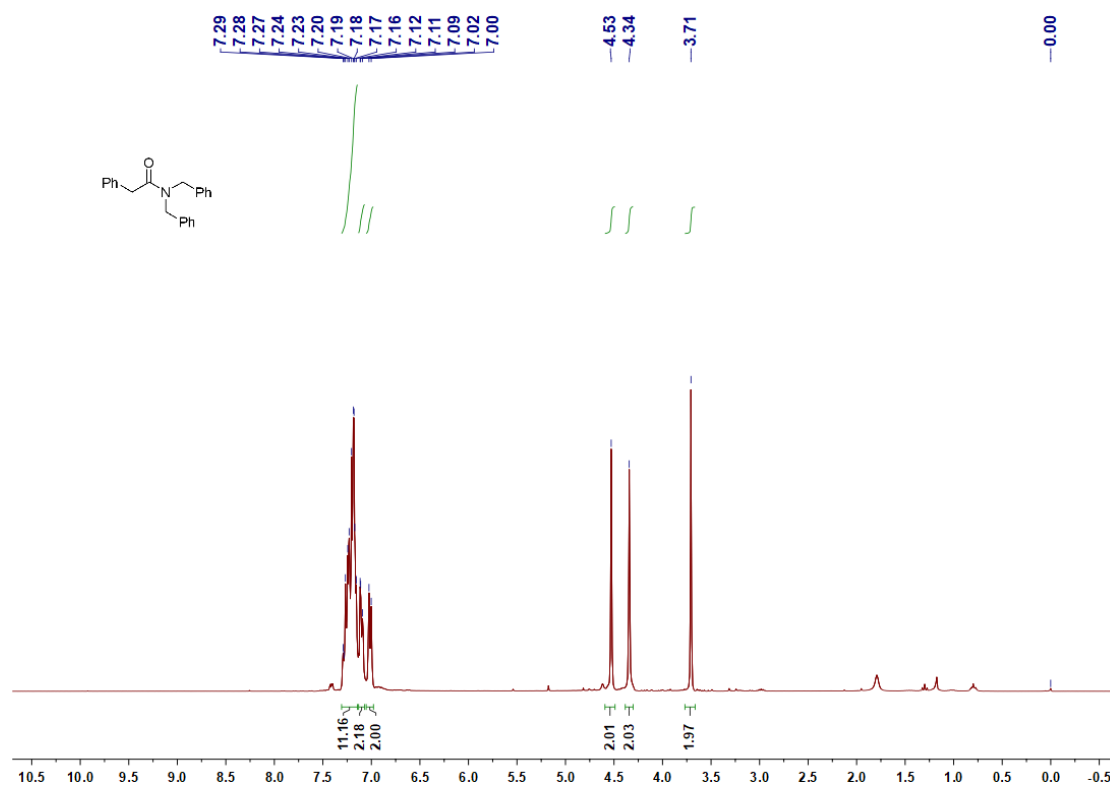


Figure S21.  $^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ ) spectrum of compound **3c**

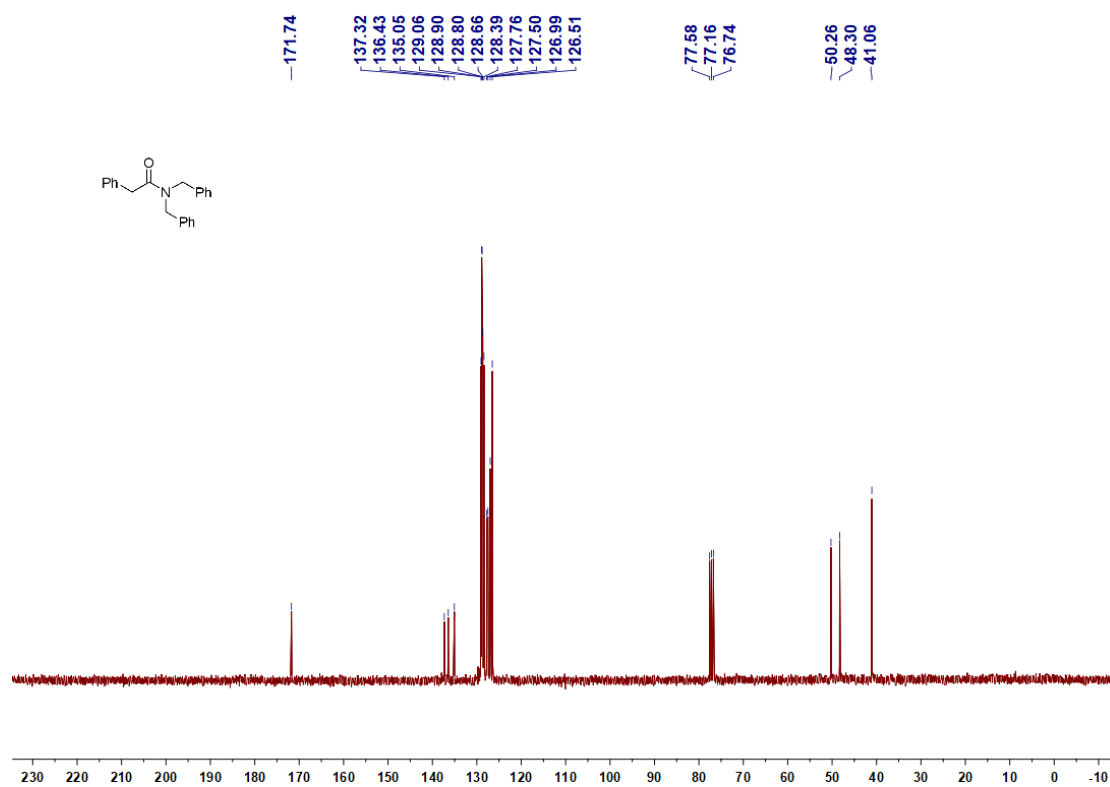


Figure S22.  $^{13}\text{C}$  NMR (75 MHz,  $\text{CDCl}_3$ ) spectrum of compound **3c**

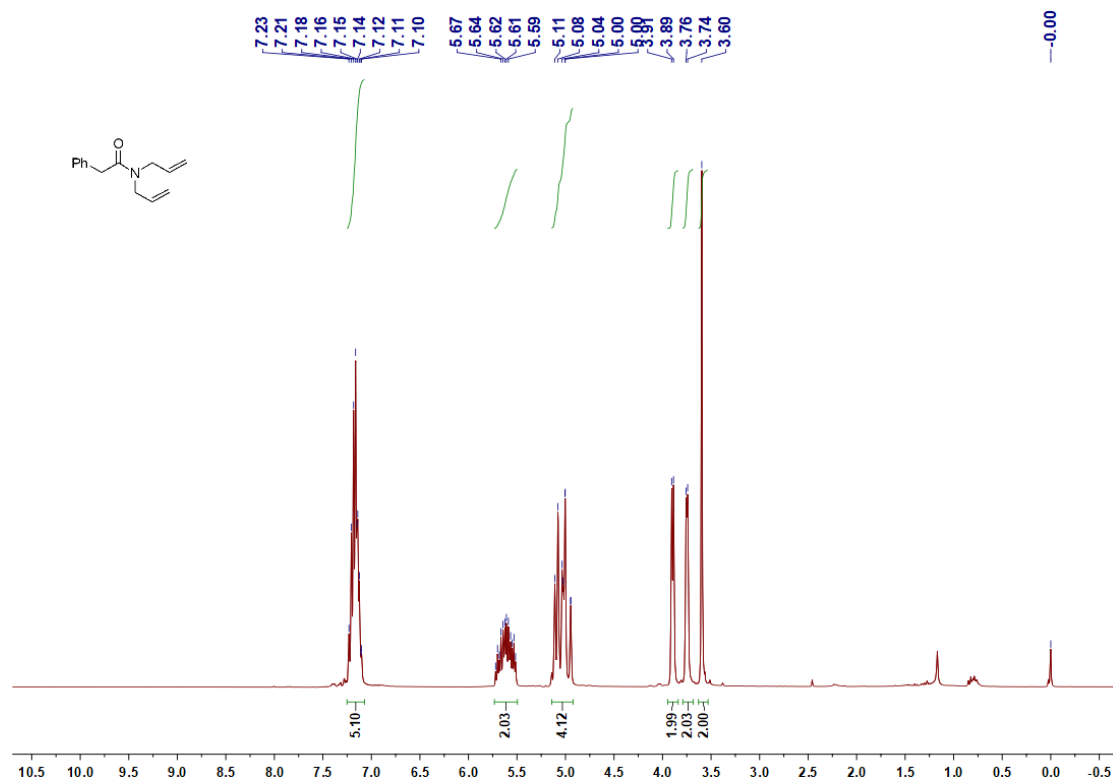


Figure S23. <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>) spectrum of compound 3d

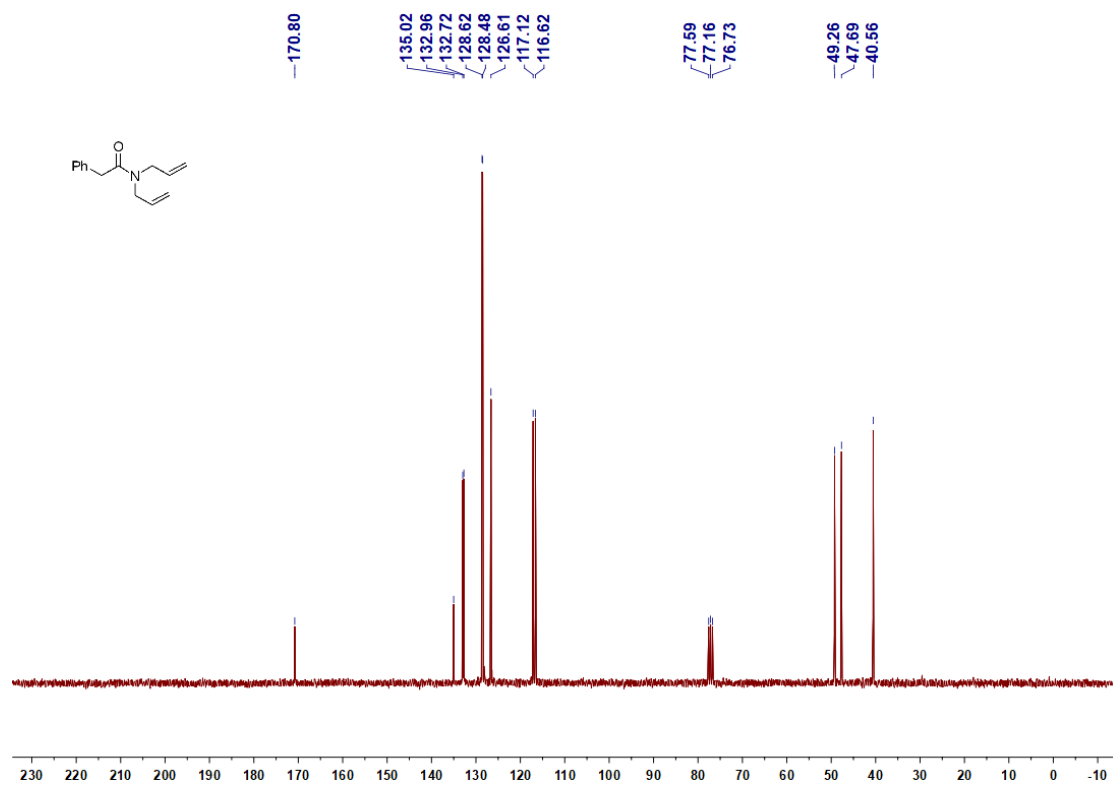


Figure S24. <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>) spectrum of compound 3d



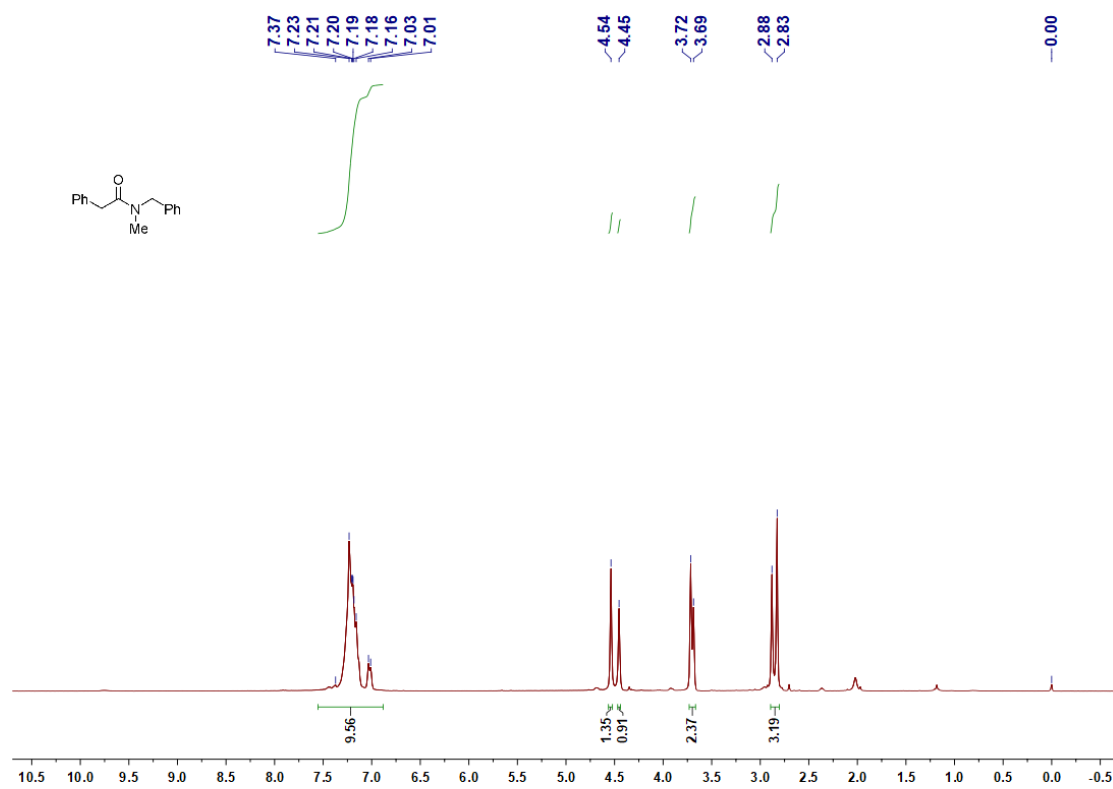


Figure S25. <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>) spectrum of compound **3e**

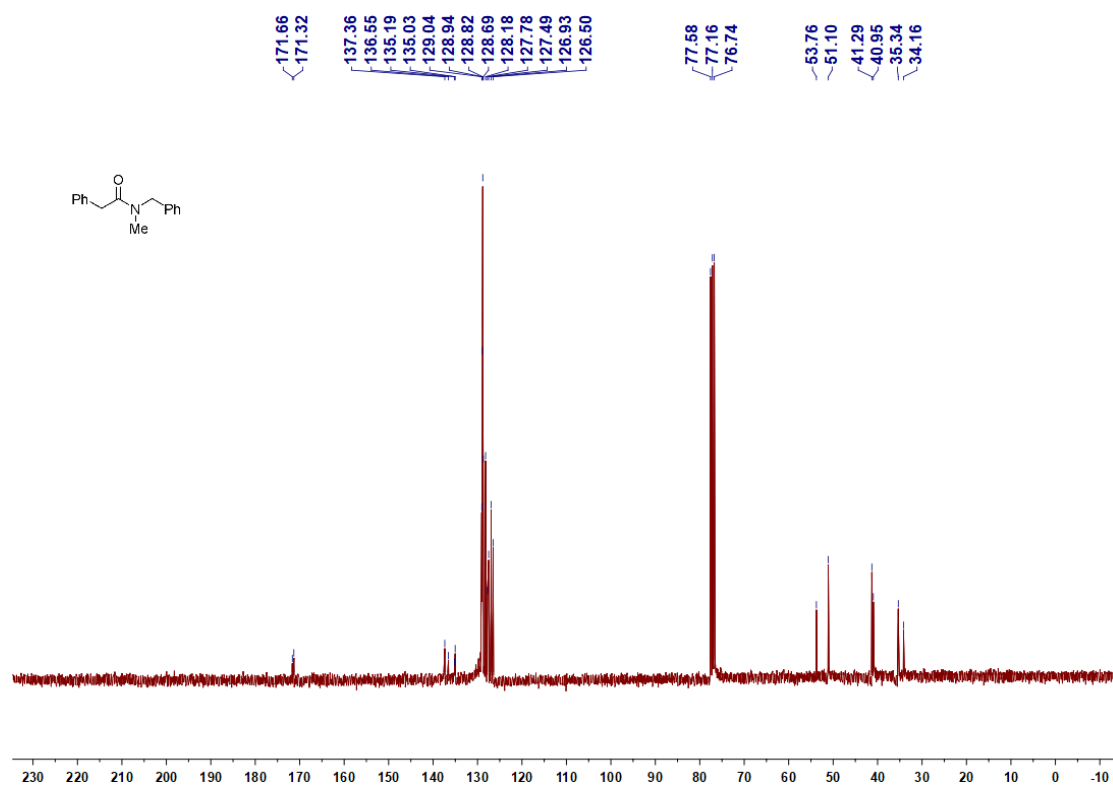


Figure S26. <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>) spectrum of compound **3e**

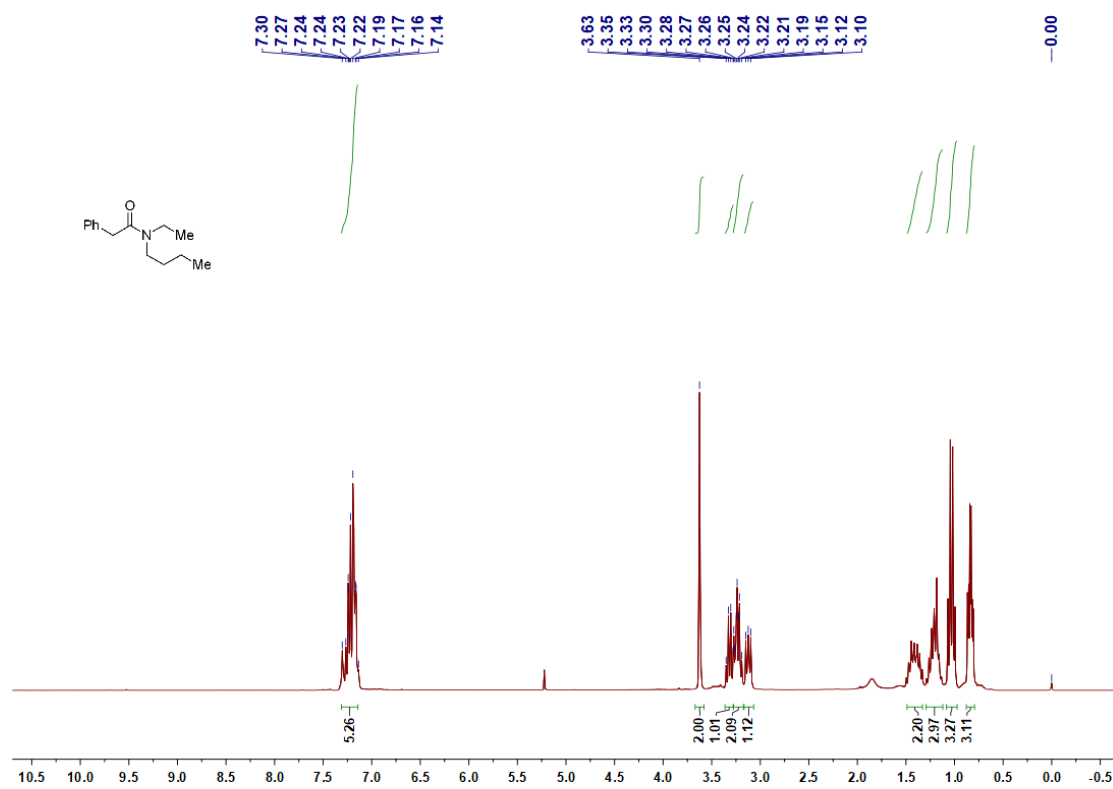


Figure S27. <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>) spectrum of compound **3f**

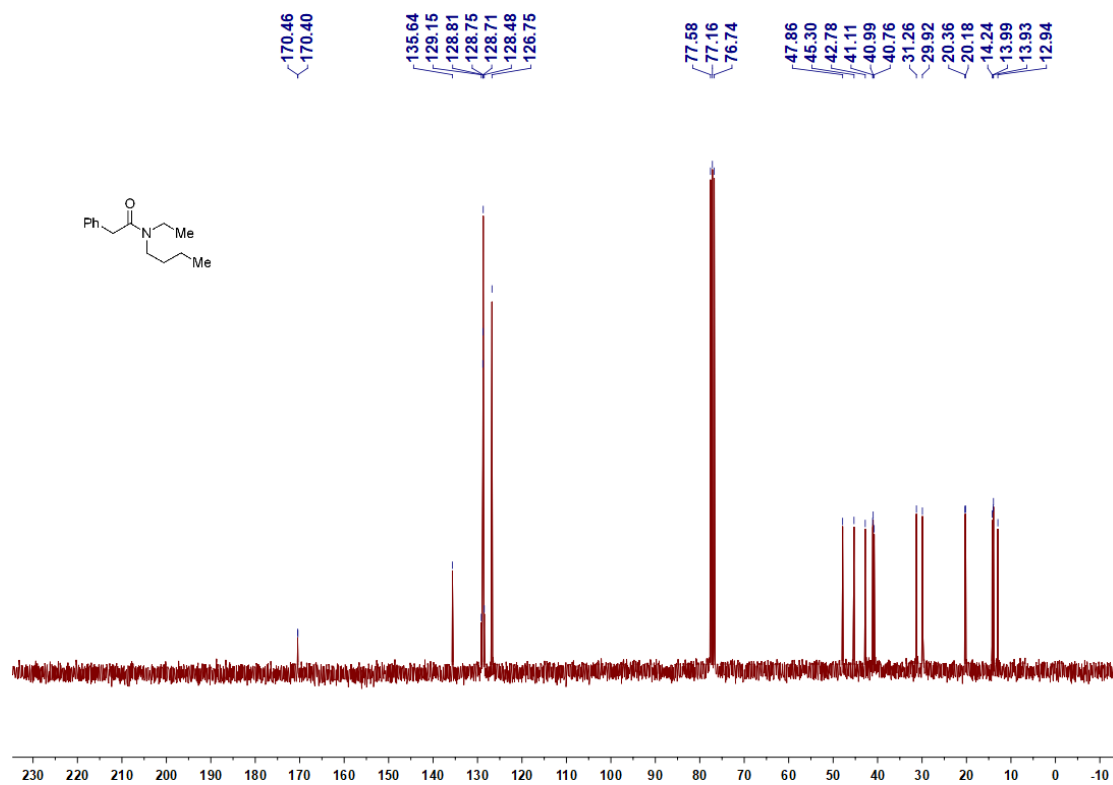


Figure S28. <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>) spectrum of compound **3f**

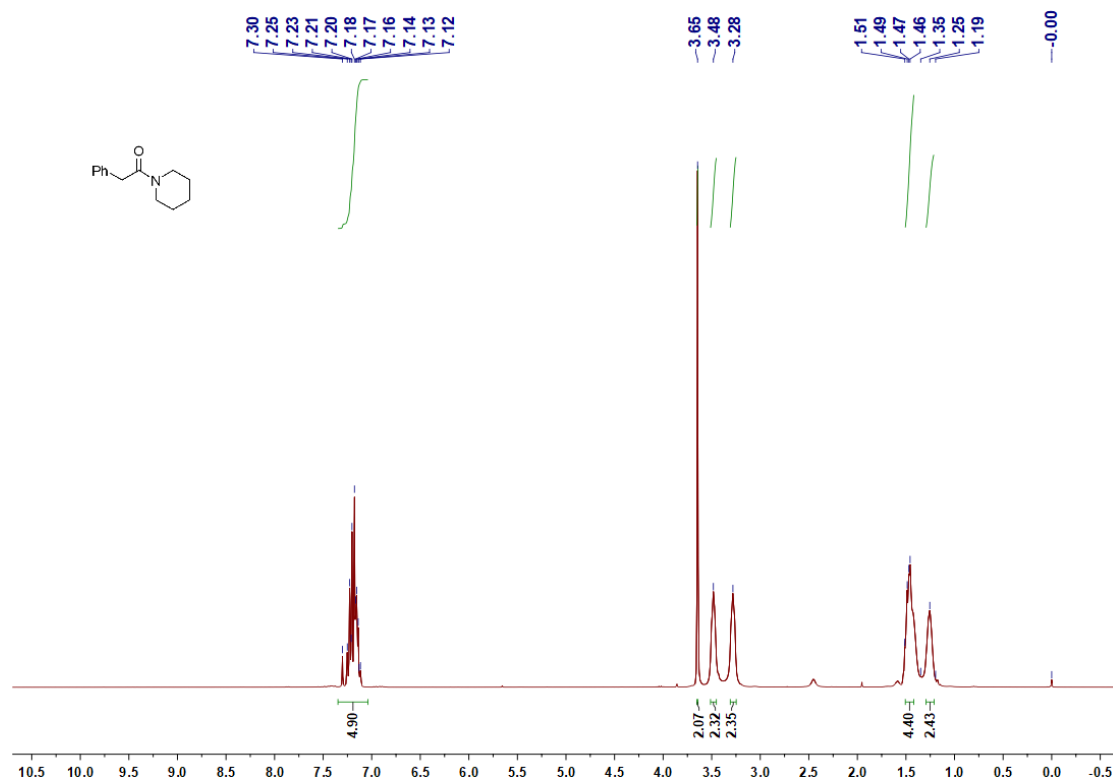


Figure S29.  $^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ ) spectrum of compound **3g**

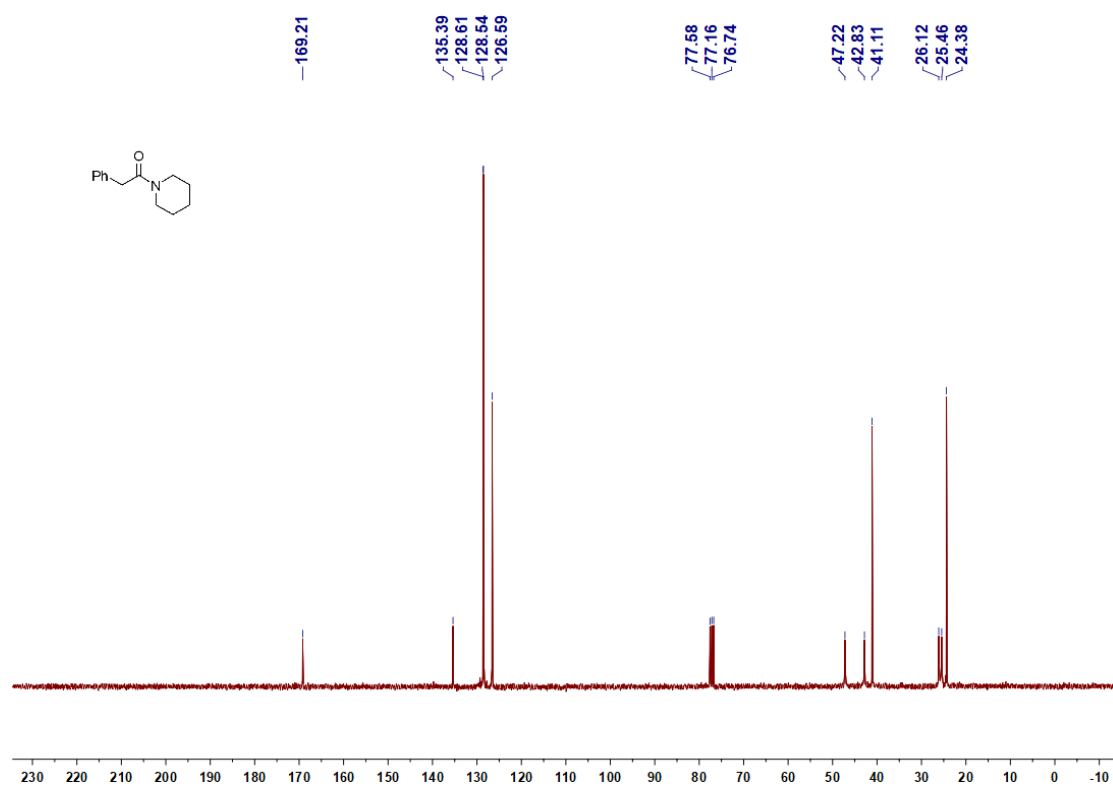


Figure S30.  $^{13}\text{C}$  NMR (75 MHz,  $\text{CDCl}_3$ ) spectrum of compound **3g**

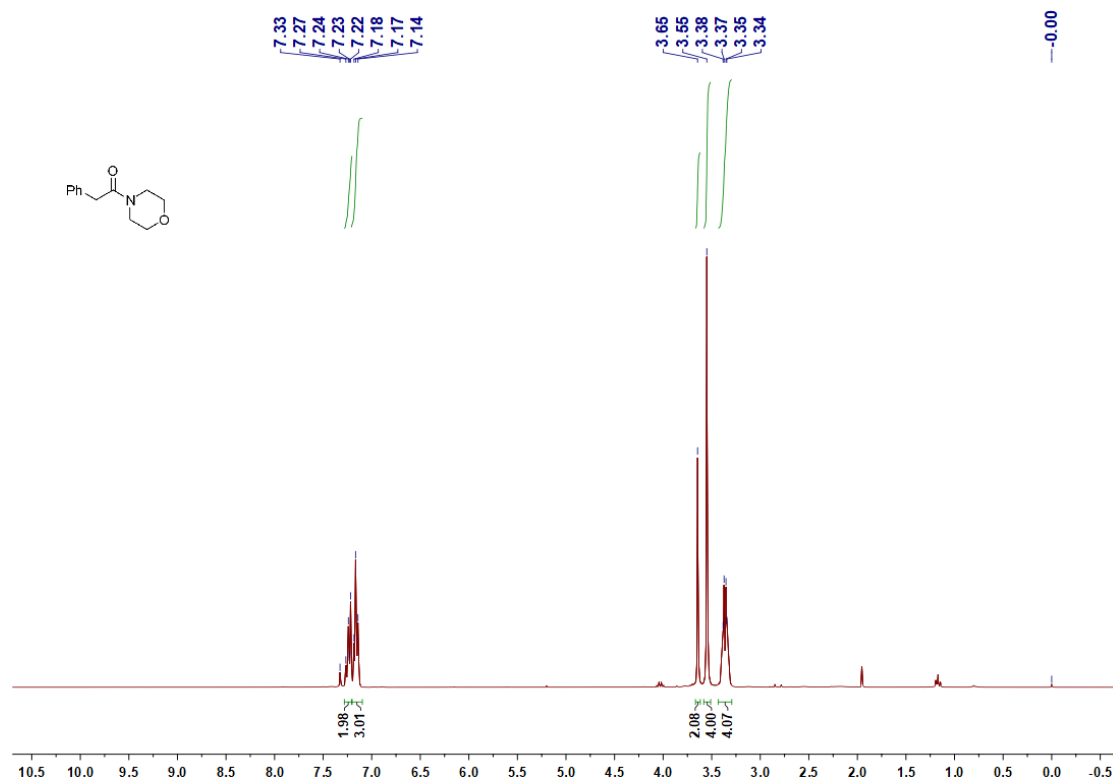


Figure S31. <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>) spectrum of compound **3h**

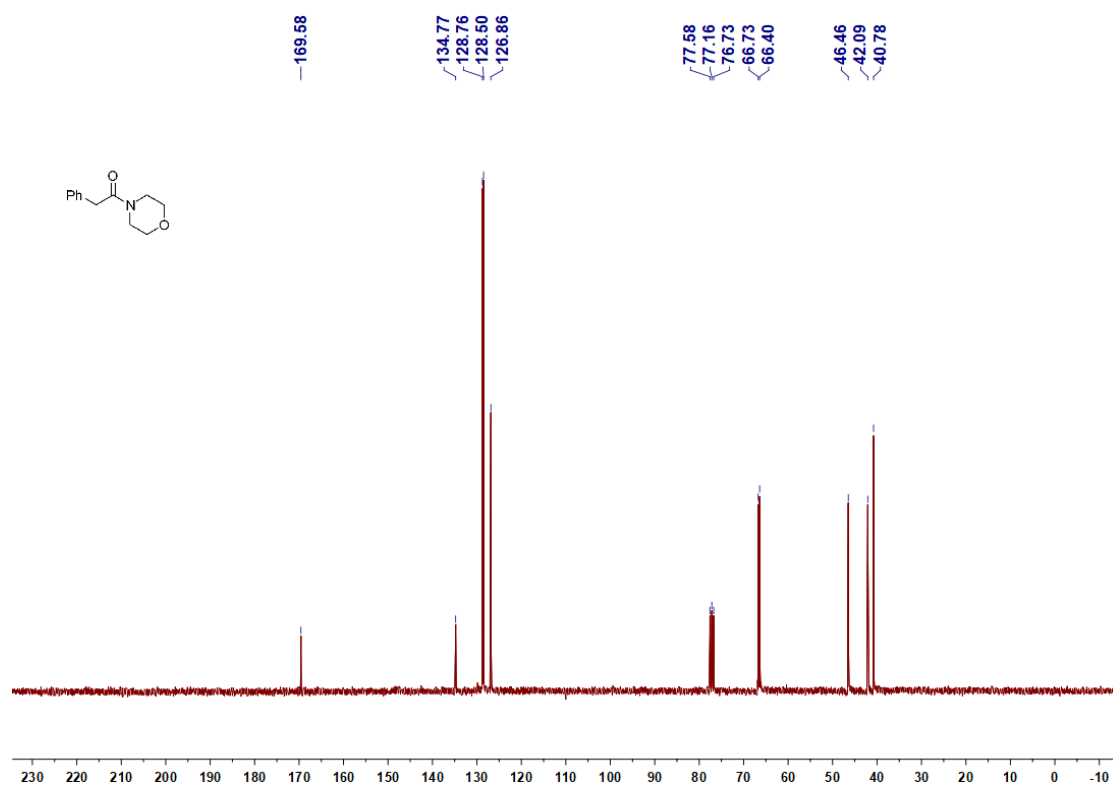


Figure S32. <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>) spectrum of compound **3h**

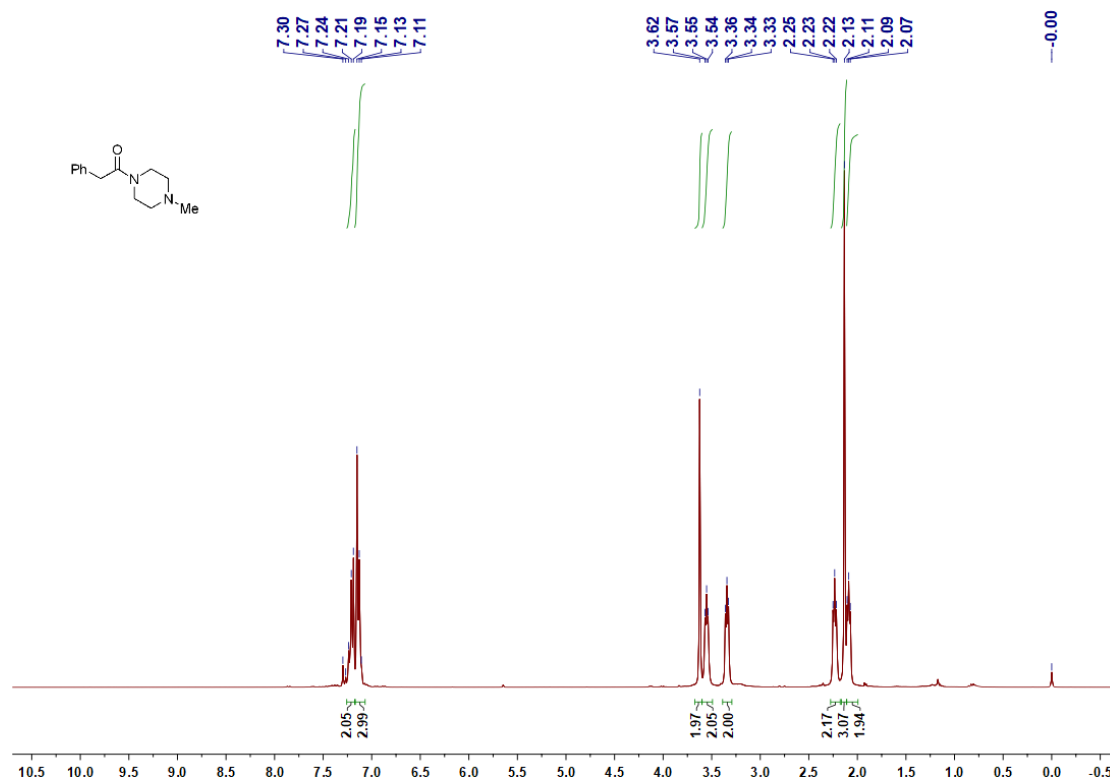


Figure S33. <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>) spectrum of compound **3i**

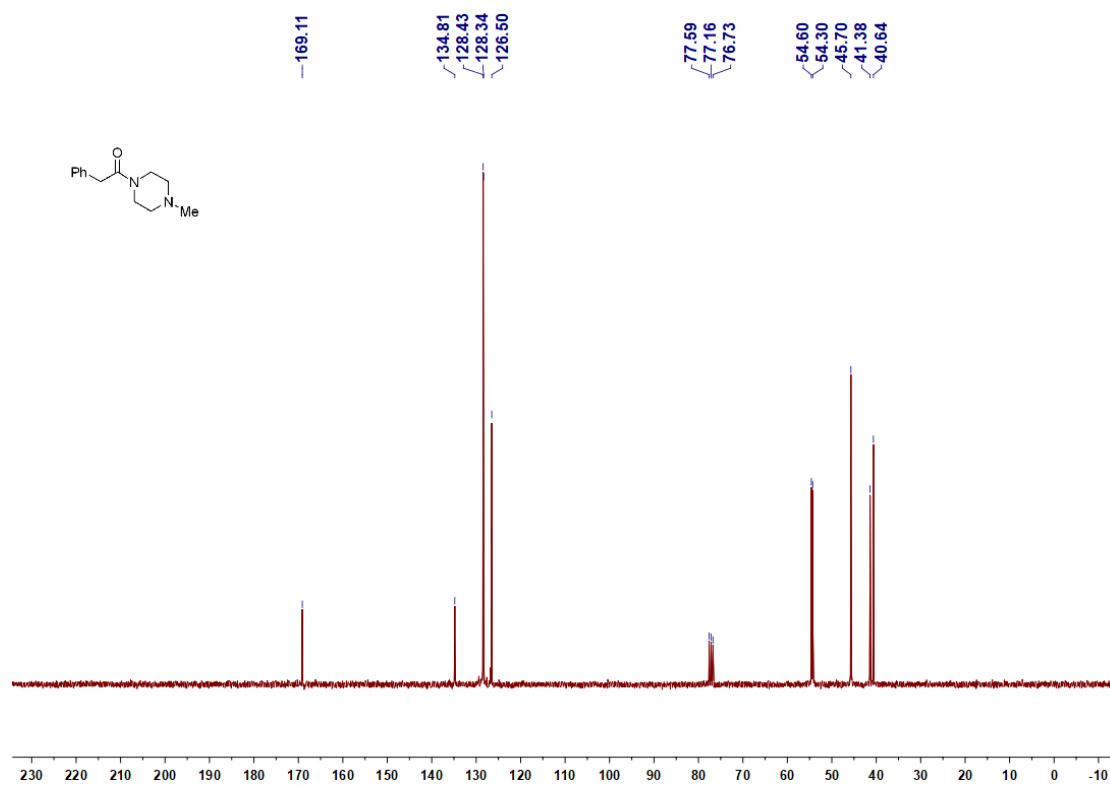


Figure S34. <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>) spectrum of compound **3i**

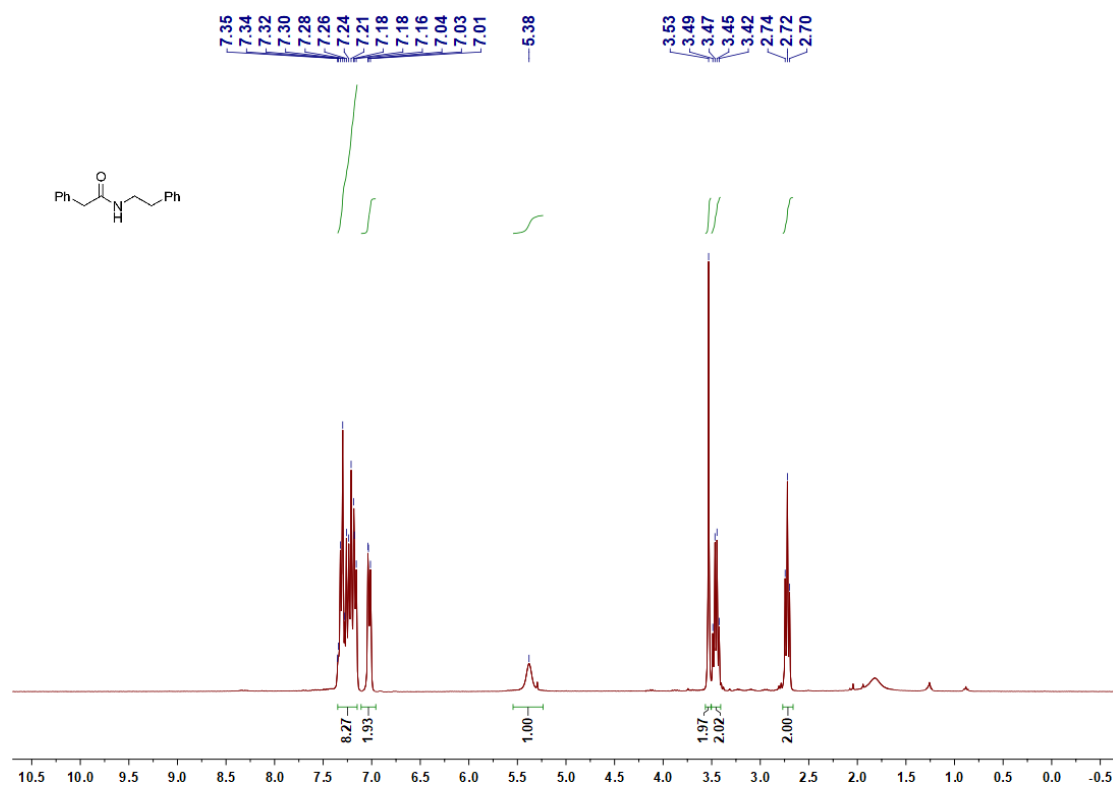


Figure S35. <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>) spectrum of compound **3j**

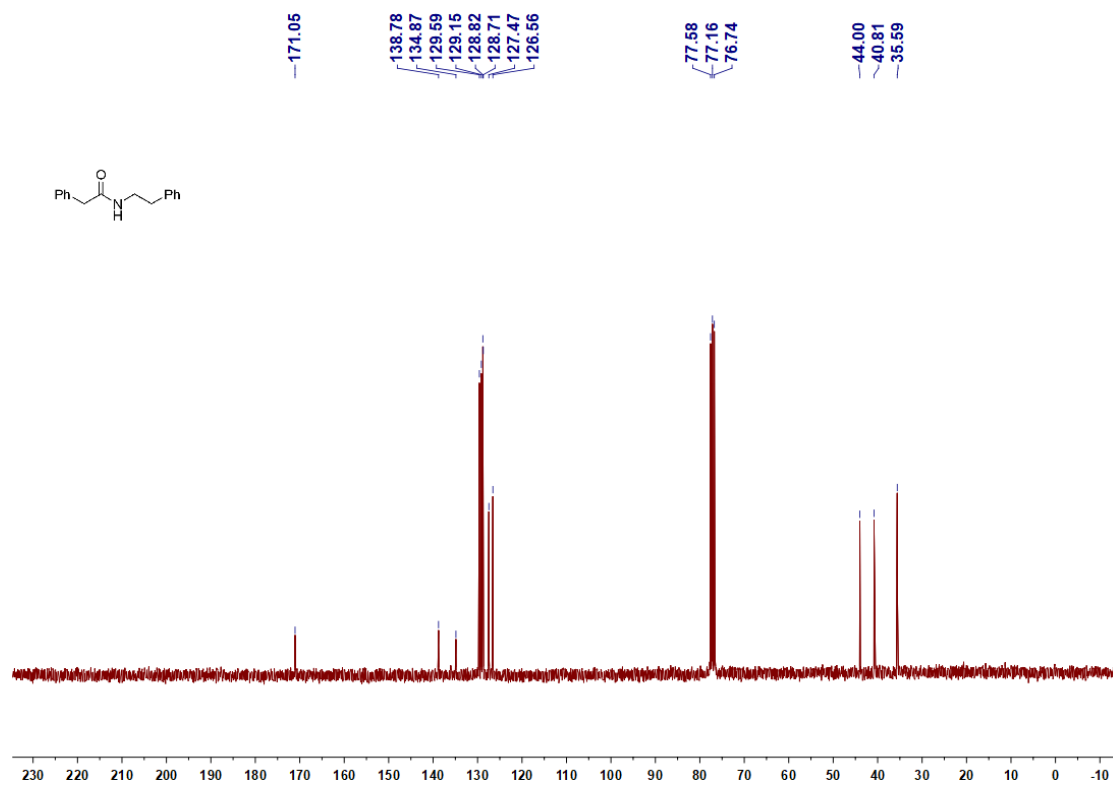


Figure S36. <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>) spectrum of compound **3j**

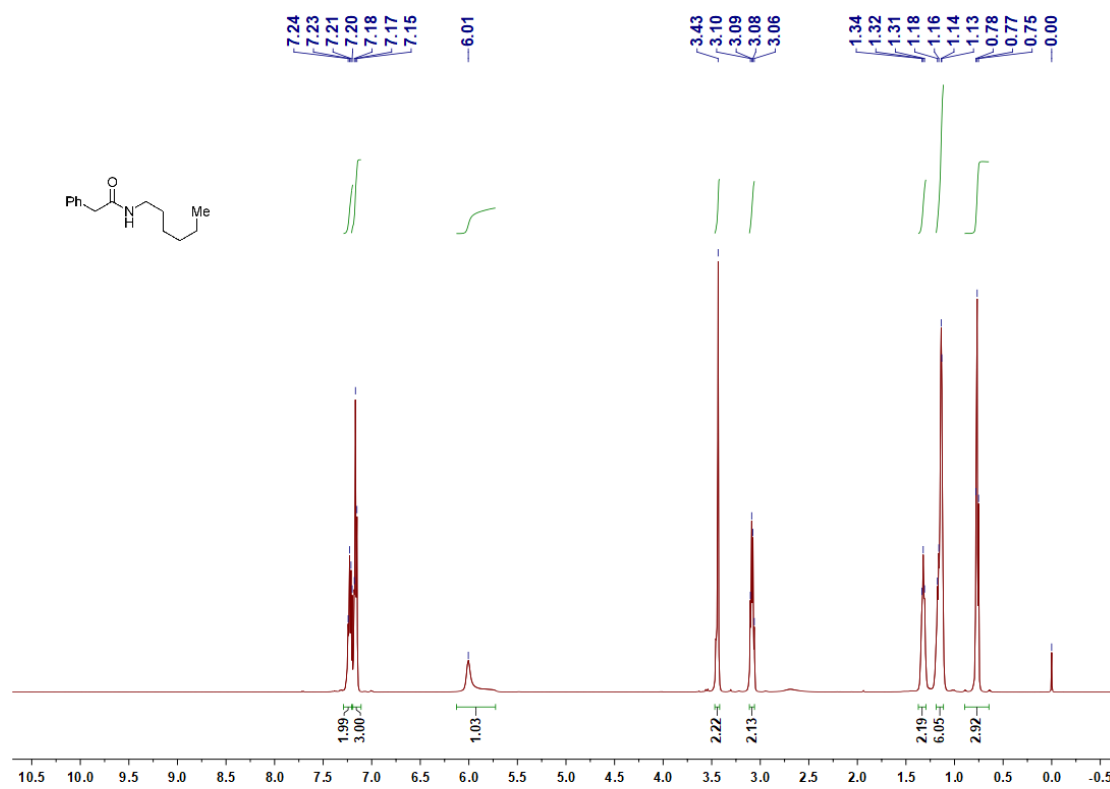


Figure S37. <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>) spectrum of compound **3k**

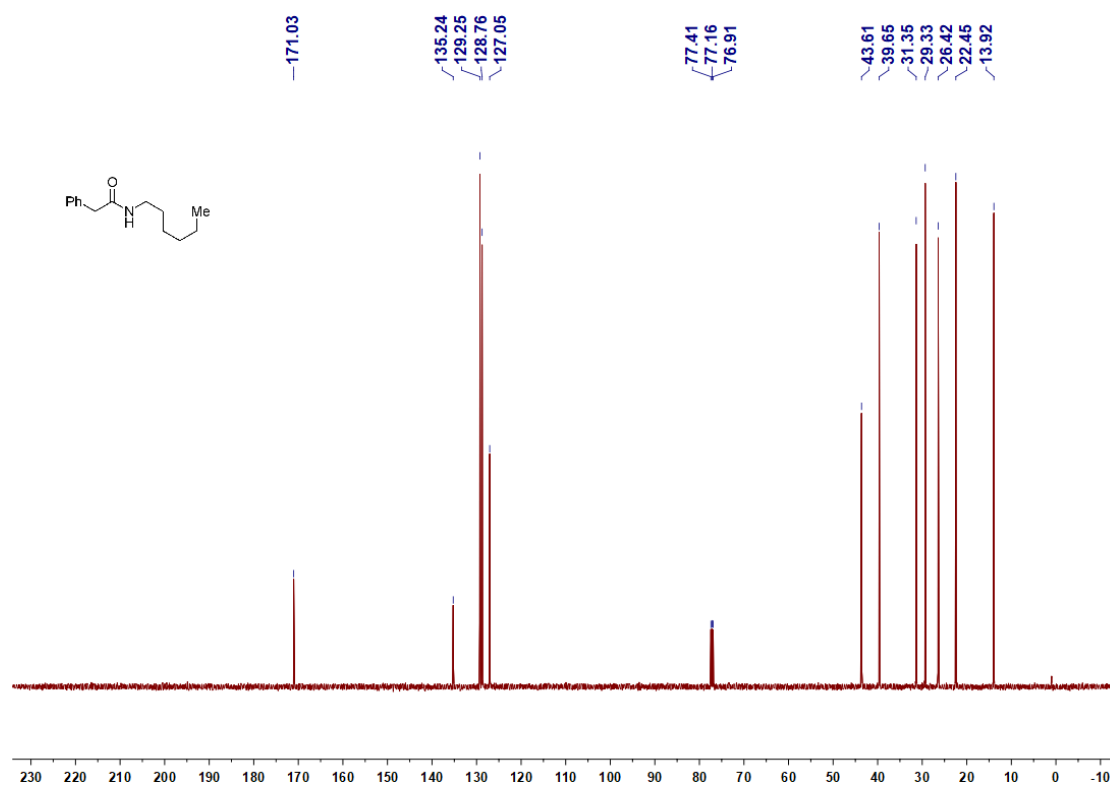


Figure S38. <sup>13</sup>C NMR (126 MHz, CDCl<sub>3</sub>) spectrum of compound **3k**

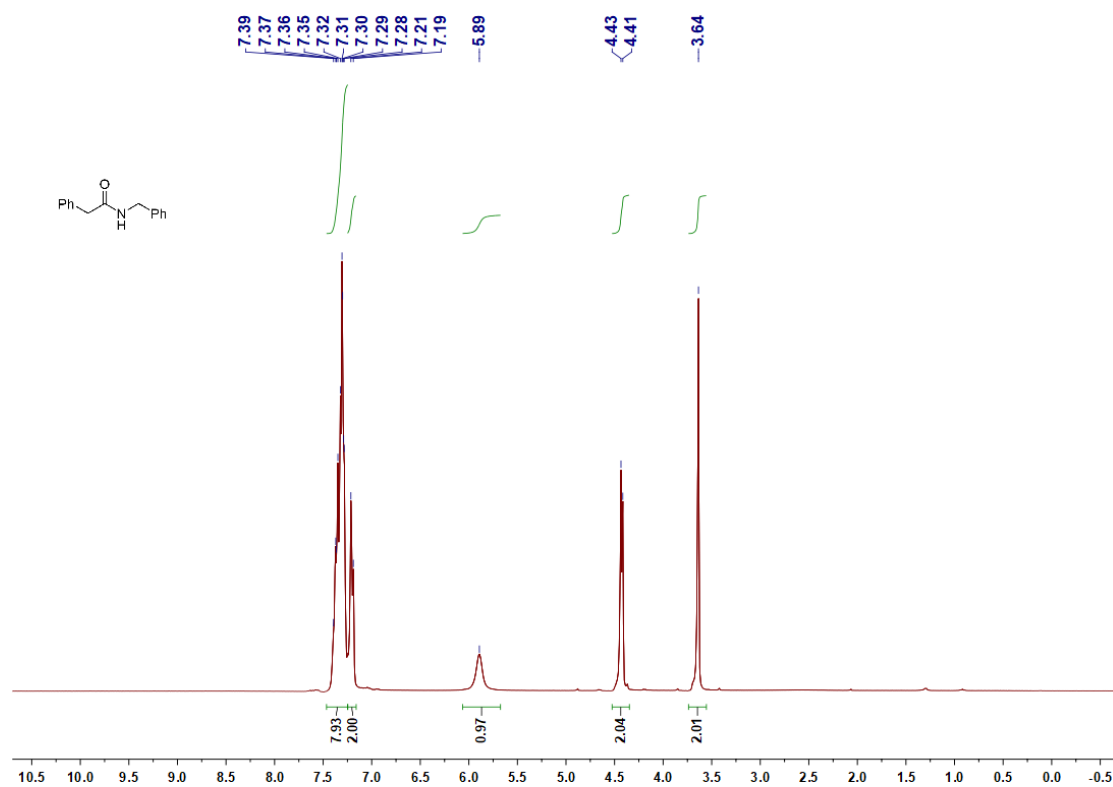


Figure S39.  $^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ ) spectrum of compound **31**

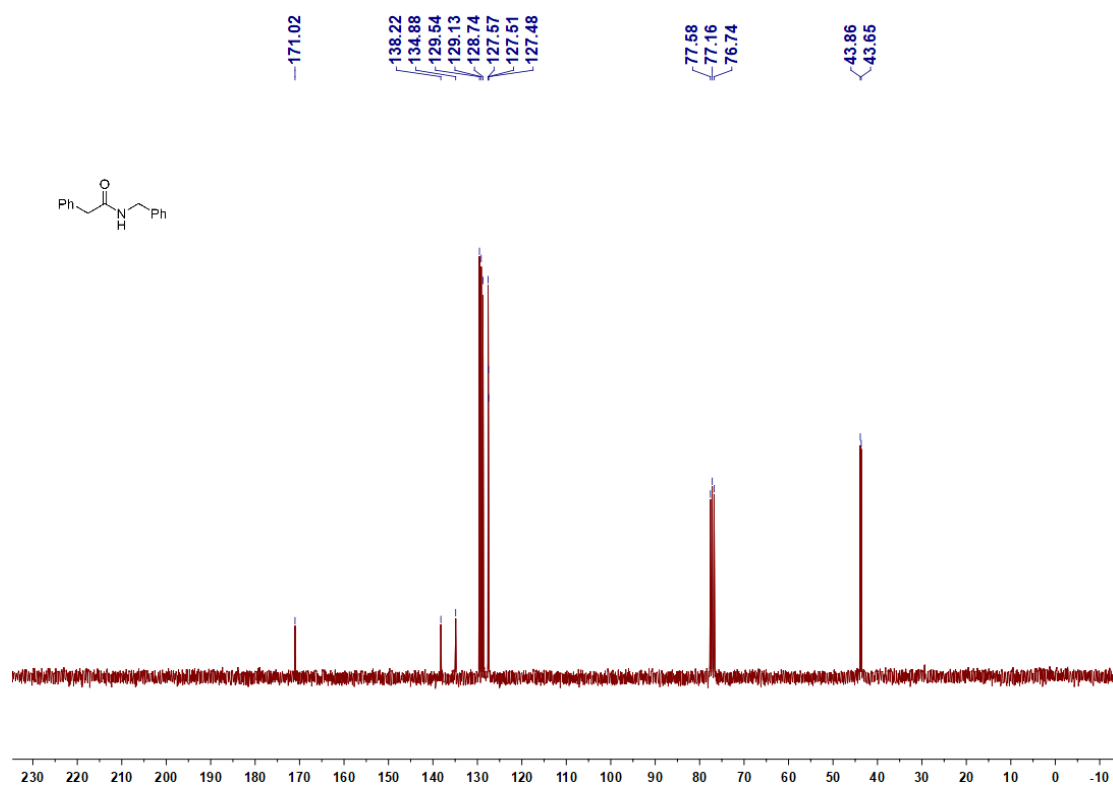


Figure S40.  $^{13}\text{C}$  NMR (75 MHz,  $\text{CDCl}_3$ ) spectrum of compound **31**



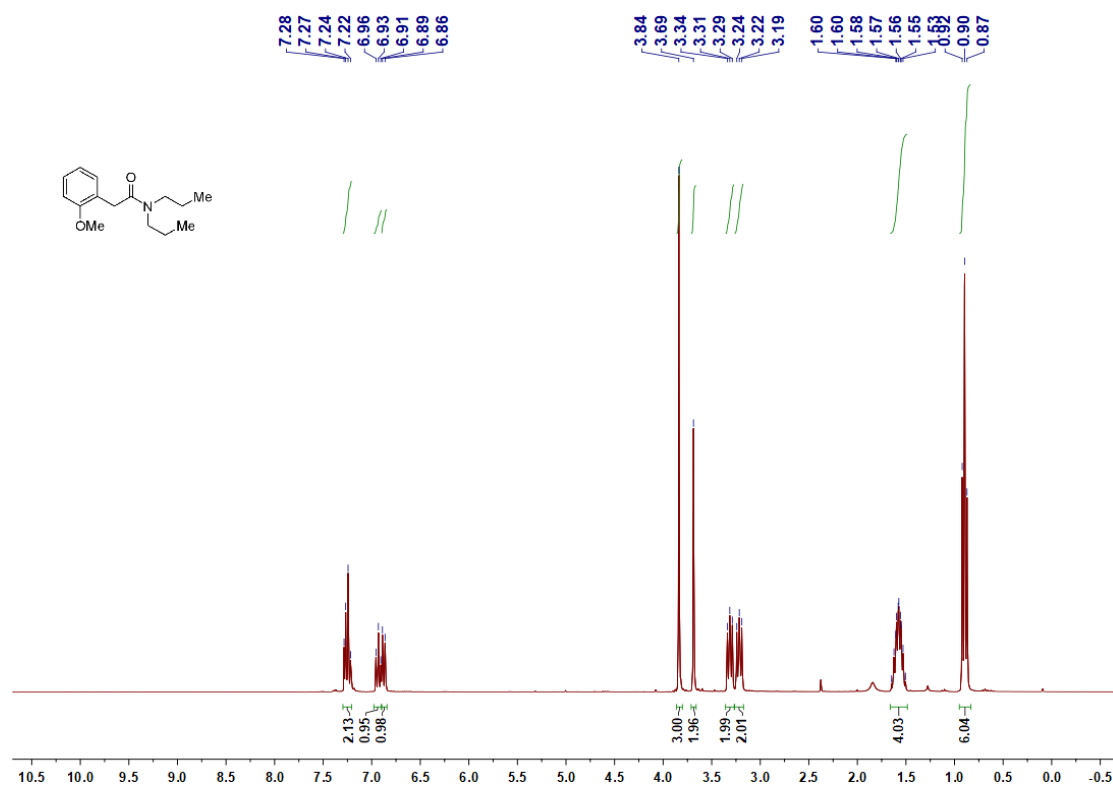


Figure S41. <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>) spectrum of compound **3m**

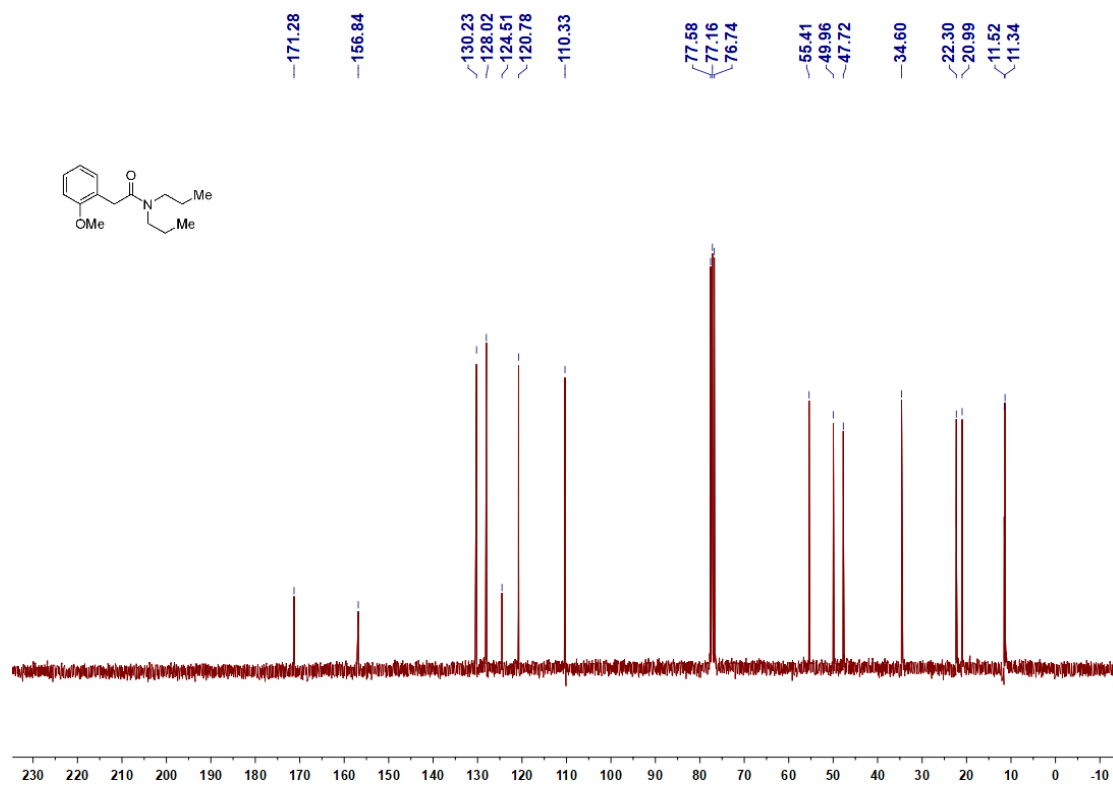


Figure S42. <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>) spectrum of compound **3m**

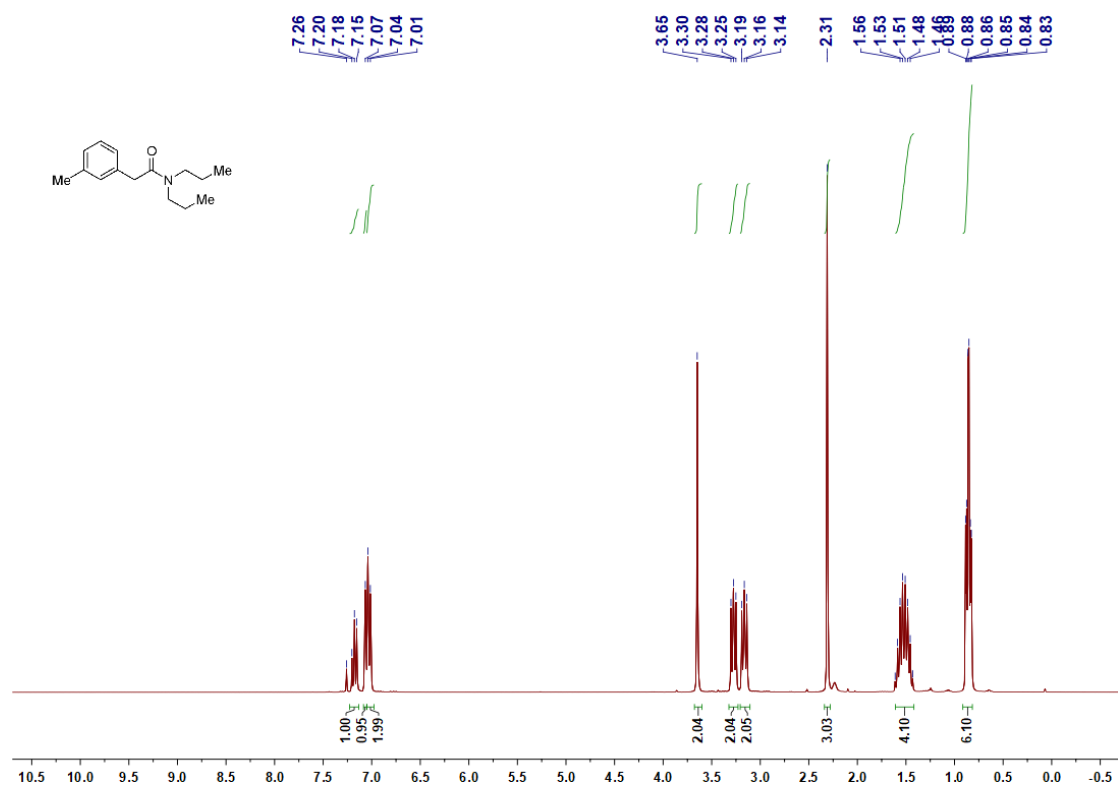


Figure S43. <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>) spectrum of compound **3n**

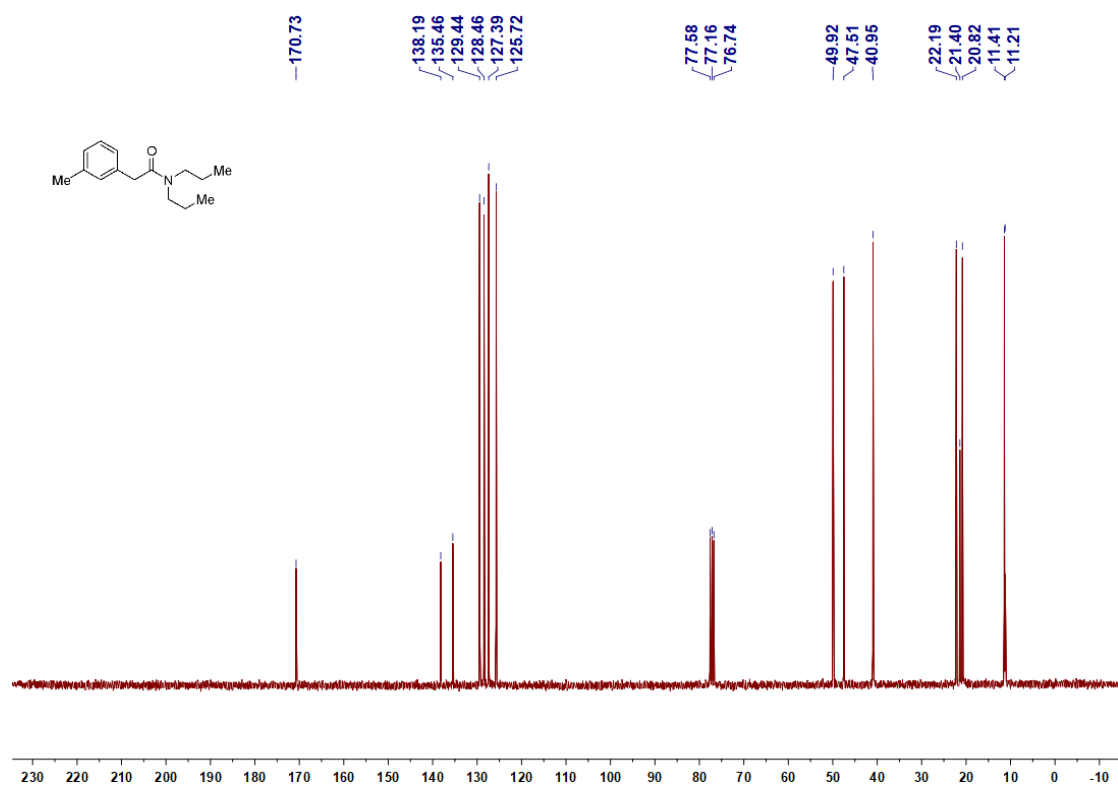


Figure S44. <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>) spectrum of compound **3n**

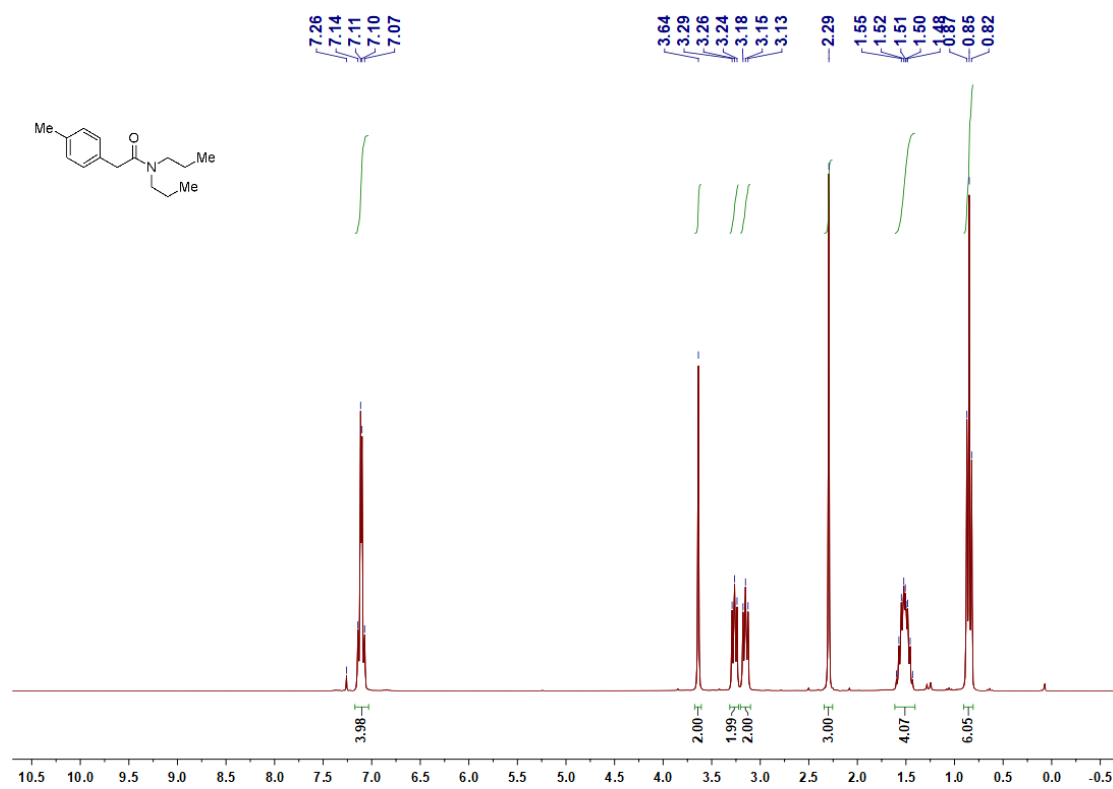


Figure S45. <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>) spectrum of compound **30**

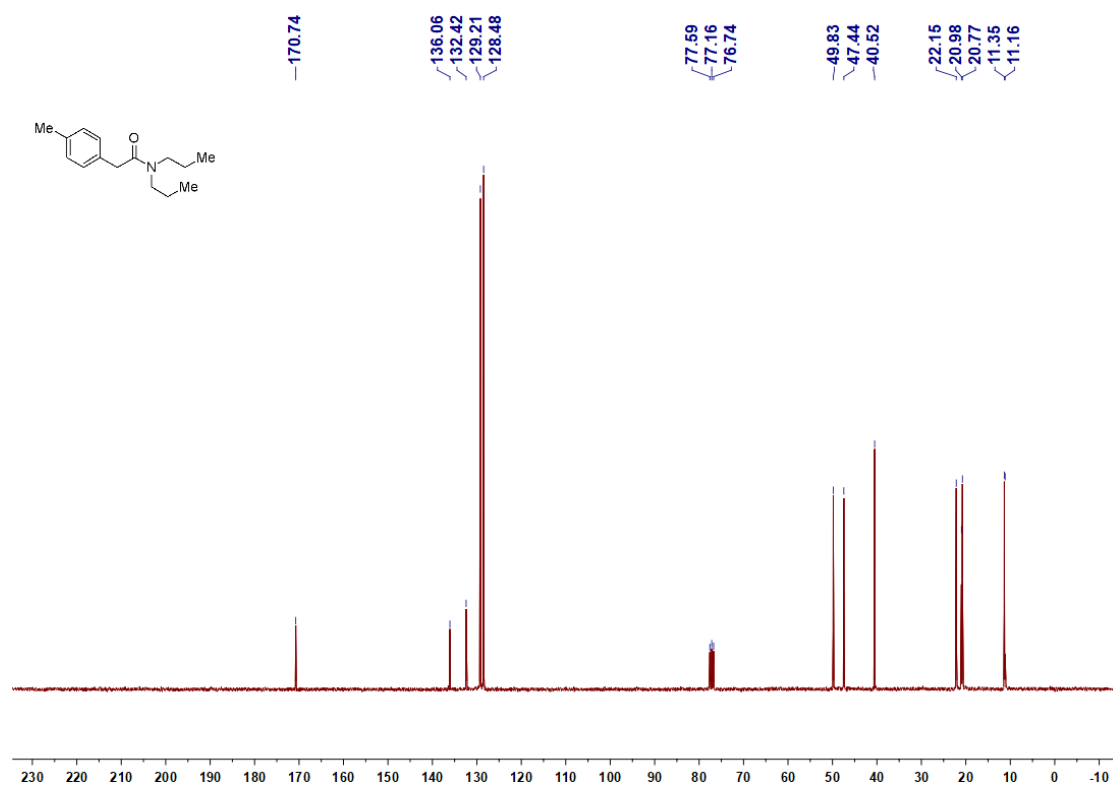


Figure S46. <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>) spectrum of compound **30**

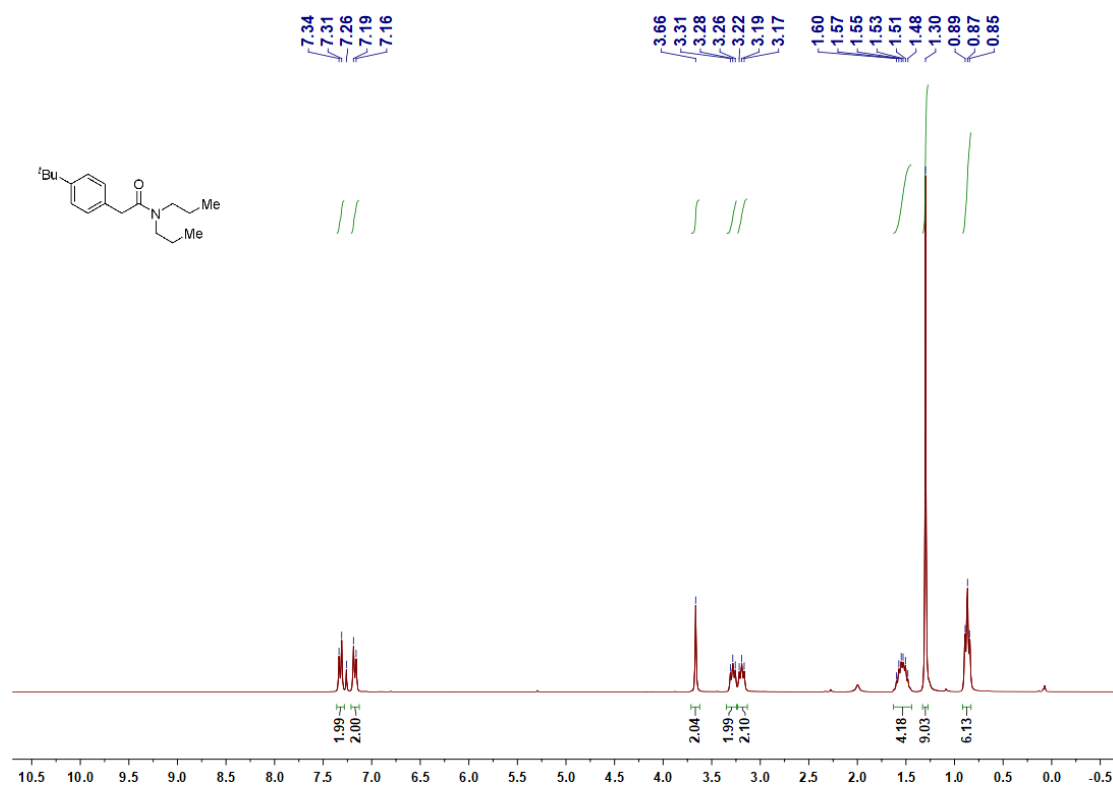


Figure S47. <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>) spectrum of compound **3p**

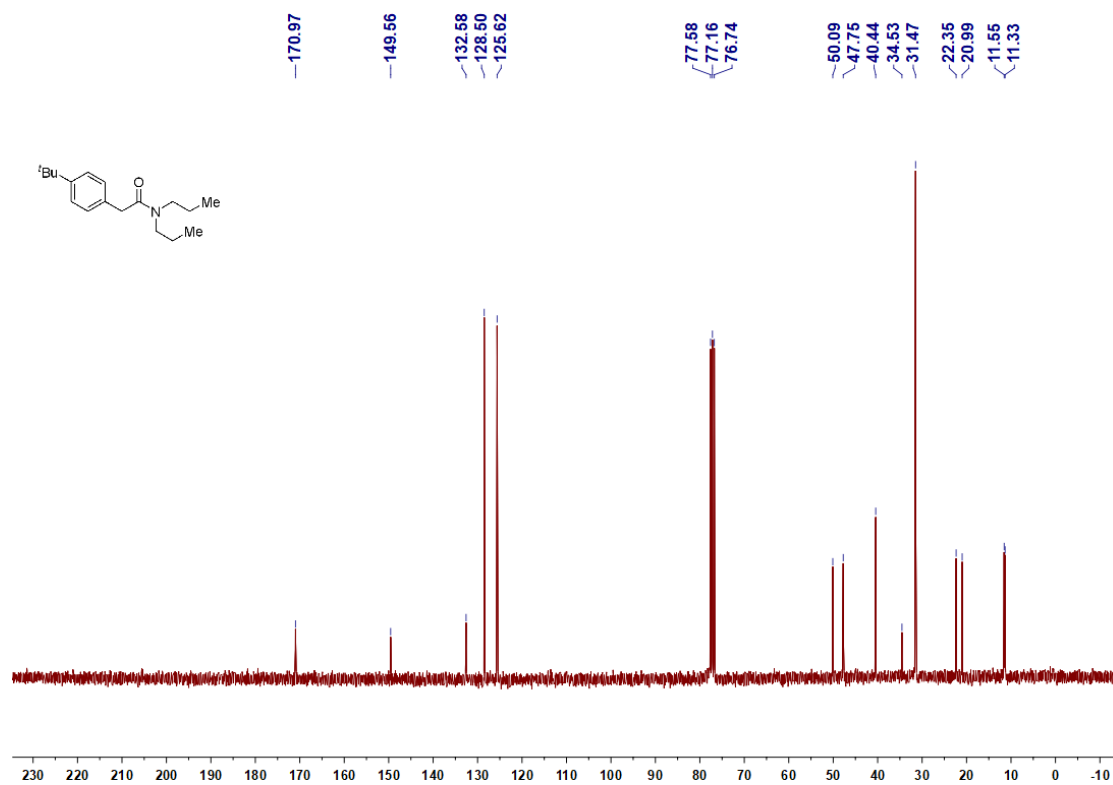


Figure S48. <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>) spectrum of compound **3p**

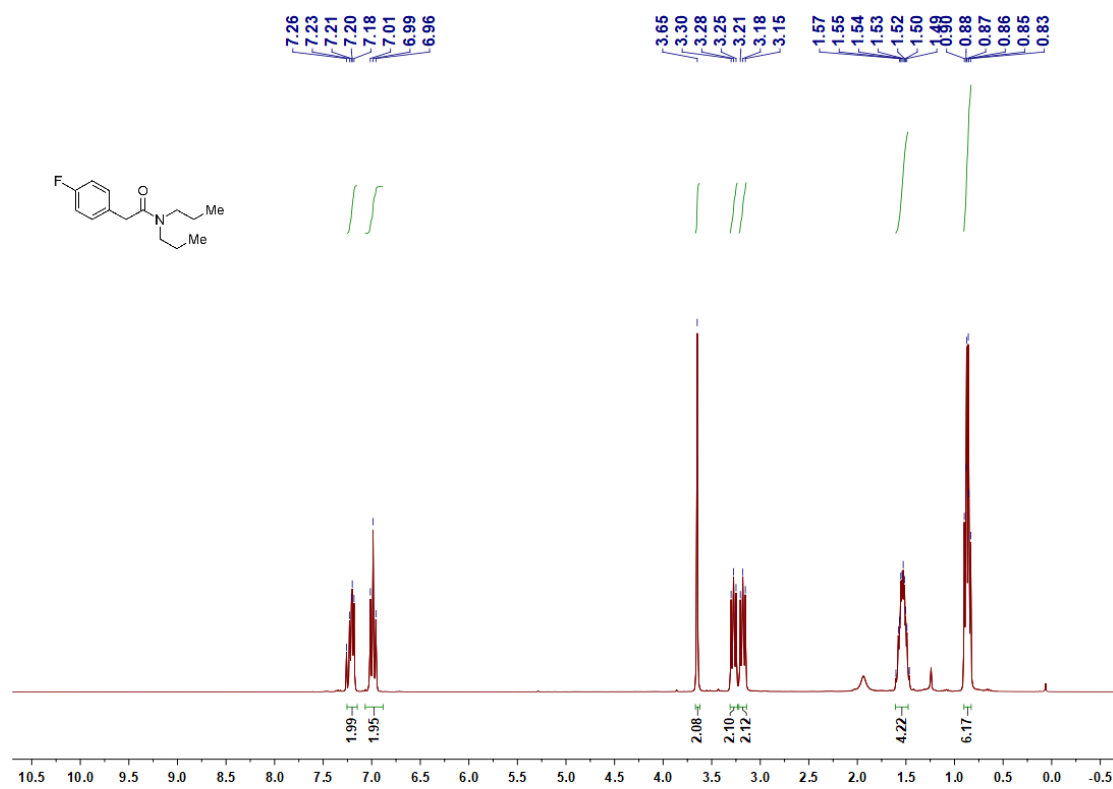


Figure S49. <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>) spectrum of compound **3q**

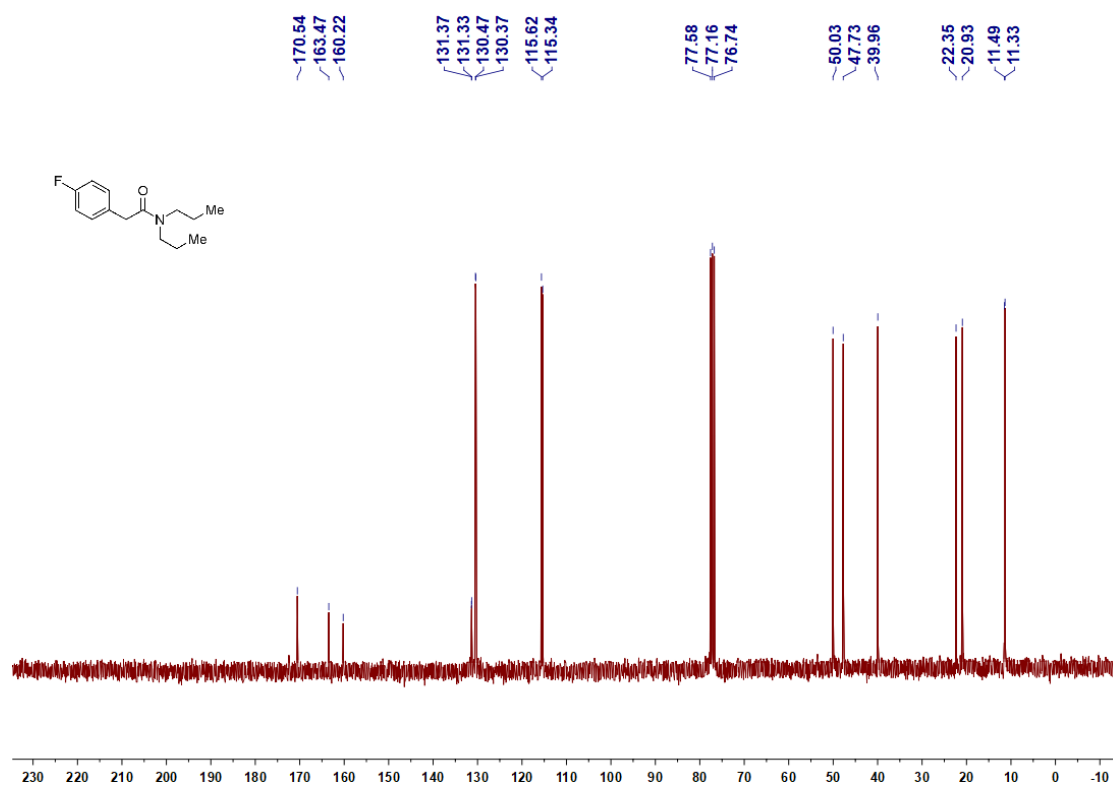


Figure S50. <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>) spectrum of compound **3q**

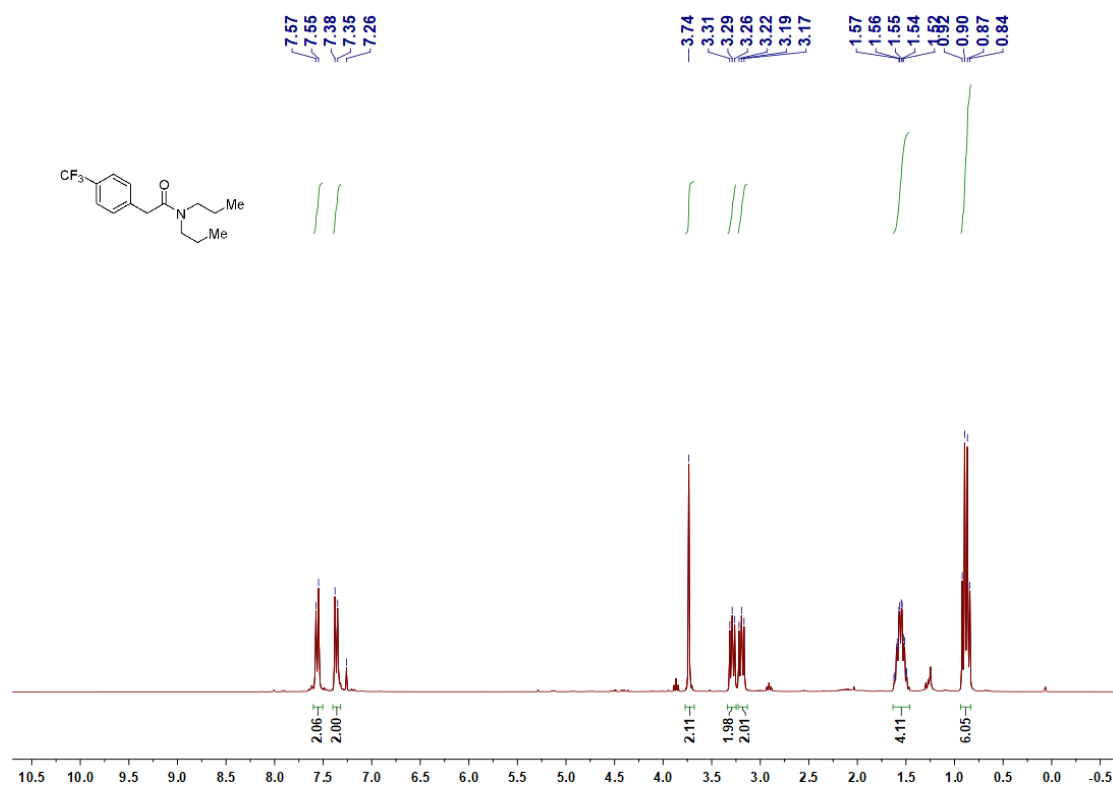


Figure S51. <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>) spectrum of compound **3r**

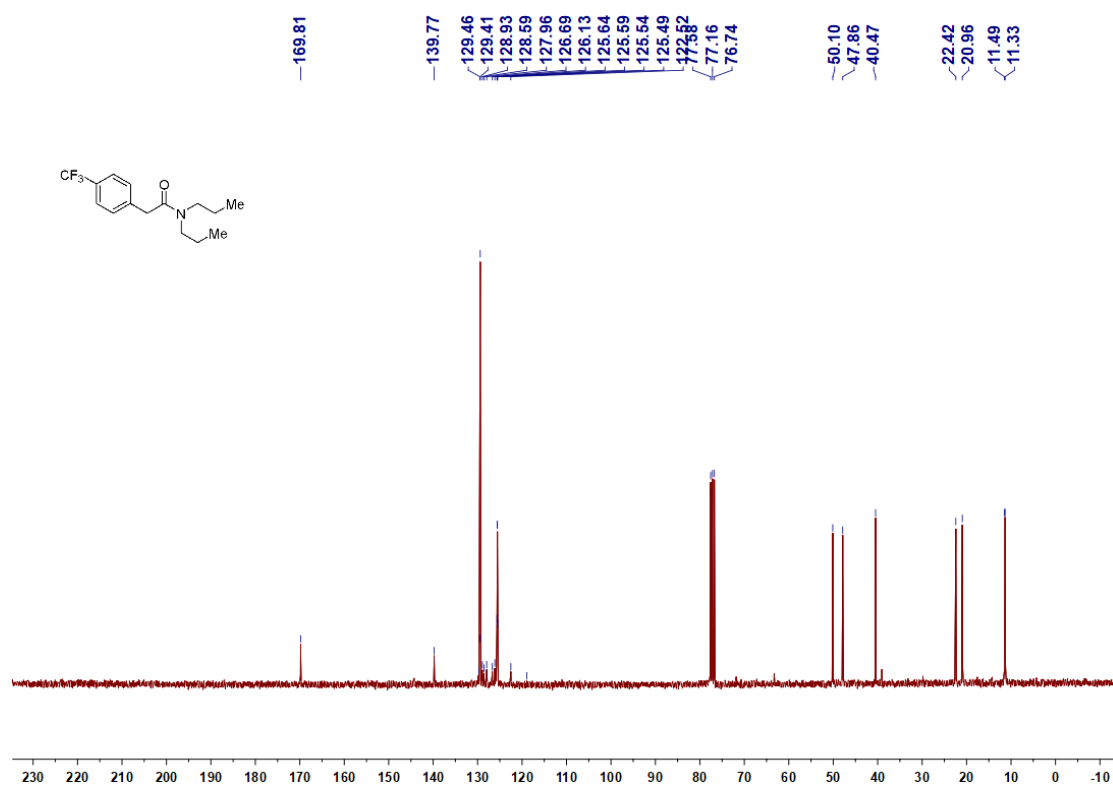


Figure S52. <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>) spectrum of compound **3r**

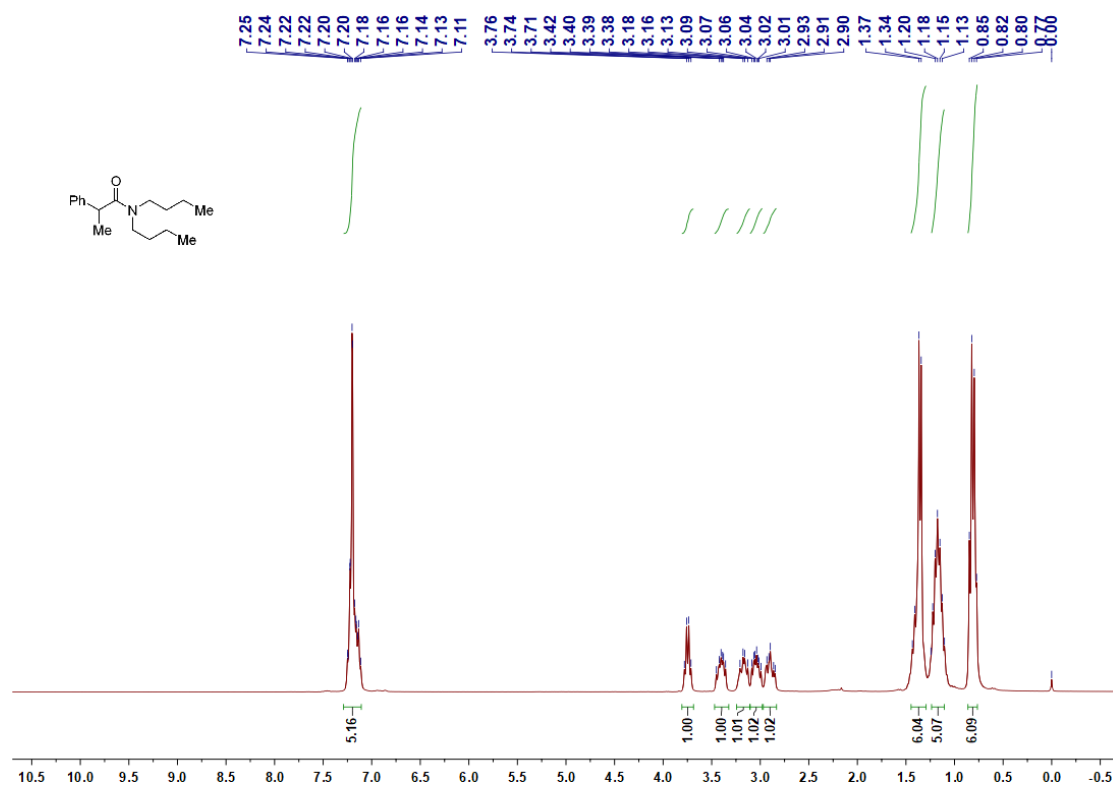


Figure S53. <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>) spectrum of compound **3s**

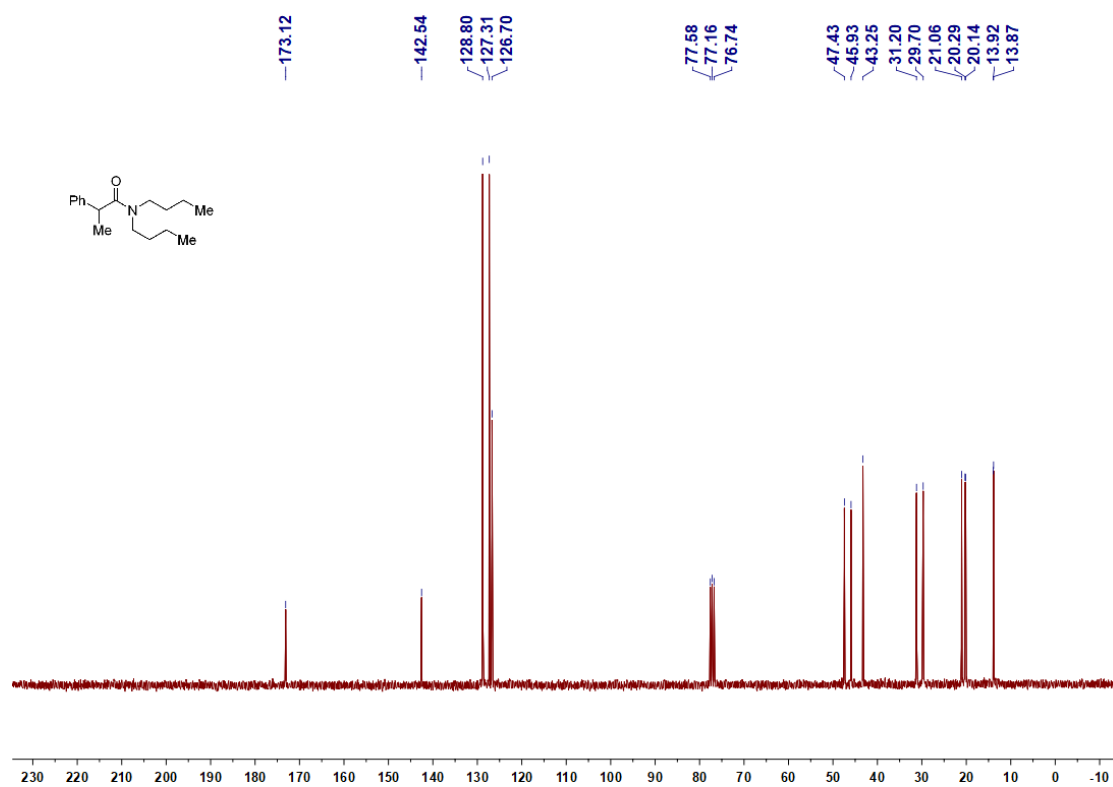


Figure S54. <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>) spectrum of compound **3s**