Electronic Supplementary Material (ESI) for Organic Chemistry Frontiers.

Rh-catalysed divergent synthesis of polysubstituted pyrroles from α,β-unsaturated ketones via selective single or double insertion of isocyanides

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1. General NMR spectra were recorded on JEOL ECX-500 spectrometer (500 MHz for ^{1}H NMR and 125 MHz for ^{13}C NMR) or JEOL ECS-400 spectrometer (400 MHz for ^{1}H NMR and 100 MHz for ^{13}C NMR). Chemical shifts are reported in δ ppm referenced to tetramethylsilane (TMS) and residual solvent for $CDCl_3$ (δ 0.00 of TMS for ^{1}H NMR and δ 77.16 of $CDCl_3$ for ^{13}C NMR). Melting points (mp) were uncorrected and measured under air on Yanaco MP-500P. Elemental analyses were performed at the Microanalysis Center of Kyoto University. High resolution mass spectrometry (HRMS) was recorded on Bruker micrOTOF II with electro spray ionization (ESI) method. Dry toluene, THF, and hexane were purified by passed through a neutral alumina column under argon pressure on a Glass Contour solvent system. *t*-BuNC was purchased from Alfa Aesar. 1-AdNC was prepared according to the literature procedure.[1] All other materials were purchased and used without further purification.

2. Preparation of α,β-unsaturated ketone

α,β-Unsaturated ketones **1a** was purchased from NacalaiTesque. α,β-Unsaturated ketones **1b-1i** and **1m-1p** were prepared according to the previous report.[2]

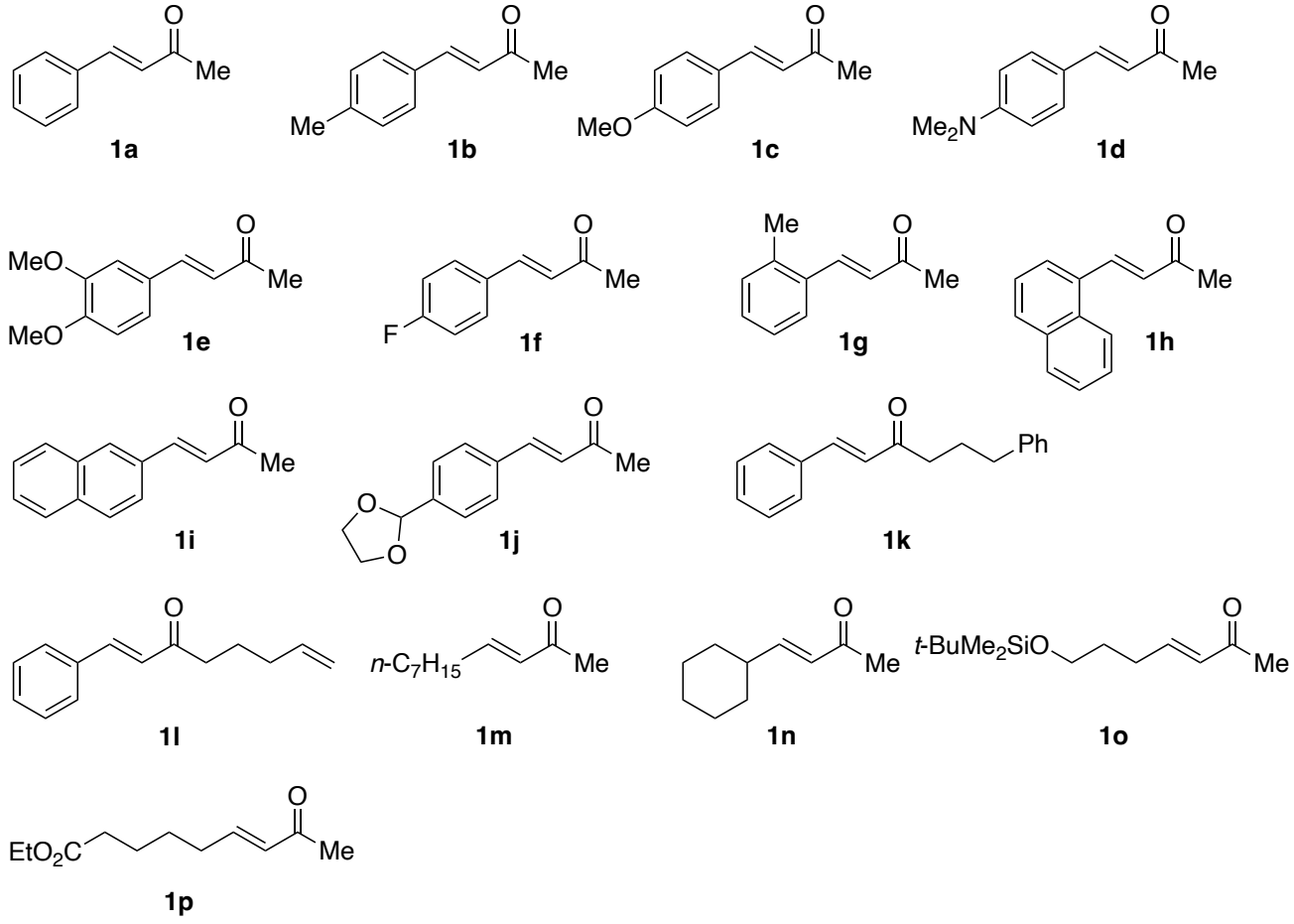
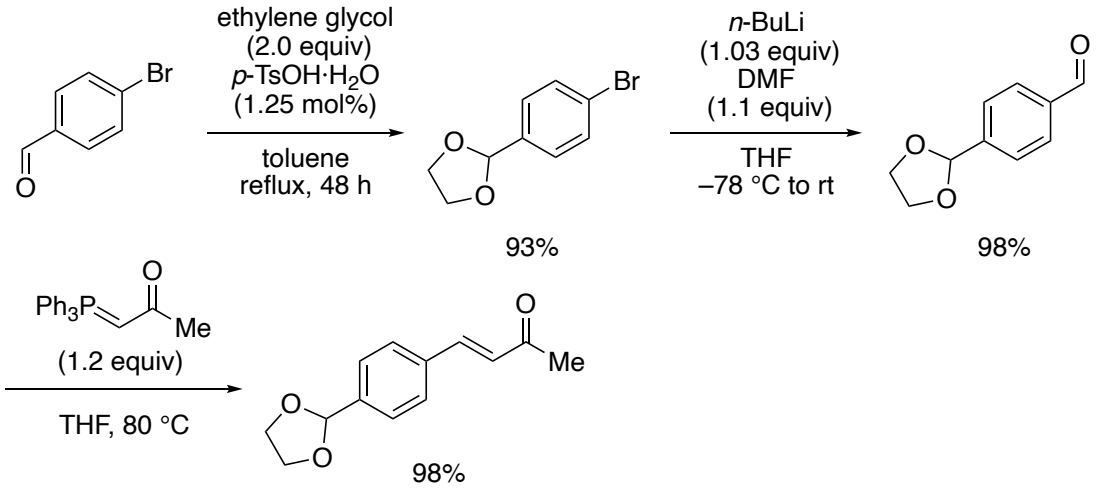
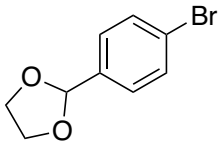


Figure S1. List of substrates employed in this study.

Preparation of ketone 1j



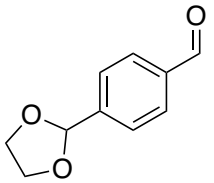
Step 1: Preparation of 2-(4-bromophenyl)-1,3-dioxolane [CAS: 10602-01-4] [3]



To a 200 mL round-bottle flask were added 4-bromobenzaldehyde (14.87 g, 80.4 mmol), *p*-toluenesulfonic acid monohydrate (190.2 mg, 1.0 mmol), ethylene glycol (9.0 mL, 161 mmol), and toluene (100 mL). The Dean-Stark apparatus was attached to the flask. The reaction mixture was refluxed for 48 h. After cooled to rt, the mixture was treated with 3N NaOH aq (10 mL) and H_2O (20 mL). The aqueous layer was extracted with AcOEt (30 mL x 2). The combined organic layer was washed with brine (30 mL), then was dried over $MgSO_4$ and filtered. The filtrate was concentrated under reduced pressure to afford crude product containing ca. 5% of unreacted aldehyde. To reduce the aldehyde to alcohol for easier separation from the desired acetal product, the crude mixture was dissolved in MeOH (20 mL), followed by treatment with $NaBH_4$ (151 mg, 4 mmol) at rt for 12 h. The solvent was removed under reduced pressure and the residue was directly subjected to silica gel column chromatography (hexane:AcOEt = 20:1) to afford 2-(4-bromophenyl)-1,3-dioxolane as a white solid (17.09 g, 74.6 mmol, 93% yield). Spectral data are consistent with the previous report.[3]

^{1}H NMR (500 MHz, $CDCl_3$, rt): δ 7.52 (d, J = 8.5 Hz, 2H), 7.36 (d, J = 8.5 Hz, 2H), 5.77 (s, 1H), 4.15-4.01 (m, 4H). ^{13}C NMR (125.8 MHz, $CDCl_3$, rt): δ 137.1, 131.6, 128.3, 123.4, 103.1, 65.4.

Step 2: Preparation of 4-(1,3-dioxolan-2-yl)benzaldehyde [CAS: 40681-88-7] [4]

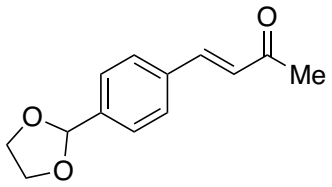


To an argon-purged 300 mL two-necked round-bottle flask were added 2-(4-bromophenyl)-1,3-dioxolane (11.45 g, 50.0 mmol) and THF (150 mL). The solution was cooled to –78 °C, followed by dropwise addition of *n*-BuLi (1.57 M in hexane, 32.8 mL, 51.5 mmol). After completion of the addition, the mixture was stirred at the same

temperature for 1 h to give a white suspension. Then, DMF (4.1 mL, 53 mmol) was slowly added to the mixture, resulting in disappearance of the suspension to give colorless solution. The mixture was gradually warmed up to rt over 5 h to give white suspension again. After adding H_2O (15 mL) to the mixture, the solution was concentrated to one-fifth volume under reduced pressure. Then, H_2O (15 mL) was added, and the mixture was extracted with AcOEt (30 mL x 3). The combined organic layer was washed with brine (20 mL), dried over $MgSO_4$, and filtered. After concentration of the filtrate under reduced pressure, the residue was subjected to silica gel column chromatography (hexane:AcOEt = 10:1 to 3:1) to afford 4-(1,3-dioxolan-2-yl)benzaldehyde as a white solid (8.77 g, 49.2 mmol, 98% yield). Spectral data are consistent with the previous report.[4]

^{1}H NMR (500 MHz, $CDCl_3$, rt): δ 10.0 (s, 1H), 7.91 (d, J = 8.0 Hz, 2H), 7.66 (d, J = 8.0 Hz, 2H), 5.88 (s, 1H), 4.15-4.05 (m, 4H). ^{13}C NMR (125.8 MHz, $CDCl_3$, rt): δ 192.1, 144.5, 137.0, 129.9, 127.2, 103.0, 65.6.

Step 3: Preparation of (*E*)-4-(4-(1,3-dioxolan-2-yl)phenyl)but-3-en-2-one (**1j**)



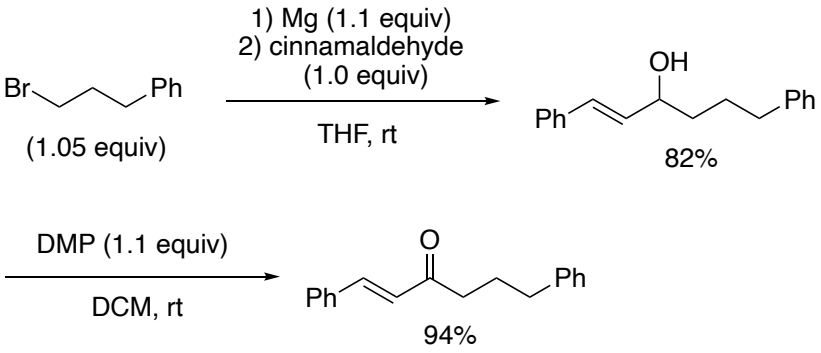
To a 50 mL J. Young Schlenk tube were added 4-(1,3-dioxolan-2-yl)benzaldehyde (1.02 g, 5.74 mmol), 1-(triphenyl-λ^5-phosphaneylidene)propan-2-one (2.19 g, 6.89 mmol), and THF (10 mL). The tube was closed and stirred for 22 h at 80 °C of oil bath temperature. After cooled to rt, the mixture was concentrated under reduced pressure, followed by subjection to silica gel column chromatography (hexane:AcOEt = 30:1 to 10:1) to afford (*E*)-4-(4-(1,3-dioxolan-2-yl)phenyl)but-3-en-2-one (**1j**) as a white solid (1.23 g, 5.62 mmol, 98% yield).

^{1}H NMR (500 MHz, $CDCl_3$, rt): δ 7.57 (d, J = 8.0 Hz, 2H), 7.52 (d, J = 8.0 Hz, 2H), 7.52 (d, J = 16.5 Hz, 1H), 6.73 (d, J = 16.5 Hz, 1H), 5.83 (s, 1H), 4.17-4.03 (m, 4H), 2.39 (s, 3H). ^{13}C NMR (125.8 MHz, $CDCl_3$, rt): δ 198.5, 142.9, 140.4, 135.3, 128.4, 127.7, 127.2, 103.2, 65.5, 27.7.

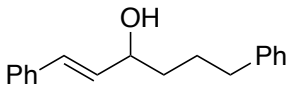
HRMS (ESI) calcd for $C_{13}H_{14}O_3Na$ $[M+Na]^+$ 241.0841; found: 241.0840.

mp: 74.0–76.0 °C.

Preparation of ketone 1k



Step 1: Preparation of (*E*)-1,6-diphenylhex-1-en-3-ol

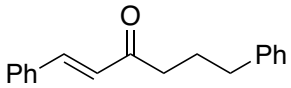


To a dry 50 mL three-necked round bottle flask equipped with a dropping funnel and a dimroth condenser was added Mg turnings (267 mg, 11 mmol). After purging the flask with argon, a small piece of I_2 and THF (2 mL) were added. 1-Bromo-3-phenylpropane (1.58 mL, 10.5 mmol) in THF (10 mL) was dropwisely added to the Mg suspension from the dropping funnel over 30 min to maintain gentle refluxing (preparation of Grignard reagent). After addition, the mixture was stirred at 60 °C for 30 min and then cooled down to rt. Cinnamaldehyde (1.26 mL, 10 mmol) was dropwisely added to the Grignard reagent at 0 °C and stirred at rt for overnight (15 h). The reaction was quenched with H_2O (5 mL) and then neutralized with HCl aq. The mixture was extracted with AcOEt (10 mL x 2). The combined organic layer was washed with brine, dried over $MgSO_4$, and filtered. The filtrate was concentrated under reduced pressure to give crude mixture, which was subjected to silica gel column chromatography (hexane:AcOEt = 10:1 to 7.5:1) to afford (*E*)-1,6-diphenylhex-1-en-3-ol as a colorless oil (2.07 g, 8.19 mmol, 82% yield).

^{1}H NMR (500 MHz, $CDCl_3$, rt): δ 7.37 (d, *J* = 7.0 Hz, 2H), 7.31 (t, *J* = 7.5 Hz, 2H), 7.28 (t, *J* = 7.5 Hz, 2H), 7.24 (t, *J* = 7.5 Hz, 1H), 7.19-7.17 (m, 3H), 6.56 (d, *J* = 16.0 Hz, 1H), 6.21 (dd, *J* = 16.0, 7.0 Hz, 1H), 4.32-4.28 (m, 1H), 2.66 (t, *J* = 7.0 Hz, 2H), 1.82-1.61 (m, 4H), 1.57 (br s, 1H). ^{13}C NMR (125.8 MHz, $CDCl_3$, rt): δ 142.4, 136.7, 132.4, 130.5, 128.7, 128.6, 128.4, 127.8, 126.6, 125.9, 73.1, 37.0, 35.9, 27.4.

HRMS (ESI) calcd for $C_{18}H_{20}ONa$ $[M+Na]^+$ 275.1412; found: 275.1419.

Step 2: Prepartion of (*E*)-1,6-diphenylhex-1-en-3-one (**1k**) [CAS: 295355-94-1] [5]

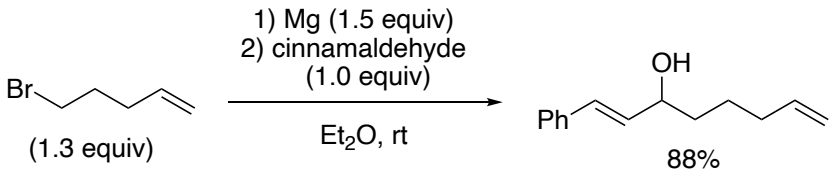


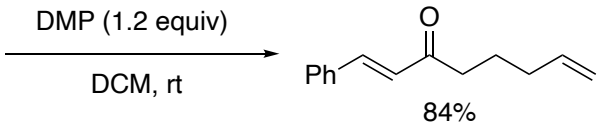
To a 50 mL round bottle flask was added (*E*)-1,6-diphenylhex-1-en-3-ol (1.432 g, 5.67 mmol) and DCM (15 mL). Dess-Martin Periodinane (DMP) (2.886 g, 6.80 mmol) was added to the solution at 0 °C. After stirred at rt for 15 min, the white suspension was filtered through Celite. The filtrate was concentrated under reduced pressure. The residue was subjected to silica gel column chromatography (hexane:AcOEt =30:1) to afford (*E*)-1,6-diphenylhex-1-en-3-one (**1k**) as a white solid (1.289 g, 5.15 mmol, 91% yield). Spectral data are consistent with the previous report.[5]

^{1}H NMR (500 MHz, $CDCl_3$, rt): δ 7.54-7.49 (m, 3H), 7.40-7.38 (m, 3H), 7.30 (t, *J* = 8.0 Hz, 2H), 7.22-7.19 (m, 3H), 6.72 (d, *J* =16.5 Hz, 1H), 2.71-2.67 (m, 4H), 2.03 (quintet, *J* = 7.5 Hz, 2H).

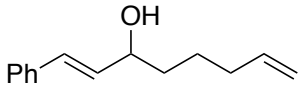
^{13}C NMR (125.8 MHz, $CDCl_3$, rt): δ 200.4, 142.6, 141.8, 134.6, 130.6, 129.1, 128.7, 128.5, 128.4, 126.3, 126.1, 40.1, 35.3, 25.8.

Preparation of ketone 1l





Step 1: Preparation of (*E*)-1-phenylocta-1,7-dien-3-ol [CAS: 129887-70-3] [6]

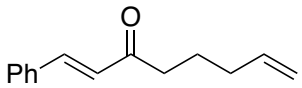


To a dried three-necked 50 mL round bottle flask were added magnesium turings (364.7 mg, 15.0 mmol), a small piece of I_2, and Et_2O (2 mL). 5-Bromopent-1-ene (1.54 mL, 13.0 mmol) in Et_2O (10 mL) was dropwisely added to the magnesium suspension from a dropping funnel over 30 min to maintain gentle refluxing (preparation of Grignard reagent). After completion of the addition, the solution was stirred for 50 min at rt. Then, cinnamaldehyde (1.26 mL, 10.0 mmol) in Et_2O (10 mL) was dropwisely added to the prepared Grignard reagent at rt over 20 min. The mixture was stirred for overnight (12 h). Sat. NH_4Cl aq. (5 mL) was added to the mixture at 0 °C to quench the reaction. After addition, H_2O (10 mL) was added and the biphasic mixture was extracted AcOEt (30 mL x 2). The combined organic layer was washed with brine, dried over $MgSO_4$, and filtered. The filtrate was concentrated under reduced pressure to give a crude product, which was subjected to silica gel column chromatography (hexane:AcOEt = 20:1 to 10:1) to afford (*E*)-1-phenylocta-1,7-dien-3-ol as a colorless oil (1.780 g, 8.80 mmol, 88% yield). Spectral data are consistent with the previous report.[6]

^{1}H NMR (500 MHz, $CDCl_3$, rt): δ 7.37 (d, *J* = 7.0 Hz, 2H), 7.31 (t, *J* = 8.0 Hz, 2H), 7.23 (t, *J* = 7.5 Hz, 1H), 6.56 (d, *J* = 15.5 Hz, 1H), 6.21 (dd, *J* = 16.0, 6.0 Hz, 1H), 5.80 (ddt, *J* = 17.3, 10.5, 7.0 Hz, 1H), 5.01 (dd, *J* = 17.3, 2.0 Hz, 1H), 4.96 (dd, *J* = 10.5, 2.0 Hz, 1H), 4.28 (td, *J* = 6.5, 6.0 Hz, 1H), 2.10 (dt, *J* = 7.5, 7.0 Hz, 2H), 1.75-1.46 (m, 5H).

^{13}C NMR (125.8 MHz, $CDCl_3$, rt): δ 138.7, 136.8, 132.6, 130.4, 128.7, 127.8, 126.6, 114.9, 73.1, 36.9, 33.7, 24.8.

Step 2: Preparation of (*E*)-1-phenylocta-1,7-dien-3-one (**1l**)

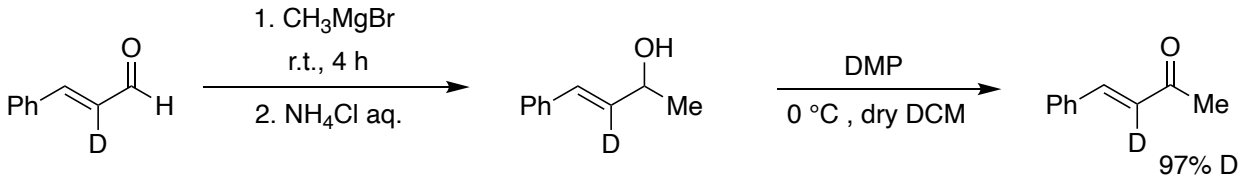


To a 50 mL round bottle flask was added (*E*)-1-phenylocta-1,7-dien-3-ol (1.42 g, 7.0 mmol) and DCM (20 mL). Dess-Martin Periodinane (DMP) (3.56 g, 8.4 mmol) was added to the solution at 0 °C. After stirred at rt for 6 h, the white suspension was filtered through Celite. The filtrate was concentrated under reduced pressure. The residue was subjected to silica gel column chromatography (hexane:AcOEt = 30:1) to afford (*E*)-1-phenylocta-1,7-dien-3-one (**1l**) as a colorless oil (1.17 g, 5.86 mmol, 84% yield).

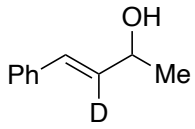
^{1}H NMR (500 MHz, $CDCl_3$, rt): δ 7.55 (d, *J* = 16.0 Hz, 1H), 7.56-7.54 (m, 2H), 7.40-7.39 (m, 3H), 6.74 (d, *J* = 16.0 Hz, 1H), 5.82 (ddt, *J* = 17.0, 10.5, 6.0 Hz, 1H), 5.05 (dd, *J* = 17.0, 1.0 Hz, 1H), 5.00 (dd, *J* = 10.5, 1.0 Hz, 1H), 2.68 (t, *J* = 7.5 Hz, 2H), 2.13 (td, *J* = 7.0, 6.5 Hz, 2H), 1.79 (quintet, *J* = 7.5 Hz, 2H).

^{13}C NMR (125.8 MHz, $CDCl_3$, rt): δ 200.4, 142.5, 138.2, 134.7, 130.5, 129.0, 128.4, 126.4, 115.4, 40.1, 33.3, 23.4. HRMS (ESI) calcd for $C_{14}H_{16}Ona$ $[M+Na]^+$ 223.1099; found 223.1096.

Preparation of (*E*)-4-Phenyl-3-buten-2-one-3-*d* (1a-α-D)



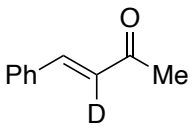
Step 1: Preparation of (*E*)-4-phenylbut-3-en-3-*d*-2-ol [CAS: 77249-48-0] [7]



To an argon-purged 50 mL two-necked round-bottle flask were added Et_2O (10 mL) and CH_3MgBr (1.4 M in THF:toluene (1:3), 6.8 mL, 9.5 mmol) at 0 °C. Then, cinnamaldehyde-2-*d* [8] (1.047 g, 7.85 mmol) was added to the solution at the same temperature. After stirred at rt for 2 h, saturated NH_4Cl aq. was added to quench the reaction. After another 2 h, the mixture was extracted with Et_2O twice, followed by washing the combined organic layer with brine. The organic layer was dried over $MgSO_4$, filtered, and concentrated under vacuum. The residue was subjected to silica gel column chromatography (hexane:AcOEt = 20:1 to 10:1), affording (*E*)-4-phenylbut-3-en-3-*d*-2-ol as colorless liquid (488.1 mg, 3.3 mmol, 42% yield).

^{1}H NMR (400 MHz, $CDCl_3$, rt): δ 7.38 (d, J = 6.8 Hz, 2H), 7.32 (t, J = 8.0 Hz, 2H), 7.24 (t, J = 7.6 Hz, 2H), 6.57 (s, 1H), 4.53-4.47 (m, 1H), 1.56 (d, J = 3.2 Hz, 1H), 1.38 (d, J = 6.4 Hz, 3H). ^{13}C NMR (100.5 MHz, $CDCl_3$, rt): δ 136.8, 133.3 (t, $J_{C\text{-}D}$ = 22.9 Hz), 129.3, 128.6, 127.7, 126.5, 68.9, 23.4.

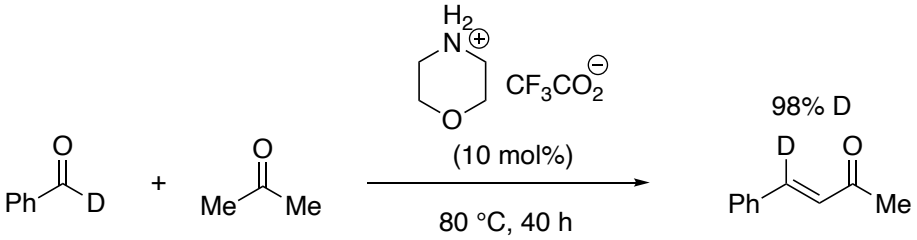
Step 2: Preparation of (*E*)-4-phenyl-3-buten-2-one-3-*d* (α-deuterated benzalacetone) [CAS: 116145-00-7] [9]



To a 50 mL round-bottle flask were added (*E*)-4-phenylbut-3-en-3-*d*-2-ol (488.1 mg, 3.3 mmol), DCM (30 mL), and Dess-Martin Periodinane (DMP) (1.5 g, 3.6 mmol) at 0 °C. After stirred at rt for 21 h, the mixture was diluted with Et_2O and filtered through Celite. The filtrate was concentrated under reduced pressure to give crude, which was subjected to silica gel column chromatography (hexane:DCM = 3:1 to 1:4) to afford (*E*)-4-phenyl-3-buten-2-one-3-*d* (**1a-α-D**) as a white solid (346.2 mg, 2.35 mmol, 71% yield).

^{1}H NMR (400 MHz, $CDCl_3$, rt): δ 7.56-7.54 (m, 2H), 7.51 (t, J = 2.8 Hz, 1H), 7.41-7.40 (m, 3H), 6.73 (d, J = 16 Hz, 0.03H, 97%D incorporated), 2.39 (s, 3H). ^{13}C NMR (125.8 MHz, $CDCl_3$, rt): δ 198.6, 143.5, 134.5, 130.6, 129.1, 128.4, 126.9 (t, $J_{C\text{-}D}$ = 23.8 Hz), 27.6.

Preparation of (*E*)-4-Phenyl-3-buten-2-one-4-*d* (1a-β-D)

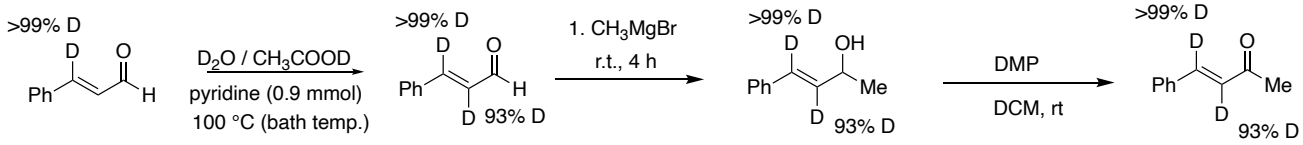


(*E*)-4-Phenyl-3-buten-2-one-4-*d* (β-deuterated benzalacetone) (**1a-β-D**) [CAS: 55320-94-0] was prepared according to literature procedure [2] using benzaldehyde-*formyl-d* as a starting material.

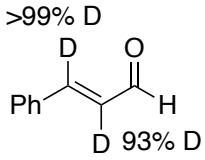
To a 50 mL J. Young Schlenk tube were added benzaldehyde-*formyl-d* [10] (556.4 mg, 5.19 mmol), acetone (12.5 mL), and morpholinium trifluoroacetate (104.6 mg, 0.52 mmol). The tube was closed and stirred for 38 h at 80 °C of oil bath temperature. After cooled to rt, the mixture was concentrated under reduced pressure, followed by subjection to silica gel column chromatography (hexane:AcOEt = 25:1 to 5:1) to afford (*E*)-4-phenyl-3-buten-2-one-4-*d* (**1a-β-D**) as a white solid (501.3 mg, 3.41 mmol, 66% yield). Spectral data are consistent with the previous report.[11]

^{1}H NMR (500 MHz, $CDCl_3$, rt): δ 7.57-7.51 (m, 2.02 H, 98%D incorporated), 7.44-7.39 (m, 3H), 6.72 (t, J = 2.5 Hz, 1H), 2.40 (s, 3H). ^{13}C NMR (125.8 MHz, $CDCl_3$, rt): δ 198.7, 143.3 (t, $J_{C\text{-}D}$ = 23.9 Hz), 134.4, 130.7, 129.1, 128.4, 127.2, 27.7.

Preparation of (*E*)-4-phenylbut-3-en-2-one-3,4-d_2 (1a-α,β-D_2)



Step 1: Preparation of (*E*)-cinnamaldehyde-2,3-d_2



(*E*)-Cinnamaldehyde-2,3-d_2 was prepared by reported deuteration method[8] from cinnamaldehyde-3-*d*[12] as a starting material.

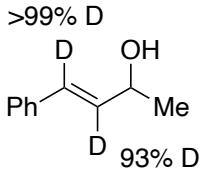
To a 15 mL J. Young. Schlenk tube were added cinnamaldehyde-3-*d* (1.2 g, 9.0 mmol), D_2O (7.5 mL), CH_3COOD (7.5 mL), and pyridine (2.2 mL, 27 mmol). The reaction mixture was heated to 100 °C for 5 days. After cooled down to rt, the mixture was extracted with DCM (20 mL x 2). The organic layer was washed with 1N HCl aq. (10 mL x 2), then dried over Na_2SO_4 and filtered. The filtrate was concentrated under reduced pressure. The residue was subjected to silica gel column chromatography (hexane:AcOEt = 20:1) to afford (*E*)-cinnamaldehyde-2,3-d_2 as a colorless oil (1.16 g, 8.65 mmol, 97% yield). The deuterium incorporation ratio at 2-position was 93%.

^{1}H NMR (500 MHz, $CDCl_3$, rt): δ 9.71 (s, 1H), 7.58-7.55 (m, 2H), 7.46-7.41 (m, 3H), 6.71 (dt, J = 8.0, 2.0 Hz, 0.07H, 93% D incorporated). ^{13}C NMR (125.8 MHz, $CDCl_3$, rt): δ 193.8, 152.4 (t, $J_{C\text{-}D}$ = 22.8 Hz), 134.0, 131.4,

129.2, 128.6, 128.3 (t, $J_{C\text{-}D}$ = 23.9 Hz).

HRMS (ESI) calcd for $C_9H_6D_2ONa$ $[M+Na]^+$ 157.0598; found: 157.0596.

Step 2: Preparation of (*E*)-4-phenylbut-3-en-3,4-d_2-2-ol

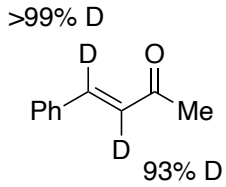


To a 50 mL round-bottle flask were added (*E*)-cinnamaldehyde-2,3-d_2 (328.0 mg, 2.44 mmol) and dry Et_2O (10 mL). MeMgBr (1.4 M in THF:toluene, 2.0 mL, 2.8 mmol) was dropwise added to the solution at 0 °C. After stirred at rt for 12 h, H_2O (5 mL) and sat. NH_4Cl aq. (5 mL) were added to the solution. The mixture was extracted with AcOEt (20 mL). The organic layer was dried over $MgSO_4$, filtered, and concentrated under reduced pressure. The residue was subjected to silica gel column (hexane:AcOEt = 10:1 to 4:1) to afford (*E*)-4-phenylbut-3-en-3,4-d_2-2-ol as a colorless oil (295.4 mg, 1.97 mmol, 81% yield).

^{1}H NMR (500 MHz, $CDCl_3$, rt): δ 7.36 (d, J = 7.5 Hz, 2H), 7.30 (t, J = 7.5 Hz, 2H), 7.23 (t, J = 7.5 Hz, 1H), 6.24 (dt, J = 6.5, 2.5 Hz, 0.07H, 93% D incorporated), 4.47 (q, J = 6.5 Hz, 1H), 1.98 (br d, J = 7.0 Hz, 1H), 1.36 (d, J = 6.5 Hz, 3H). ^{13}C NMR (125.8 MHz, $CDCl_3$, rt): δ 136.7, 133.2 (t, J = 22.8 Hz), 129.0 (t, J = 24.0 Hz), 128.7, 127.7, 126.5, 68.9, 23.5.

HRMS (ESI) calcd for $C_{10}H_{10}D_2ONa$ $[M+Na]^+$ 173.0911; found: 173.0909.

Step 3: Preparation of (*E*)-4-phenylbut-3-en-2-one-3,4-d_2 (**1a-α,β-D$_2$**)



To a 50 mL round-bottle flask were added (*E*)-4-phenylbut-3-en-3,4-d_2-2-ol (273.3 mg, 1.82 mmol) and DCM (5 mL). DMP (0.926 g, 2.18 mmol) was added to the solution at 0 °C. After stirred at rt for 4 h, the white suspension was filtered through Celite using Et_2O as an eluent. The filtrate was concentrated under reduced pressure. The residue was subjected to silica gel column chromatography (hexane:AcOEt = 30:1 to 7:1) to afford (*E*)-4-phenylbut-3-en-2-one-3,4-d_2 (**1a-α,β-D$_2$**) as a white solid (206.8 mg, 1.40 mmol, 75% yield).

^{1}H NMR (500 MHz, rt, $CDCl_3$) δ 7.57-7.54 (m, 2H), 7.42-7.39 (m, 3H), 6.71 (t, J = 2.0 Hz, 0.07H, 93% D incorporated), 2.39 (s, 3H). ^{13}C NMR (125.8 MHz, rt, $CDCl_3$) δ 198.5, 143.2 (t, $J_{C\text{-}D}$ = 23.9 Hz), 134.4, 130.6, 129.1, 128.4, 126.9 (t, $J_{C\text{-}D}$ = 23.9 Hz), 27.6.

HRMS (ESI) calcd for $C_{10}H_8D_2ONa$ $[M+Na]^+$ 171.0755; found: 171.0760.

mp: 37.8-39.4 °C.

3. General procedure for the catalytic reaction giving pyrrole products

General procedure A: Synthesis of pyrrole **3**

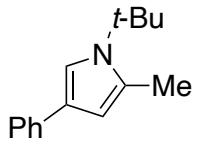
To a 15 mL J. Young. Schlenk tube were added $[Rh(OMe)(cod)]_2$ (2.4 mg, 0.0050 mmol, 2.5 mol% Rh) and B_2pin_2 (111.7 mg, 0.44 mmol). The tube was purged with argon, followed by addition of toluene (1.0 mL). The solution was stirred for 1 h resulting in color change from yellow to red-brown. Then, isocyanide (0.44 mmol) was added to the solution to give clear yellow solution. Finally, α,β-unsaturated ketone (0.40 mmol) and toluene (1.0-4.0 mL) were added to the mixture. The tube was sealed, and the solution was stirred at designated temperature (60-100 °C) for 14 h. After cooled to rt, the reaction mixture was diluted with DCM and then transferred to 50 mL round-bottle flask. The solution was concentrated under reduced pressure to give crude mixture, which was analyzed with ^{1}H NMR ($CDCl_3$) by using nitromethane as an internal standard. The mixture was subjected to silica gel column chromatography (hexane:AcOEt as eluent) to afford pyrrole **3**.

*Note: Pyrroles **3** were generally not stable compounds in the condensed form. They should be stored in a refrigerator under inert atmosphere to avoid decomposition. Solution state (solvent: DCM, MeOH, etc.) is better for long term storage.*

General procedure B: Synthesis of pyrrole **4**

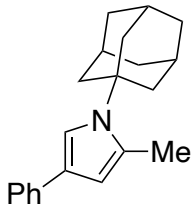
To a 15 mL J. Young. Schlenk tube were added $[Rh(OMe)(cod)]_2$ (2.4 mg, 0.005 mmol, 2.5 mol% Rh) and B_2pin_2 (111.7 mg, 0.44 mmol). The tube was purged with argon, followed by addition of toluene (1.0 mL). The solution was stirred for 1 h resulting in color change from yellow to red-brown. Then, isocyanide (1.2 mmol) was added to the solution to give clear yellow solution. Finally, α,β-unsaturated ketone (0.40 mmol) and toluene (1.0 mL) were added to the mixture. The tube was sealed, and the solution was stirred at 35 °C for 14 h. After cooled to rt, the reaction mixture was diluted with DCM and then transferred to 50 mL round-bottle flask. The solution was concentrated under reduced pressure to give crude mixture, which was analyzed with ^{1}H NMR ($CDCl_3$) by using nitromethane as an internal standard. To hydrolyze the imine moiety to the corresponding aldehyde, the mixture was dissolved in Et_2O (2 mL) and H_2O (0.5 mL), followed by addition of trifluoroacetic acid (TFA, 1.3 mmol, 3.3 equiv). After stirred for 1 day at rt or 30 °C, the mixture was concentrated under vacuum and then subjected to silica gel column chromatography (hexane:AcOEt or hexane:DCM as eluent) to afford pyrrole **4**.

1-(*tert*-butyl)-2-methyl-4-phenyl-1*H*-pyrrole (3aa)



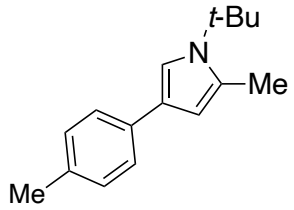
According to the general procedure A, the reaction was performed at 60 °C for 14 h in toluene (5 mL). A pale yellow oil (73.1 mg, 0.343 mmol, 86% yield). ^{1}H NMR (500 MHz, rt, $CDCl_3$): δ 7.47 (d, J = 7.0 Hz, 2H), 7.29 (t, J = 7.5 Hz, 2H), 7.11 (t, J = 7.5 Hz, 1H), 7.08 (d, J = 2.5 Hz, 1H), 6.24 (dd, J = 2.5, 1.0 Hz, 1H), 2.47 (s, 3H), 1.63 (s, 9H). ^{13}C NMR (100.5 MHz, rt, $CDCl_3$): δ 136.2, 130.1, 128.5, 124.9, 124.7, 121.6, 115.2, 108.4, 56.2, 30.7, 16.5. HRMS (ESI) calcd for $C_{15}H_{20}N$ $[M+H]^+$ 214.1590; found: 214.1586.

1-(adamantan-1-yl)-2-methyl-4-phenyl-1*H*-pyrrole (3ab)



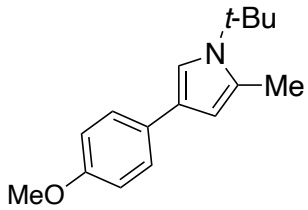
According to the general procedure A, the reaction was performed at 60 °C for 14 h in toluene (5 mL). A white solid (92.4 mg, 0.317 mmol, 79% yield). Single crystals suitable for X-ray crystallographic analysis were obtained by slow evaporation of DCM solution. The CCDC number is 2269832. ^{1}H NMR (500 MHz, rt, $CDCl_3$): δ 7.46 (d, J = 7.0 Hz, 2H), 7.28 (t, J = 8.0 Hz, 2H), 7.12 (d, J = 2.0 Hz, 1H), 7.10 (t, J = 7.0 Hz, 1H), 6.22 (s, 1H), 2.52 (s, 3H), 2.25 (s, 6 H), 2.23 (br s, 3H), 1.76 (br s, 6H). ^{13}C NMR (125.8 MHz, rt, $CDCl_3$) δ 136.3, 130.0, 128.6, 124.9, 124.8, 121.6, 114.6, 108.5, 57.3, 42.7, 36.3, 30.0, 17.1. HRMS (ESI) calcd for $C_{21}H_{26}N$ $[M+H]^+$ 292.2060; found: 292.2058. m.p. 73.8-75.0 °C.

1-(*tert*-butyl)-2-methyl-4-(*p*-tolyl)-1*H*-pyrrole (3ba)



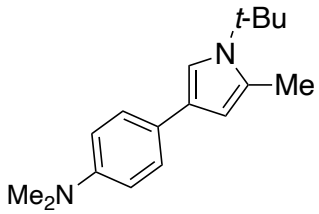
According to the general procedure A, the reaction was performed at 60 °C for 14 h in toluene (2.0 mL). A pale yellow oil (50.5 mg, 0.222 mmol, 55% yield). ^{1}H NMR (400 MHz, rt, $CDCl_3$) δ 7.36 (d, J = 8.0 Hz, 2H), 7.10 (d, J = 8.0 Hz, 2H), 7.04 (d, J = 2.4 Hz, 1H), 6.20 (dd, J = 2.4, 0.8 Hz, 1H), 2.45 (s, 3H), 2.31 (s, 3H), 1.62 (s, 9H). ^{13}C NMR (100.5 MHz, rt, $CDCl_3$) δ 134.4, 133.4, 130.0, 129.3, 124.7, 121.7, 114.9, 108.3, 56.2, 30.8, 21.2, 16.5. HRMS (ESI) calcd for $C_{16}H_{22}N$ $[M+H]^+$ 228.1747; found: 228.1740.

1-(*tert*-butyl)-4-(4-methoxyphenyl)-2-methyl-1*H*-pyrrole (3ca)



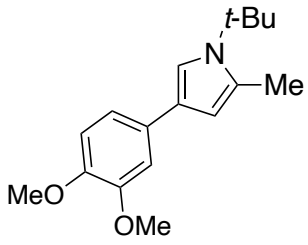
According to the general procedure A, the reaction was performed at 60 °C for 72 h in toluene (5.0 mL). A pale yellow oil (67.2 mg, 0.276 mmol, 69% yield). ^{1}H NMR (400 MHz, rt, $CDCl_3$) δ 7.39 (d, J = 8.4 Hz, 2H), 6.99 (d, J = 2.4 Hz, 1H), 6.85 (d, J = 8.4 Hz, 2H), 6.17 (dd, J = 2.4, 1.2 Hz, 1H), 3.79 (s, 3H), 2.45 (s, 3H), 1.62 (s, 9H). ^{13}C NMR (100.5 MHz, rt, $CDCl_3$) δ 157.4, 130.0, 129.2, 125.9, 121.4, 114.5, 114.0, 108.3, 56.2, 55.4, 30.8, 16.5. HRMS (ESI) calcd for $C_{16}H_{22}NO$ $[M+H]^+$ 244.1696; found: 244.1698.

4-(1-(*tert*-butyl)-5-methyl-1*H*-pyrrol-3-yl)-*N*,*N*-dimethylaniline (3da)



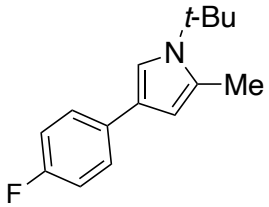
According to the general procedure A, the reaction was performed at 60 °C for 14 h in toluene (2.2 mL). A pale yellow oil (66.1 mg, 0.258 mmol, 65% yield). ^{1}H NMR (500 MHz, rt, $CDCl_3$) δ 7.35 (d, J = 9.0 Hz, 2H), 6.96 (d, J = 2.0 Hz, 1H), 6.73 (d, J = 8.5 Hz, 2H), 6.15 (dd, J = 2.0, 1.0 Hz, 1H), 2.91 (s, 6H), 2.45 (s, 3H), 1.61 (s, 9H). ^{13}C NMR (125.8 MHz, rt, $CDCl_3$) δ 148.7, 129.7, 125.7, 125.6, 121.9, 114.0, 113.4, 108.2, 56.0, 41.1, 30.8, 16.5. HRMS (ESI) calcd for $C_{17}H_{25}N_2$ $[M+H]^+$ 257.2012; found: 257.2007.

1-(*tert*-butyl)-4-(3,4-dimethoxyphenyl)-2-methyl-1*H*-pyrrole (3ea)



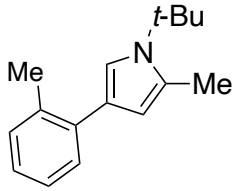
According to the general procedure A, the reaction was performed at 60 °C for 14 h in toluene (2.0 mL). A pale yellow oil (73.0 mg, 0.267 mmol, 67% yield). ^{1}H NMR (400 MHz, rt, $CDCl_3$) δ 7.02-6.99 (m, 3H), 6.82 (d, J = 8.4 Hz, 1H), 6.18 (dd, J = 2.2, 1.2 Hz, 1H), 3.91 (s, 3H), 3.87 (s, 3H), 2.46 (s, 3H), 1.62 (s, 9H). ^{13}C NMR (100.5 MHz, $CDCl_3$) δ 148.9, 146.8, 130.0, 129.6, 121.6, 117.0, 114.5, 111.5, 108.6, 108.3, 56.2, 55.95, 55.85, 30.7, 16.5. HRMS (ESI) calcd for $C_{17}H_{24}NO_2$ $[M+H]^+$ 274.1802; found: 274.1808.

1-(*tert*-butyl)-4-(4-fluorophenyl)-2-methyl-1*H*-pyrrole (3fa)



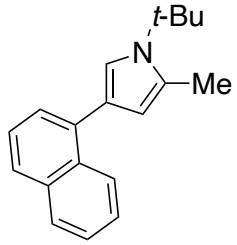
According to the general procedure A, the reaction was performed at 60 °C for 45 h in toluene (5.0 mL). A pale yellow oil (57.2 mg, 0.247 mmol, 62% yield). ^{1}H NMR (500 MHz, rt, $CDCl_3$) δ 7.40 (dd, J = 8.6, 5.6 Hz, 2H), 7.01 (d, J = 2.5 Hz, 1H), 6.97 (t, J = 8.8 Hz, 2H), 6.17 (dd, J = 2.5, 1.0 Hz, 1H), 2.45 (s, 3H), 1.62 (s, 9H). ^{13}C NMR (125.8 MHz, $CDCl_3$) δ 161.0 (d, $J_{C\text{-}F}$ = 242.4 Hz), 132.4, 130.3, 126.1 (d, $J_{C\text{-}F}$ = 7.2 Hz), 120.8, 115.3 (d, $J_{C\text{-}F}$ = 21.5 Hz), 115.0, 108.4, 56.3, 30.8, 16.5. HRMS (ESI) calcd for $C_{15}H_{19}NF$ $[M+H]^+$ 232.1496; found: 232.1500.

1-(*tert*-butyl)-2-methyl-4-(*o*-tolyl)-1*H*-pyrrole (3ga)



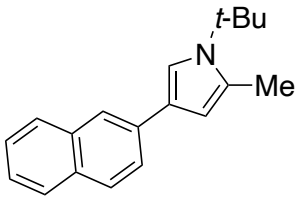
According to the general procedure A, the reaction was performed at 80 °C for 14 h in toluene (2.0 mL). A white solid (43.0 mg, 0.189 mmol, 47% yield). ^{1}H NMR (500 MHz, rt, $CDCl_3$) δ 7.36 (d, J = 8.0 Hz, 1H), 7.18 (d, J = 7.5 Hz, 1H), 7.15 (t, J = 7.0 Hz, 1H), 7.08 (t, J = 7.0 Hz, 1H), 6.87 (d, J = 2.0 Hz, 1H), 6.11 (dd, J = 2.0, 1.5 Hz, 1H), 2.47 (s, 3H), 2.45 (s, 3H), 1.62 (s, 9H). ^{13}C NMR (125 MHz, rt, $CDCl_3$) δ 136.2, 134.8, 130.7, 128.9, 128.8, 125.8, 125.4, 121.3, 117.5, 111.2, 56.1, 30.9, 21.8, 16.5. HRMS (ESI) calcd for $C_{16}H_{22}N$ $[M+H]^+$ 228.1747; found: 228.1751. m.p. 86.0-87.5 °C.

1-(*tert*-butyl)-2-methyl-4-(naphthalen-1-yl)-1*H*-pyrrole (3ha)



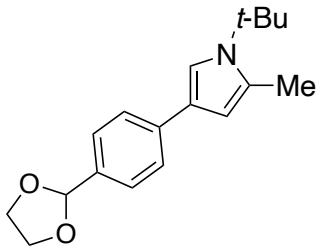
According to the general procedure A, the reaction was performed at 80 °C for 14 h in toluene (2.0 mL). A pale yellow oil (63.3 mg, 0.240 mmol, 60% yield). ^{1}H NMR (500 MHz, rt, $CDCl_3$) δ 8.43 (dd, J = 6.0, 3.5 Hz, 1H), 7.84 (dd, J = 5.8, 3.5 Hz, 1H), 7.70 (d, J = 7.5 Hz, 1H), 7.47-7.42 (m, 4H), 7.01 (d, J = 1.5 Hz, 1H), 6.24 (dd, J = 1.5, 1.0 Hz, 1H), 2.53 (s, 3H), 1.66 (s, 9H). ^{13}C NMR (125.8 MHz, rt, $CDCl_3$) δ 135.3, 134.2, 131.9, 129.2, 128.3, 126.7, 126.1, 126.0, 125.7, 125.54, 125.49, 120.4, 118.0, 112.1, 56.3, 30.9, 16.6. HRMS (ESI) calcd for $C_{19}H_{22}N$ $[M+H]^+$ 264.1747; found: 264.1755.

1-(*tert*-butyl)-2-methyl-4-(naphthalen-2-yl)-1*H*-pyrrole (3ia)



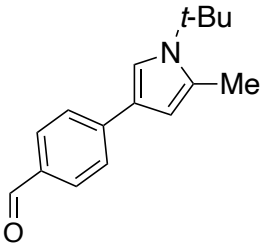
According to the general procedure A, the reaction was performed at 60 °C for 24 h in toluene (5.0 mL). A pale yellow oil (66.6 mg, 0.253 mmol, 63% yield) ; ^{1}H NMR (400 MHz, rt, $CDCl_3$) δ 7.87 (s, 1H), 7.79-7.76 (m, 3H), 7.65 (dd, J = 8.8, 2.0 Hz, 1H), 7.42 (t, J = 7.6 Hz, 1H), 7.35 (t, J = 8.4 Hz, 1H), 7.21 (d, J = 2.0 Hz, 1H), 6.38 (dd, J = 2.0, 1.2 Hz, 1H), 2.51 (s, 3H), 1.67 (s, 9H). ^{13}C NMR (100.5 MHz, rt, $CDCl_3$) δ 134.2, 133.7, 131.8, 130.5, 128.0, 127.73, 127.67, 126.0, 124.6, 124.5, 121.9, 121.6, 115.8, 108.6, 56.4, 30.8, 16.6. HRMS (ESI) calcd for $C_{19}H_{22}N$ $[M+H]^+$ 264.1747; found: 264.1753.

4-(4-(1,3-dioxolan-2-yl)phenyl)-1-(*tert*-butyl)-2-methyl-1*H*-pyrrole (3ja)



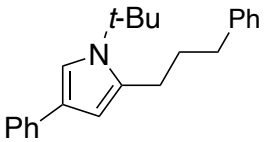
According to the general procedure A, the reaction was performed at 60 °C for 48 h in toluene (5.0 mL). A pale yellow oil (81.0 mg, 0.284 mmol, 71% yield). ^{1}H NMR (400 MHz, rt, $CDCl_3$) δ 7.47 (d, J = 8.0 Hz, 2H), 7.39 (d, J = 8.0 Hz, 2H), 7.09 (d, J = 1.6 Hz, 1H), 6.24 (dd, J = 1.6, 1.2 Hz, 1H), 5.78 (s, 1H), 4.17-3.97 (m, 4H), 2.46 (s, 3H), 1.62 (s, 9H). ^{13}C NMR (100.5 MHz, rt, $CDCl_3$) δ 137.3, 134.1, 130.2, 126.8, 124.6, 121.2, 115.5, 108.5, 104.1, 65.3, 56.3, 30.8, 16.5. HRMS (ESI) calcd for $C_{18}H_{23}NO_2Na$ $[M+Na]^+$ 308.1621; found: 308.1617.

4-(1-(*tert*-butyl)-5-methyl-1*H*-pyrrol-3-yl)benzaldehyde (6ja)



To a 50 mL round bottle flask were added 4-(4-(1,3-dioxolan-2-yl)phenyl)-1-(*tert*-butyl)-2-methyl-1*H*-pyrrole (**3ja**) (81.0 mg, 0.284 mmol), Et_2O (3 mL), H_2O (0.5 mL), and CF_3CO_2H (11 μL, 0.14 mmol). The reaction mixture was stirred at rt for 2 days. The solution was concentrated under reduced pressure. The residue was subjected to sílica gel column chromatography (hexane:AcOEt = 20:1) to afford 4-(1-(*tert*-butyl)-5-methyl-1*H*-pyrrol-3-yl)benzaldehyde(5mb) as a white solid (58.0 mg, 0.240 mmol, 60% yield for 2 steps from **1j**). ^{1}H NMR (400 MHz, rt, $CDCl_3$) δ 9.92 (s, 1H), 7.80 (d, J = 8.0 Hz, 2H), 7.60 (d, J = 8.0 Hz, 2H), 7.22 (d, J = 2.0 Hz, 1H), 6.31 (s, 1H), 2.48 (s, 3H), 1.65 (s, 9H). ^{13}C NMR (125.8 MHz, rt, $CDCl_3$) δ 191.9, 142.7, 133.2, 131.1, 130.6, 124.5, 120.4, 117.1, 108.7, 56.7, 30.7, 16.5. HRMS (ESI) calcd for $C_{18}H_{23}NO_2Na$ $[M+Na]^+$ 308.1621; found: 308.1617. m.p. 81.8-83.2 °C.

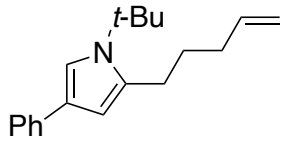
1-(*tert*-butyl)-4-phenyl-2-(3-phenylpropyl)-1*H*-pyrrole (3ka)



According to the general procedure A, the reaction was performed at 60 °C for 14 h in toluene (5.0 mL). A pale yellow oil (95.7 mg, 0.301 mmol, 75% yield). ^{1}H NMR (500 MHz, rt, $CDCl_3$) δ 7.47 (d, J = 8.0 Hz, 2H), 7.31-7.26 (m, 4H), 7.23-7.18 (m, 3H), 7.10 (t, J = 7.5 Hz, 1H), 7.06 (d, J = 2.0 Hz, 1H), 6.33 (s, 1H), 2.82 (t, J = 7.5 Hz, 2H),

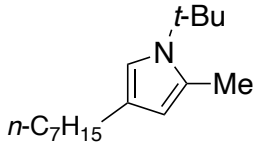
2.78 (t, J = 7.5 Hz, 2H), 2.10 (quint, J = 7.5 Hz, 2H), 1.58 (s, 9H). ^{13}C NMR (125.8 MHz, rt, $CDCl_3$) δ 142.3, 136.3, 134.9, 128.6 (strong signal due to probable overlap of two peaks), 128.5, 126.0, 125.0, 124.8, 121.6, 114.9, 106.3, 56.3, 36.0, 31.3, 31.1, 29.0. HRMS (ESI) calcd for $C_{23}H_{28}N$ $[M+H]^+$ 318.2216; found: 318.2222.

1-(*tert*-butyl)-2-(pent-4-en-1-yl)-4-phenyl-1*H*-pyrrole (3la)



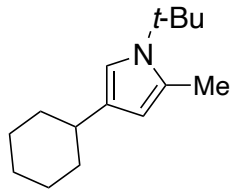
According to the general procedure A, the reaction was performed at 60 °C for 24 h in toluene (5.0 mL). A colorless oil (67.6 mg, 0.253 mmol, 63% yield). ^{1}H NMR (500 MHz, rt, $CDCl_3$) δ 7.48 (d, J = 7.0 Hz, 2H), 7.29 (t, J = 7.5 Hz, 2H), 7.10 (t, J = 7.5 Hz, 1H), 7.07 (d, J = 2.0 Hz, 1H), 6.32 (d, J = 2.0 Hz, 1H), 5.87 (ddt, J = 17.0, 10.5, 7.0 Hz, 1H), 5.07 (dd, J = 17.0, 1.5 Hz, 1H), 5.01 (dd, J = 10.5, 1.5 Hz, 1H), 2.80 (t, J = 8.0 Hz, 2H), 2.22 (q, J = 6.5 Hz, 2H), 1.86 (tt, J = 8.0, 7.5 Hz, 2H), 1.62 (s, 9H). ^{13}C NMR (125.8 MHz, rt, $CDCl_3$) δ 138.6, 136.3, 135.1, 128.6, 125.0, 124.8, 121.6, 115.1, 114.9, 106.3, 56.3, 33.9, 31.1, 28.94, 28.91. HRMS (ESI) calcd for $C_{19}H_{26}N$ $[M+H]^+$ 268.2060; found: 268.2052.

1-(*tert*-butyl)-4-heptyl-2-methyl-1*H*-pyrrole (3ma)



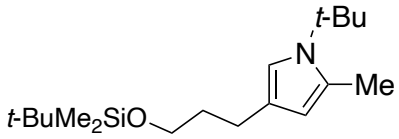
According to the general procedure A, the reaction was performed at 80 °C for 14 h in toluene (2.0 mL). A pale yellow oil (61.7 mg, 0.262 mmol, 66% yield). ^{1}H NMR (400 MHz, rt, $CDCl_3$) δ 6.53 (d, J = 2.0 Hz, 1H), 5.77 (d, J = 1.2 Hz, 1H), 2.39 (s, 3H), 2.39-2.35 (m, 2H), 1.57-1.48 (m, 2H), 1.56 (s, 9H), 1.36-1.22 (m, 8H), 0.88 (t, J = 6.8 Hz, 3H). ^{13}C NMR (100.5 MHz, rt, $CDCl_3$) δ 128.6, 121.7, 115.4, 110.4, 55.6, 32.0, 31.3, 30.9, 29.9, 29.4, 27.3, 22.8, 16.5, 14.3. HRMS (ESI) calcd for $C_{16}H_{30}N$ $[M+H]^+$ 236.2373; found: 236.2375.

1-(*tert*-butyl)-4-cyclohexyl-2-methyl-1*H*-pyrrole (3na)



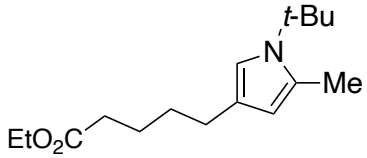
According to the general procedure A, the reaction was performed at 80 °C for 14 h in toluene (2.0 mL). A colorless oil (44.8 mg, 0.204 mmol, 51% yield). ^{1}H NMR (500 MHz, rt, $CDCl_3$) δ 6.53 (d, J = 2.5 Hz, 1H), 5.80 (d, J = 1.0 Hz, 1H), 2.40 (s, 3H), 2.36 (tt, J = 11.5, 3.5 Hz, 1H), 1.94 (br d, J = 12 Hz, 2H), 1.78-1.75 (m, 2H), 1.70-1.66 (m, 1H), 1.56 (s, 9H), 1.37-1.14 (m, 5H). ^{13}C NMR (125.8 MHz, rt, $CDCl_3$) δ 128.4, 127.7, 114.0, 108.7, 55.7, 36.4, 34.7, 30.9, 26.9, 26.5, 16.6. HRMS (ESI) calcd for $C_{15}H_{26}N$ $[M+H]^+$ 220.2060; found: 220.2054.

1-(*tert*-butyl)-4-(3-((*tert*-butyldimethylsilyl)oxy)propyl)-2-methyl-1*H*-pyrrole (3oa)



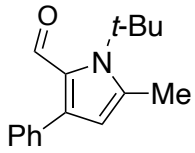
According to the general procedure A, the reaction was performed at 80 °C for 14 h in toluene (2.0 mL). A pale orange liquid (79.1 mg, 0.255 mmol, 64% yield). ^{1}H NMR (400 MHz, rt, $CDCl_3$) δ 6.54 (d, J = 2.0 Hz, 1H), 5.77 (dd, J = 2.0, 0.8 Hz, 1H), 3.65 (t, J = 6.4 Hz, 2H), 2.43 (t, J = 7.8 Hz, 2H), 2.39 (s, 3H), 1.77 (tt, J = 7.8, 6.4 Hz, 2H), 1.56 (s, 9H), 0.90 (s, 9H), 0.05 (s, 6H). ^{13}C NMR (100.5 MHz, rt, $CDCl_3$) δ 128.7, 120.8, 115.6, 110.4, 63.2, 55.7, 34.2, 30.9, 26.1, 23.3, 18.5, 16.5, –5.1. HRMS (ESI) calcd for $C_{18}H_{36}NOSi$ $[M+H]^+$ 310.2561; found: 310.2568.

ethyl 5-(1-(*tert*-butyl)-5-methyl-1*H*-pyrrol-3-yl)pentanoate (3pa)



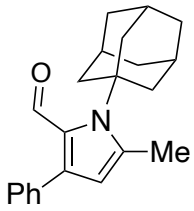
According to the general procedure A, the reaction was performed at 80 °C for 14 h in toluene (2.0 mL). A pale orange oil (46.0 mg, 0.173 mmol, 43% yield). ^{1}H NMR (400 MHz, rt, $CDCl_3$) δ 6.53 (d, J = 2.4 Hz, 1H), 5.76 (dd, J = 2.4, 0.8 Hz, 1H), 4.12 (q, J = 6.8 Hz, 2H), 2.40 (t, J = 7.6 Hz, 2H), 2.39 (s, 3H), 2.32 (t, J = 7.2 Hz, 2H), 1.72-1.53 (m, 4H), 1.56 (s, 9H), 1.25 (t, J = 6.8 Hz, 3H). ^{13}C NMR (100.5 MHz, rt, $CDCl_3$) δ 174.1, 128.7, 121.0, 115.6, 110.3, 60.3, 55.7, 34.5, 30.84, 30.76, 26.8, 25.1, 16.5, 14.4. HRMS (ESI) calcd for $C_{16}H_{28}NO_2$ $[M+H]^+$ 266.2115; found: 266.2116.

1-(*tert*-butyl)-5-methyl-3-phenyl-1*H*-pyrrole-2-carbaldehyde (5aa)



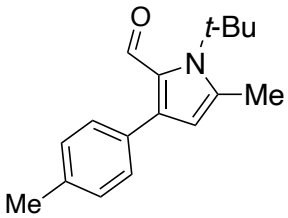
According to the general procedure B, the reaction was performed at 35 °C for 14 h in cyclohexane (2.0 mL). A white solid (74.0 mg, 0.307 mmol, 77% yield). ^{1}H NMR (500 MHz, rt, $CDCl_3$): δ 9.31 (s, 1H), 7.39-7.31 (m, 5H), 6.02, (s, 1H), 2.53 (s, 3H), 1.80 (s, 9H). ^{13}C NMR (125.8 MHz, rt, $CDCl_3$): δ 178.8, 145.3, 141.1, 135.0, 130.2, 129.8, 128.2, 127.6, 114.3, 61.1, 31.6, 19.1. HRMS (ESI) calcd for $C_{16}H_{19}NONa$ $[M+Na]^+$ 264.1359; found: 264.1357. mp: 86.6-87.8 °C.

1-(adamantan-1-yl)-5-methyl-3-phenyl-1*H*-pyrrole-2-carbaldehyde (5ab)



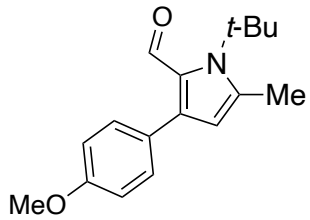
According to the general procedure B, the reaction was performed at 35 °C for 14 h in toluene (2.0 mL). A white solid (45.8 mg, 0.143 mmol, 36% yield). ^{1}H NMR (500 MHz, rt, $CDCl_3$): δ 9.30 (s, 1H), 7.40-7.32 (m, 5H), 6.01 (s, 1H), 2.59 (s, 3H), 2.50 (d, J = 2.0 Hz, 6H), 2.22 (s, 3H), 1.88 (d, J = 12.0 Hz, 3H), 1.71 (d, J = 12.0 Hz, 3H). ^{13}C NMR (100.5 MHz, rt, $CDCl_3$): δ 178.6, 145.9, 140.9, 135.3, 130.2, 129.4, 128.2, 127.5, 115.0, 63.0, 42.3, 35.9, 30.5, 19.8. HRMS (ESI) calcd for $C_{22}H_{25}NONa$ $[M+Na]^+$ 342.1828; found: 342.1827. mp: 137.5-139.0 °C.

1-(*tert*-butyl)-5-methyl-3-(*p*-tolyl)-1*H*-pyrrole-2-carbaldehyde (5ba)



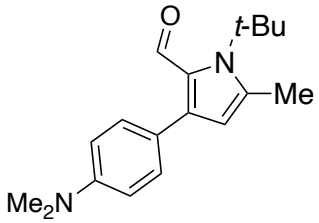
According to the general procedure B, the reaction was performed by using 0.40 mmol (1.0 equiv) of B_2pin_2 at 35 °C for 62 h in toluene (2.0 mL). Hydrolysis was performed by using TFA (61 μL, 0.80 mmol), Et_2O (3.0 mL), and H_2O (1.0 mL) for 1 day. A white solid (80.4 mg, 0.315 mmol, 79% yield). ^{1}H NMR (500 MHz, rt, $CDCl_3$) δ 9.30 (s, 1H), 7.26 (d, J = 8.5 Hz, 2H), 7.19 (d, J = 8.0 Hz, 2H), 6.00 (s, 1H), 2.53 (s, 3H), 2.38 (s, 3H), 1.80 (s, 9H). ^{13}C NMR (100.5 MHz, $CDCl_3$) δ 178.8, 145.4, 141.1, 137.4, 132.0, 130.0, 129.7, 129.0, 114.2, 61.0, 31.5, 21.3, 19.0. HRMS (ESI) Calcd. for $C_{17}H_{21}NONa$ $[M+Na]^+$ 278.1521; found: 278.1525. Anal. Calcd. for $C_{17}H_{21}NO$: C, 79.96; H, 8.29; N, 5.49. found: C, 80.06; H, 8.30; N, 5.27. mp: 90.6-92.0 °C.

1-(*tert*-butyl)-3-(4-methoxyphenyl)-5-methyl-1*H*-pyrrole-2-carbaldehyde (5ca)



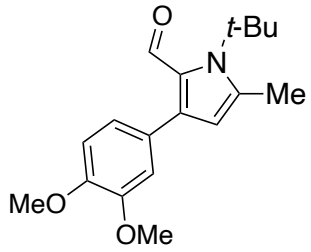
According to the general procedure B, the reaction was performed by using 1.0 equiv (0.40 mmol) of B_2pin_2 at 35 °C for 62 h in toluene (2.0 mL). Hydrolysis was performed by using TFA (34 μL, 0.44 mmol), Et_2O (2.0 mL), and H_2O (0.4 mL) for 4 days. A white solid (85.8 mg, 0.316 mmol, 79% yield). ^{1}H NMR (500 MHz, rt, $CDCl_3$) δ 9.29 (s, 1H), 7.29 (d, J = 9.0 Hz, 2H), 6.91 (d, J = 9.0 Hz, 2H), 5.98 (s, 1H), 3.83 (s, 3H), 2.52 (s, 3H), 1.80 (s, 9H). ^{13}C NMR (125.8 MHz, rt, $CDCl_3$) δ 178.8, 159.3, 145.1, 141.1, 131.2, 129.7, 127.3, 114.1, 113.7, 60.9, 55.4, 31.5, 19.0. HRMS (ESI) calcd for $C_{17}H_{22}NO_2$ $[M+H]^+$ 272.1645; found: 272.1649. mp: 91.5-92.7 °C.

1-(*tert*-butyl)-3-(4-(dimethylamino)phenyl)-5-methyl-1*H*-pyrrole-2-carbaldehyde (5da)



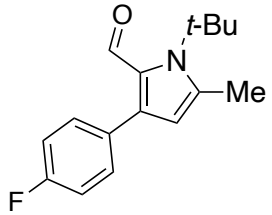
According to the general procedure B, the reaction was performed by using 1.0 equiv (0.40 mmol) of B_2pin_2 at 35 °C for 88 h in toluene (2.0 mL). Hydrolysis was performed by using HCl aq. (5 mL, pH = 3 after addition to the crude) and Et_2O (5.0 mL) for 2 days. A white solid (87.3 mg, 0.307 mmol, 77% yield). Single crystals suitable for X-ray crystallographic analysis were obtained by slow evaporation of DCM solution. The CCDC number is 2269833. ^{1}H NMR (500 MHz, rt, $CDCl_3$) δ 9.31 (s, 1H), 7.26 (d, J = 8.5 Hz, 2H), 6.73 (d, J = 8.5 Hz, 2H), 5.97 (s, 1H), 2.98 (s, 6H), 2.51 (s, 3H), 1.80 (s, 9H). ^{13}C NMR (125.8 MHz, rt, $CDCl_3$) δ 179.1, 150.1, 146.0, 141.2, 130.9, 129.6, 122.8, 113.9, 112.1, 60.8, 40.6, 31.6, 19.1. HRMS (ESI) calcd for $C_{18}H_{25}N_2O$ $[M+H]^+$ 285.1961; found: 285.1954. mp: 111.9-113.0 °C.

1-(*tert*-butyl)-3-(3,4-dimethoxyphenyl)-5-methyl-1*H*-pyrrole-2-carbaldehyde (5ea)



According to the general procedure B, the reaction was performed by using 1.0 equiv (0.40 mmol) of B_2pin_2 at 35 °C for 60 h in toluene (2.0 mL). Hydrolysis was performed by using TFA (61 μL, 0.80 mmol), Et_2O (3.0 mL), and H_2O (1.0 mL). A pale yellow gummy oil (97.9 mg, 0.325 mmol, 81% yield). ^{1}H NMR (500 MHz, rt, $CDCl_3$) δ 9.31 (s, 1H), 6.93-6.88 (m, 3H), 6.01 (s, 1H), 3.92 (s, 3H), 3.90 (s, 3H), 2.54 (s, 3H), 1.81 (s, 9H). ^{13}C NMR (100.5 MHz, $CDCl_3$) δ 178.8, 148.8, 148.6, 145.2, 141.1, 129.8, 127.6, 122.7, 114.2, 113.2, 110.9, 61.0, 56.0 (two MeO carbon peaks are probably overlapped), 31.5, 19.0. HRMS (ESI) calcd for $C_{18}H_{24}NO_3$ $[M+H]^+$ 302.1751; found: 302.1754.

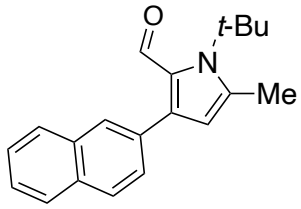
1-(*tert*-butyl)-3-(4-fluorophenyl)-5-methyl-1*H*-pyrrole-2-carbaldehyde (5fa)



According to the general procedure B, the reaction was performed at 35 °C for 14 h in toluene (2.0 mL). A pale yellow oil (44.2 mg, 0.170 mmol, 43% yield). ^{1}H NMR (400 MHz, rt, $CDCl_3$) δ 9.27 (s, 1H), 7.32 (dd, J = 8.8, 5.6

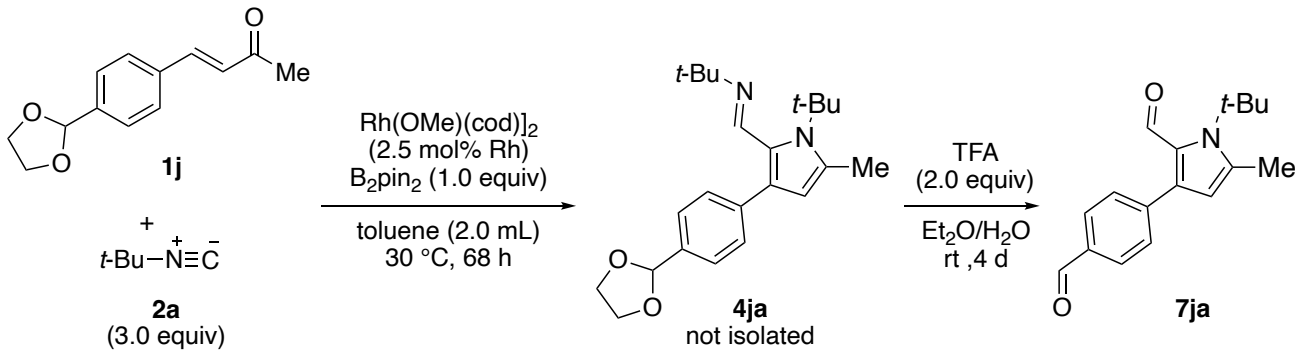
Hz, 2H), 7.07 (t, J = 8.8 Hz, 2H), 5.98 (s, 1H), 2.53 (s, 3H), 1.80 (s, 9H). ^{13}C NMR (100.5 MHz, rt, $CDCl_3$) δ 178.5, 162.6 (d, $J_{C\text{-}F}$ = 246.3 Hz), 144.1, 141.1, 131.7 (d, $J_{C\text{-}F}$ = 8.6 Hz), 131.0 (d, $J_{C\text{-}F}$ = 2.8 Hz), 129.8, 115.2 (d, $J_{C\text{-}F}$ = 21.0 Hz), 114.3, 61.1, 31.6, 19.0. HRMS (ESI) calcd for $C_{16}H_{19}NOF$ $[M+H]^+$ 260.1445; found: 260.1439.

1-(*tert*-butyl)-5-methyl-3-(naphthalen-2-yl)-1*H*-pyrrole-2-carbaldehyde (5ia)



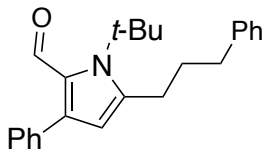
According to the general procedure B, the reaction was performed at 60 °C for 14 h in toluene (2.0 mL). A white solid (39.2 mg, 0.135 mmol, 34% yield). ^{1}H NMR (400 MHz, rt, $CDCl_3$) δ 9.40 (s, 1H), 7.87-7.83 (m, 4H), 7.52-7.49 (m, 3H), 6.12, (s, 1H), 2.57 (s, 3H), 1.84 (s, 9H). ^{13}C NMR (100.5 MHz, rt, $CDCl_3$) δ 179.0, 145.2, 141.2, 133.2, 132.7, 132.4, 130.0, 129.2, 128.2 (two peaks are probably overlapped), 127.846, 127.78, 126.5, 126.3, 114.6, 61.2, 31.6, 19.1. HRMS (ESI) calcd for $C_{20}H_{21}NONa$ $[M+Na]^+$ 314.1521; found: 314.1519. mp: 158.3-159.6 °C.

1-(*tert*-butyl)-3-(4-formylphenyl)-5-methyl-1*H*-pyrrole-2-carbaldehyde (7ja)



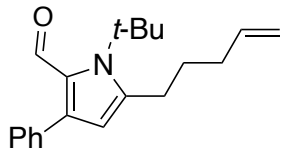
According to the general procedure B, the reaction was performed by using 1.0 equiv (0.40 mmol) of B_2pin_2 at 30 °C for 68 h in toluene (2.0 mL) to afford **4ja** in 43% NMR yield. After the catalytic reaction, the crude mixture was hydrolyzed with TFA (61 μL, 0.80 mmol), Et_2O (3 mL), and H_2O (0.6 mL) for 4 days. After hydrolysis, the crude was subjected to sílica gel column chromatography (hexane:AcOEt = 15:1 to 10:1) to afford 1-(*tert*-butyl)-3-(4-formylphenyl)-5-methyl-1*H*-pyrrole-2-carbaldehyde as a white solid (40.6 mg, 0.151 mmol, 38% yield). ^{1}H NMR (500 MHz, rt, $CDCl_3$) δ 10.0 (s, 1H), 9.3 (s, 1H), 7.90 (d, J = 8.5 Hz, 2H), 7.54 (d, J = 8.0 Hz, 2H), 6.07 (s, 1H), 2.56 (s, 3H), 1.81 (s, 9H). ^{13}C NMR (125.8 MHz, rt, $CDCl_3$) δ 192.0, 178.3, 143.5, 141.6, 141.3, 135.4, 130.7, 129.9, 129.6, 114.5, 61.4, 31.6, 19.1. HRMS (ESI) calcd for $C_{17}H_{20}NO_2$ $[M+H]^+$ 270.1489; found: 270.1487. mp: 134.2-135.8 °C.

1-(*tert*-butyl)-3-phenyl-5-(3-phenylpropyl)-1*H*-pyrrole-2-carbaldehyde (5ka)



According to the general procedure B, the reaction was performed at 35 °C for 40 h in toluene (2.0 mL). Hydrolysis was performed by using 0.025 M HCl aq. (2.0 mL, pH 2~3) in Et_2O (4 mL). A colorless oil (82.1 mg, 0.238 mmol, 59% yield). ^{1}H NMR (400 MHz, rt, $CDCl_3$) δ 9.31 (s, 1H), 7.37-7.28 (m, 7H), 7.23-7.19 (m, 3H), 6.11 (s, 1H), 2.91 (t, J = 7.8 Hz, 2H), 2.73 (t, J = 7.6 Hz, 2H), 2.05 (quint, J = 7.6 Hz, 2H), 1.78 (s, 9H). ^{13}C NMR (100.5 MHz, rt, $CDCl_3$) δ 179.1, 145.8, 145.4, 141.6, 135.1, 130.2, 129.9, 128.6, 128.5, 128.2, 127.6, 126.2, 112.2, 61.2, 35.8, 31.9, 31.6, 30.9. HRMS (ESI) calcd for $C_{24}H_{27}NONa$ $[M+Na]^+$ 368.1990; found: 368.1993.

1-(*tert*-butyl)-5-(pent-4-en-1-yl)-3-phenyl-1*H*-pyrrole-2-carbaldehyde (5la)

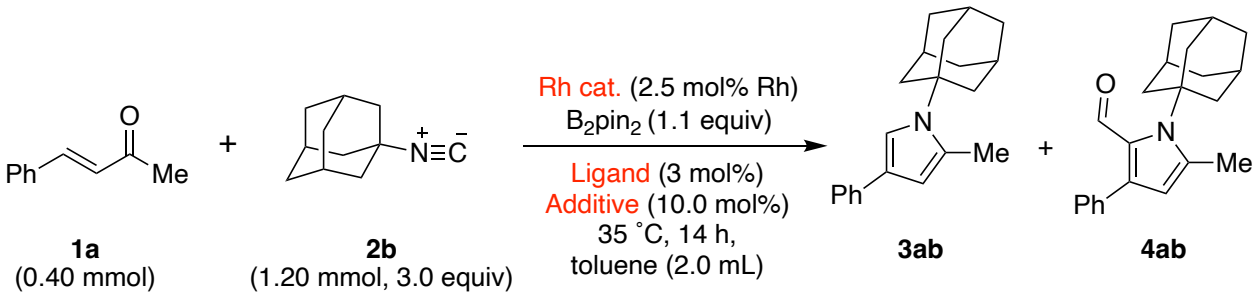


According to the general procedure B, the reaction was performed at 35 °C for 40 h in cyclohexane (2.0 mL). Hydrolysis was performed by using TFA (61 μL, 0.80 mmol, 2.0 equiv). A colorless oil (50.1 mg, 0.170 mmol, 42% yield). ^{1}H NMR (500 MHz, rt, $CDCl_3$) δ 9.31 (s, 1H), 7.40-7.31 (m, 5H), 6.11 (s, 1H), 5.83 (ddt, J = 16.8, 10.8, 7.0 Hz, 1H), 5.07 (dd, J = 16.8, 1.5 Hz, 1H), 5.02 (dd, J = 10.8, 1.5 Hz, 1H), 2.90 (t, J = 8.0 Hz, 2H), 1.85-1.79 (m, 11H). ^{13}C NMR (125.8 MHz, rt, $CDCl_3$) δ 179.1, 146.0, 145.4, 137.9, 135.1, 130.2, 129.9, 128.2, 127.6, 115.6, 112.3, 61.2, 33.7, 31.7, 30.8, 29.4. HRMS (ESI) calcd for $C_{20}H_{26}NO$ $[M+H]^+$ 296.2009; found: 296.2000.

4. Optimization of the reaction conditions: additional test

Other Rh precursors, ligands, and additive were tested for pyrrole **4ab** synthesis (Table S1).

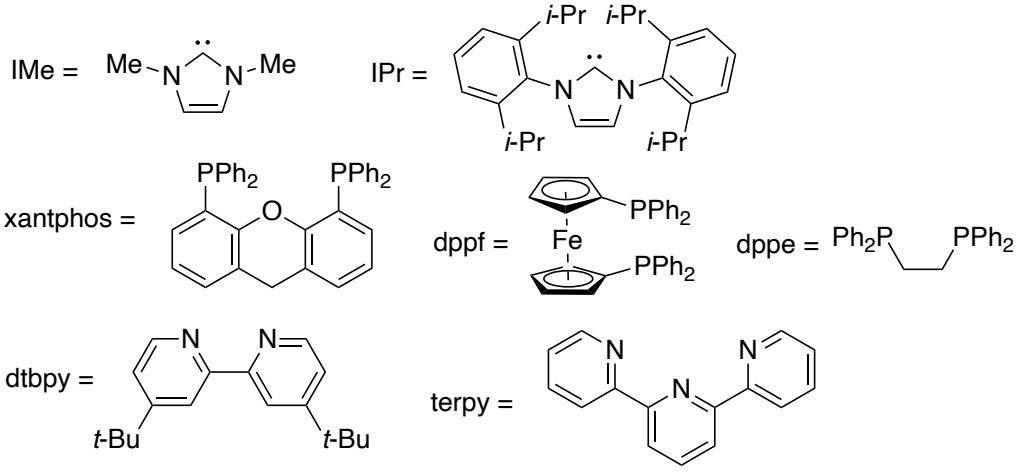
Table S1. Effect of catalyst precursor, ligand, and additive



1a (0.40 mmol) **2b** (1.20 mmol, 3.0 equiv) **3ab** **4ab**

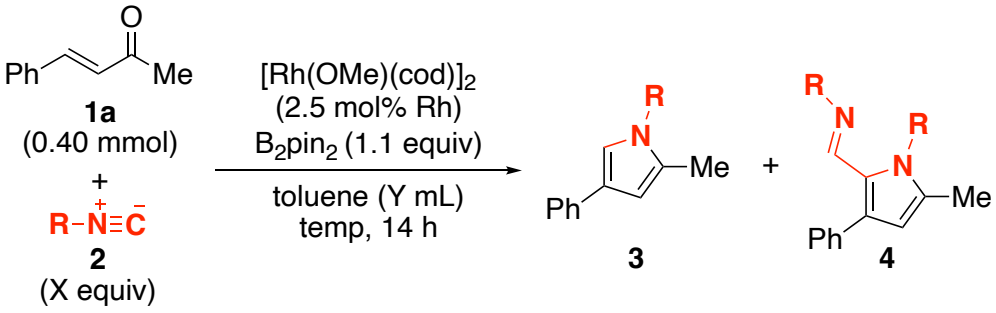
entry	Rh cat. (2.5 mol% Rh)	Ligand (3 mol%)	Additive (10.0 mol%)	conv.	NMR Yields (%)	
					3ab	**4ab**
1	$[Rh(OMe)cod]_2$	-	-	100	7	59
2	$[RhCl(cod)]_2$	-	-	0	0	0
3[a]	Rh(IPr)Cl(cod)	-	-	27	0	0
4[a]	Rh(IMe)Cl(cod)	-	-	0	0	0
5[a]	$[Cp^*RhCl_2]_2$	-	-	16	0	0
6	$[Rh(OMe)cod]_2$	xantphos	-	0	0	0
7	$[Rh(OMe)cod]_2$	dppf	-	27	0	0
8	$[Rh(OMe)cod]_2$	dppe	-	0	0	0
9	$[Rh(OMe)cod]_2$	dtbpy	-	100	8	53
10	$[Rh(OMe)cod]_2$	terpy	-	100	14	52
11	$[Rh(OMe)cod]_2$	-	H_2O	17	4	0
12	$[Rh(OMe)cod]_2$	-	PhOH	100	21	51
13	$[Rh(OMe)cod]_2$	-	CH_3COOH	49	19	3
14	$[Rh(OMe)cod]_2$	-	Et_3N	100	13	55
15	$[Rh(OMe)cod]_2$	-	2,6-lutidine	100	13	54

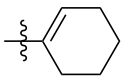
^{1}H NMR yields using $MeNO_2$ as an internal standard are shown.
[a] KO*t*Bu (10.0 mol%) was added.



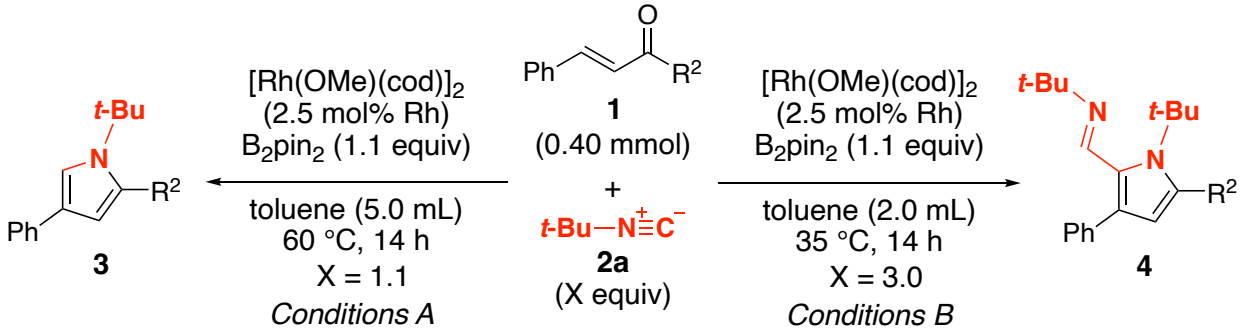
5. Attempt for employing other isocyanides and α,β-unsaturated ester or amides

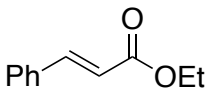
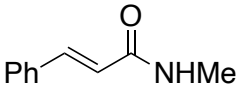
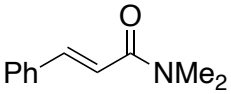
Table S2. Reactions employing other isocyanides than *t*-BuNC



entry	R	X	Y	temp (°C)	conv.(%)	**3a** (%)	**4a** (%)
1	$PhCH_2$	1.1	5.0	60	15	2	0
2	$PhCH_2$	3.0	2.0	35	<1	<1	0
3	2-naph	1.1	5.0	60	4	0	0
4	2-naph	3.0	2.0	35	0	0	0
5	cyclohexyl	1.1	5.0	60	28	5	19
6[a]	cyclohexyl	3.0	2.0	60	90	8	18
7	cyclohexyl	3.0	2.0	35	32	6	2
8		1.1	5.0	60	8	0	0
9		3.0	2.0	35	5	0	0

[1]H NMR yields and conversion using $MeNO_2$ as an internal standard are shown.
[a] For 42 h.

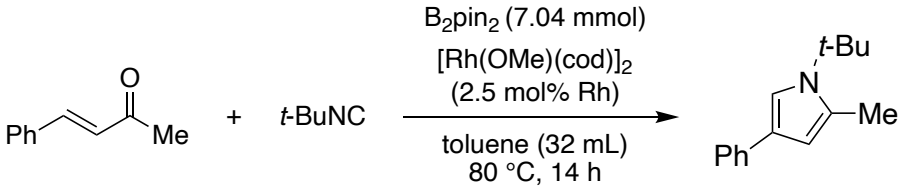


substrate			
	Conditions A: 0% conv. Conditions B: 0% conv.	Conditions A: 0% conv. Conditions B: 0% conv.	Conditions A: 18% conv., no pyrrole Conditions B: 0% conv.

Scheme S1. Reactions employing α,β-unsaturated ester or amide instead of ketone

6. Gram scale experiments

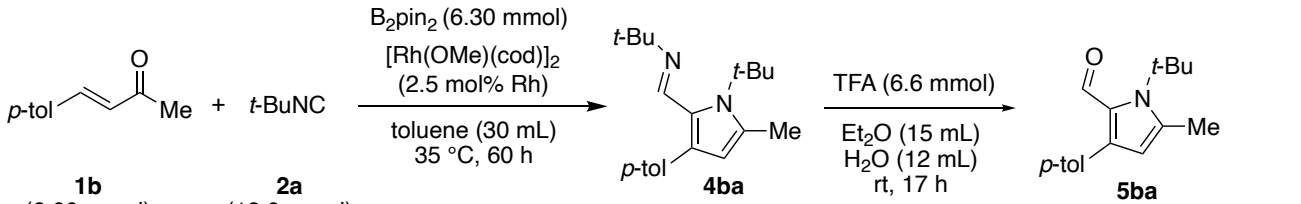
Gram scale synthesis of pyrrole 3aa



1a (6.40 mmol) **2a** (7.04 mmol) **3aa** 1.125 g, 5.27 mmol, 82% yield

To an argon-purged 50 mL J. Young Schlenk tube were added $[Rh(OMe)(cod)]_2$ (38.7 mg, 0.080 mmol, 2.5 mol% Rh) and B_2pin_2 (1.79 g, 7.04 mmol). The tube was purged again with argon for three times. Toluene (16 mL) was added and the solution was stirred for 1 h at rt, resulting in color change of the solution from yellow to dark brown. Then, *t*-BuNC (**2a**) (0.796 mL, 7.04 mmol) was added to afford yellow solution. Finally, benzalacetone (**1a**) (0.936 g, 6.40 mmol) was added to the mixture. The tube was closed and heated to 80 °C for 14 h. After cooled to rt, the reaction mixture was diluted with DCM and then transferred to 200 mL round-bottle flask. The solution was concentrated under reduced pressure. The residue was subjected to silica gel column chromatography (hexane:AcOEt = 30:1) to afford pyrrole **3aa** as a pale yellow oil (1.125 g, 5.27 mmol, 82% yield).

Gram scale synthesis of pyrrole 5ba

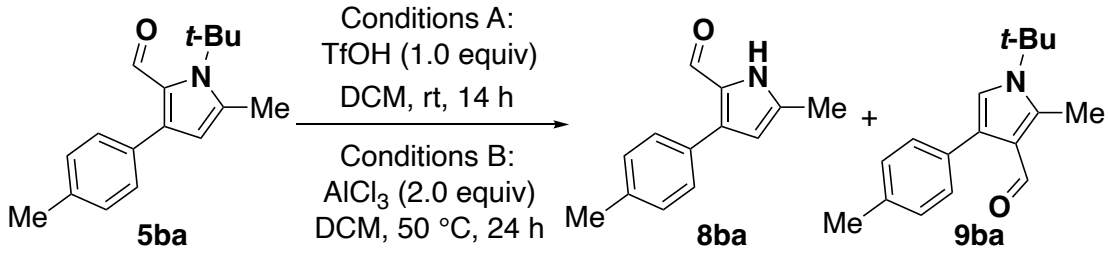


1b (6.00 mmol) **2a** (18.0 mmol) **4ba** **5ba** 1.310 g, 5.13 mmol, 86% yield

To an argon-purged 50 mL J. Young Schlenk tube were added $[Rh(OMe)(cod)]_2$ (36.3 mg, 0.075 mmol, 2.5 mol% Rh) and B_2pin_2 (1.60 g, 6.30 mmol). The tube was purged again with argon for three times. Toluene (15 mL) was added and the solution was stirred for 1 h at rt, resulting in color change of the solution from yellow to dark brown. Then, *t*-BuNC (**2a**) (2.04 mL, 18.0 mmol) was added to afford yellow solution. Finally, (*E*)-4-(*p*-tolyl)but-3-en-2-one (**1b**) (0.961 g, 6.00 mmol) was added to the mixture. The tube was closed and the solution was stirred at 35 °C for 60 h. The reaction mixture was diluted with DCM and then transferred to 200 mL round-bottle flask. The solution was concentrated under reduced pressure. An aliquot of the residue was analyzed with ^1H NMR to confirm formation of **4ba**. Then, the aliquot was returned to the crude mixture which was dissolved in Et_2O (15 mL). To the solution were added TFA (0.505 mL, 6.6 mmol, 1.1 equiv) and H_2O (12 mL). Hydrolysis was performed at rt for 17 h. The biphasic mixture was extracted with Et_2O (15 mL x 2). The combined organic phase was concentrated under reduced pressure. The residue was subjected to silica gel column chromatography (hexane:AcOEt = 40:1 to 20:1) to afford pyrrole **5ba** as a white solid (1.310 g, 5.13 mmol, 86% yield).

7. Transformation of pyrrole product

Retro-Friedel-Crafts type reaction: Removal of *t*-Bu group on the nitrogen atom



Conditions A:	64%	10%
Conditions B:	74%	11%

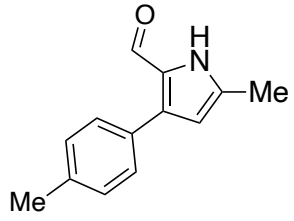
Conditions A: Reaction with TfOH

To an argon purged 15 mL J. Young. Schlenk tube were added pyrrole **5ba** (102.1 mg, 0.40 mmol) and DCM (4.0 mL). TfOH (35.4 μL, 0.40 mmol) was dropwise added to the solution at 0 °C. After stirred at rt for 14 h, 3N NaOH aq. (0.14 mL) was added to the solution, followed by concentrated under reduced pressure. The residue was subjected to silica gel column chromatography (hexane:AcOEt = 20:1 to 10:1, then to 5:1) to afford 5-methyl-3-(*p*-tolyl)-1*H*-pyrrole-2-carbaldehyde (**8ba**) as a white solid (51.3 mg, 0.257 mmol, 64% yield) and 1-(*tert*-butyl)-2-methyl-4-(*p*-tolyl)-1*H*-pyrrole-3-carbaldehyde (**9ba**) as a colorless oil (10.5 mg, 0.0411 mmol, 10% yield).

Conditions B: Reaction with $AlCl_3$

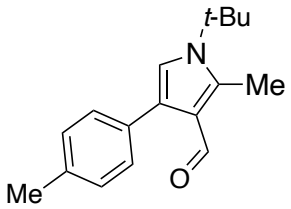
To an argon purged 15 mL J. Young. Schlenk tube were added pyrrole **5ba** (102.1 mg, 0.40 mmol) and DCM (4.0 mL). $AlCl_3$ (53.3 mg, 0.40 mmol) was added to the solution at 0 °C. After stirred at 50 °C for 12 h, additional $AlCl_3$ (53.3 mg, 0.40 mmol) was added to the solution at rt. After stirred for another 12 h at 50 °C, 3N NaOH aq. (0.40 mL) was added to the solution at rt. The resulted white suspension was filtered through Celite. The filtrate was concentrated under reduced pressure, followed by subjection of the residue to silica gel column chromatography (DCM only to DCM:AcOEt = 20:1 to 10:1) to afford 5-methyl-3-(*p*-tolyl)-1*H*-pyrrole-2-carbaldehyde (**8ba**) as a white solid (59.0 mg, 0.296 mmol, 74% yield) and 1-(*tert*-butyl)-2-methyl-4-(*p*-tolyl)-1*H*-pyrrole-3-carbaldehyde (**9ba**) as a colorless oil (11.5 mg, 0.0451 mmol, 11% yield).

5-methyl-3-(*p*-tolyl)-1*H*-pyrrole-2-carbaldehyde (8ba) [CAS:1785091-62-4]



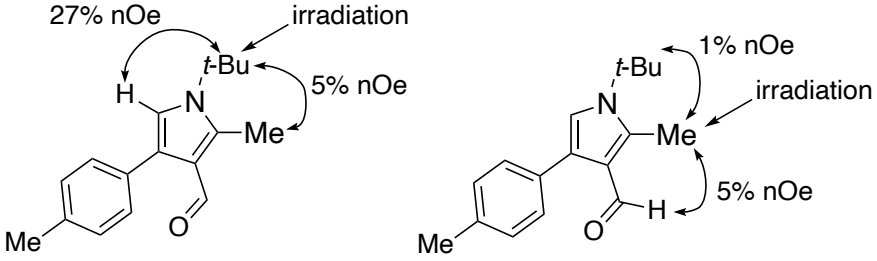
A white solid. mp. 211.5-212.5 °C. Single crystals suitable for X-ray crystallographic analysis were obtained by slow evaporation of DCM solution. The CCDC number is 2269834. ^{1}H NMR (500 MHz, rt, $CDCl_3$) δ 9.89 (br s, 1H), 9.49 (s, 1H), 7.37 (d, J = 8.0 Hz, 2H), 7.23 (d, J = 7.5 Hz, 2H), 6.15 (d, J = 2.0 Hz, 1H), 2.40 (s, 3H), 2.38 (s, 3H). ^{13}C NMR (125.8 MHz, rt, $CDCl_3$) δ 178.8, 139.0, 138.0, 137.7, 131.1, 129.5, 129.1, 128.0, 110.7, 21.3, 13.4. HRMS (ESI) calcd for $C_{13}H_{13}NONa$ $[M+Na]^+$ 222.0889; found: 222.0886.

1-(*tert*-butyl)-2-methyl-4-(*p*-tolyl)-1*H*-pyrrole-3-carbaldehyde (9ba)



A colorless oil. ^{1}H NMR (500 MHz, rt, $CDCl_3$) δ 9.93 (s, 1H), 7.28 (d, J = 8.0 Hz, 2H), 7.19 (d, J = 7.5 Hz, 2H), 6.78 (s, 1H), 2.83 (s, 3H), 2.37 (s, 3H), 1.67 (s, 9H). ^{13}C NMR (125.8 MHz, rt, $CDCl_3$) δ 188.2, 137.1, 136.4, 131.2, 129.24, 129.23, 126.5, 120.4, 117.3, 57.5, 30.7, 21.3, 14.8. HRMS (ESI) calcd for $C_{17}H_{22}NO$ $[M+H]^+$ 256.1696; found: 256.1692.

Structure determination was supported by nOe measurement as follows.



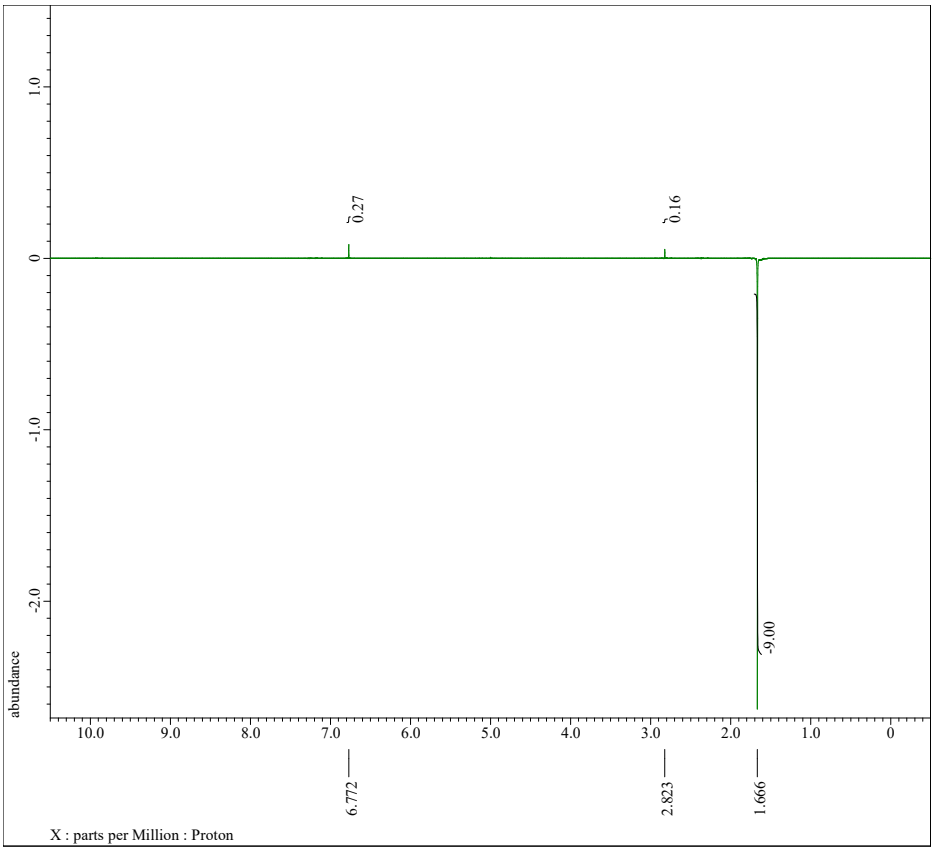


Figure S2. nOe measurement of **9ba** by irradiation at *t*-Bu group (1.67 ppm).

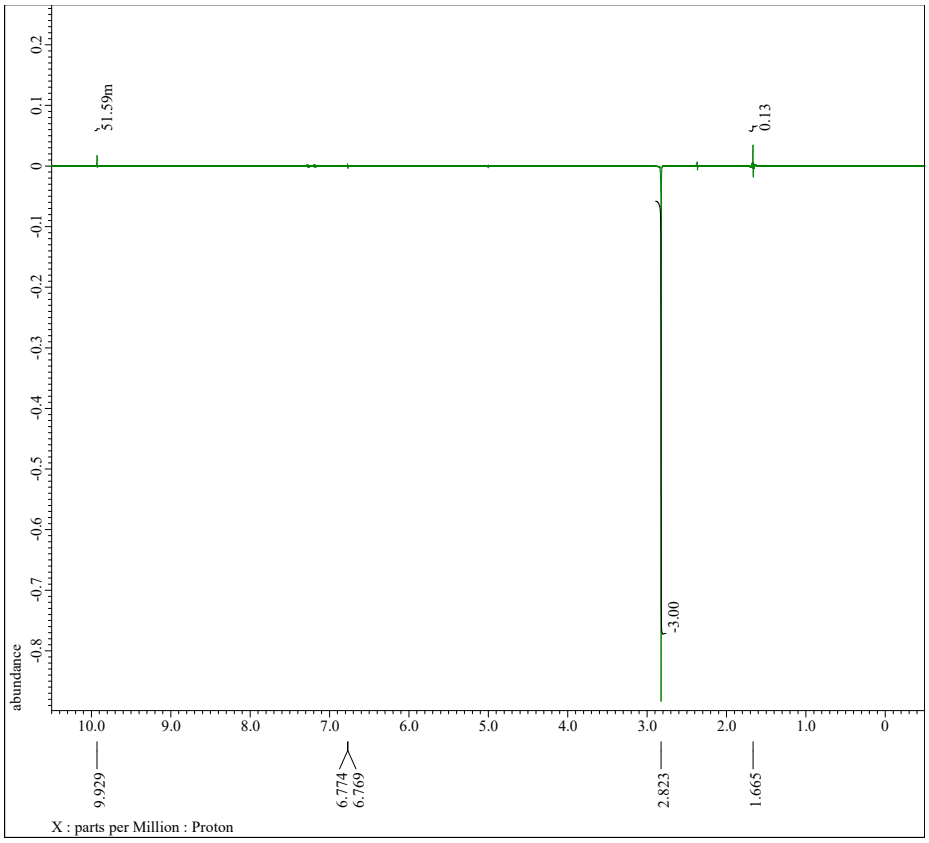
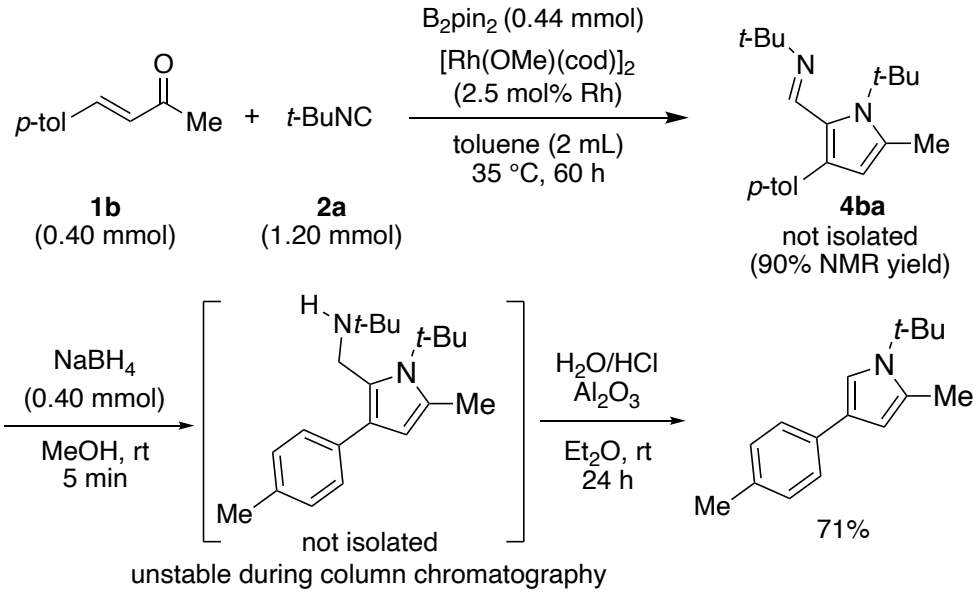


Figure S3. nOe measurement of **9ba** by irradiation at Me group on pyrrole ring (2.82 ppm).

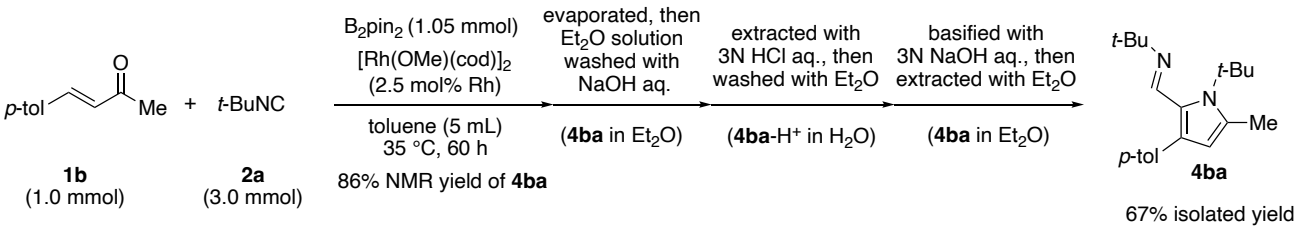
Reduction with $NaBH_4$ followed by acidic hydrolysis



Crude mixture of **4ba** was prepared according to general procedure. The mixture was dissolved in MeOH (2 mL). $NaBH_4$ (15.1 mg, 0.40 mmol) was added to the solution causing immediate generation of gas. After stirred at rt for 5 min, the mixture was concentrated under reduced pressure. Full conversion of **4ba** was confirmed by ^1H NMR ($CDCl_3$). Reduced amine product was not enough stable to isolate by column chromatography. Treatment of the amine product with H_2O (0.5 mL) and two drops of 3N HCl aq. in the presence of neutral alumina (500 mg) in Et_2O (3 mL) solvent at rt for 24 h allowed good conversion to pyrrole **3ba**. The alumina was filtered off with AcOEt eluent. The filtrate was concentrated under reduced pressure. The residue was subjected to silica gel column chromatography (hexane:AcOEt = 30:1) to afford pyrrole **3ba** as a colorless oil (64.4 mg, 0.283 mmol, 71% yield).

8. Interconversion test of pyrroles 3 and 4

Isolation of imine 4ba



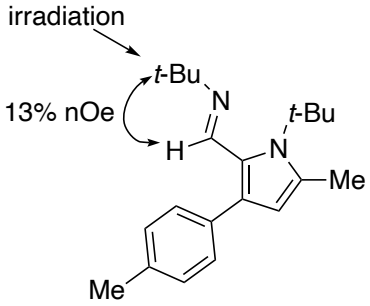
Note: Key for successful isolation of imine 4ba is slow hydrolysis rate at low pH conditions and a relatively stable water-soluble iminium ion formation in the same conditions. Hence, weakly acidic conditions (pH 4-7) shouled be avoided during an extraction process.

To a 15 mL J. Young. Schlenk tube were added $[Rh(OMe)(cod)]_2$ (6.1 mg, 0.0125 mmol, 2.5 mol% Rh) and B_2pin_2 (256.5 mg, 1.05 mmol). The tube was purged with argon, followed by addition of toluene (2.5 mL). The solution was stirred for 1 h resulting in color change from yellow to red-brown. Then, *t*-butylisocyanide (**2a**) (339 μL, 3.0 mmol) was added to the solution to give clear yellow solution. Finally, α,β-unsaturated ketone **1b** (160.2

mg, 1.00 mmol) and toluene (2.5 mL) were added to the mixture. The tube was sealed and stirred at 35 °C for 60 h. After cooled to rt, the reaction mixture was diluted with DCM and then transferred to 50 mL round-bottle flask. The solution was concentrated under reduced pressure to give crude mixture, containing 86% NMR yield of pyrrole **4ba**. The mixture was dissolved in Et_2O (15 mL), followed by washing with 3N NaOH aq. (10 mL x 3). To the ethereal layer was added 3N HCl (15 mL) to extract **4ba** as an iminium ion form. The aqueous layer was washed with Et_2O (10 mL x 2), then rapidly basified with 3N NaOH (20 mL) affording clouded solution. The solution was extracted with Et_2O (15 mL x 2). The ethereal layer was dried over Na_2SO_4, filtered, and concentrated under reduced pressure to afford (*E*)-*N*-*tert*-butyl-1-(1-(*tert*-butyl)-5-methyl-3-(*p*-tolyl)-1*H*-pyrrol-2-yl)methanimine (**4ba**) as a colorless oil (207.9 mg, 0.670 mmol, 67% yield).

^{1}H NMR (500 MHz, rt, $CDCl_3$) δ 8.33 (s, 1H), 7.21 (d, J = 7.5 Hz, 2H), 7.09 (d, J = 8.0 Hz, 2H), 5.96 (s, 1H), 2.47 (s, 3H), 2.33 (s, 3H), 1.74 (s, 9H), 1.17 (s, 9H). ^{13}C NMR (125.8 MHz, rt, $CDCl_3$) δ 151.0, 135.2, 133.9, 133.1, 129.6, 129.1, 128.6, 128.4, 112.4, 59.6, 57.5, 32.6, 29.4, 21.2, 18.8. HRMS (ESI) calcd for $C_{21}H_{31}N_2$ $[M+H]^+$ 311.2482; found: 311.2489.

Geometry of imine moiety was determined by nOe measurement as follows.



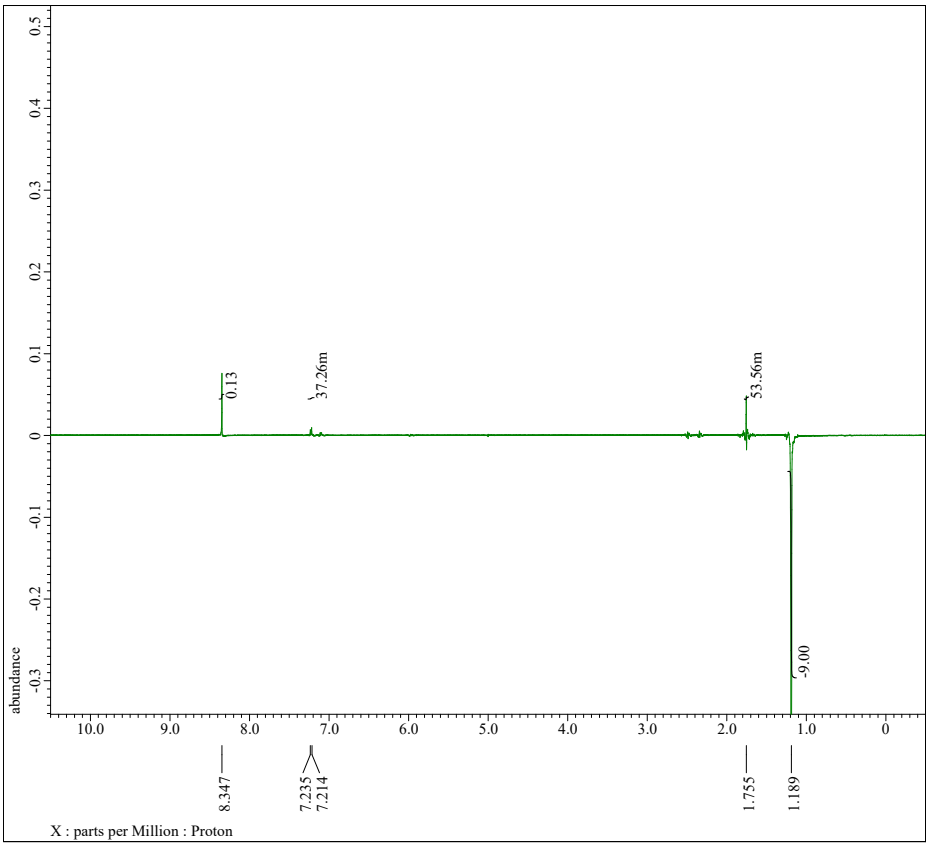
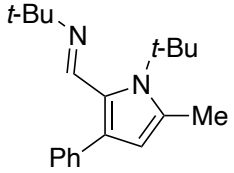


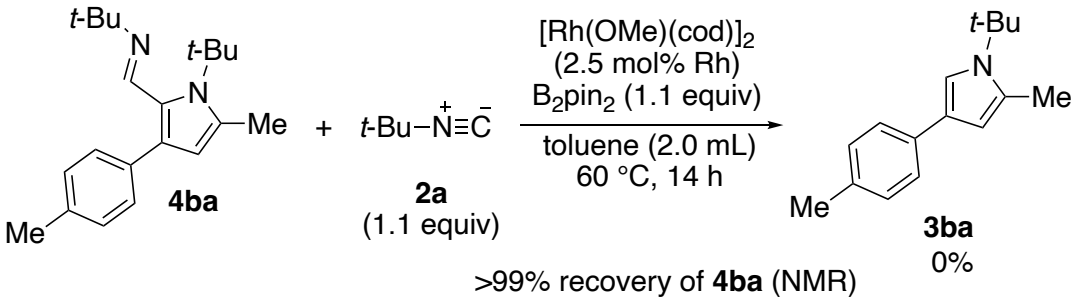
Figure S4. nOe measurement of **4ba** by irradiation at *t*-Bu proton on imine nitrogen (1.189 ppm).

(*E*)-*N*-*tert*-butyl-1-(1-(*tert*-butyl)-5-methyl-3-phenyl-1*H*-pyrrol-2-yl)methanimine (**4aa**)



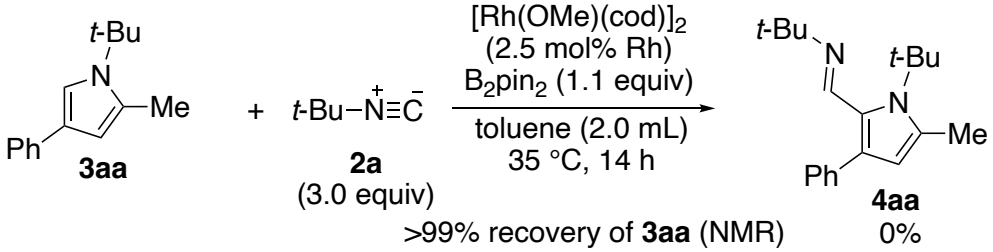
Imine **4aa** was isolated as a yellow oil (121.2 mg, 0.409 mmol, 41% yield) according to the similar procedure for the isolation of imine **4ba** with deviation of the reaction time as 14 h. ^{1}H NMR (500 MHz, rt, $CDCl_3$) δ 8.35 (s, 1H), 7.31 (d, J = 8.0 Hz, 2H), 7.26 (t, J = 8.0 Hz, 2H), 7.17 (t, J = 7.0 Hz, 1H), 5.98 (s, 1H), 2.48 (s, 3H), 1.73 (s, 9H), 1.16 (s, 9H). ^{13}C NMR (125.8 MHz, rt, $CDCl_3$) δ 151.0, 136.9, 132.9, 129.8, 128.8, 128.7, 127.7, 125.7, 112.5, 59.6, 57.5, 32.6, 29.3, 18.7. HRMS (ESI) calcd for $C_{20}H_{29}N_2$ $[M+H]^+$ 297.2331; found: 297.2327.

Subjection of pyrrole 3 to the catalytic conditions for synthesis of pyrrole 4



Imine **4ba** (124.2 mg, 0.40 mmol) was subjected to pyrrole **3ba** forming conditions similar to general procedure A using 2.0 mL of toluene. No **3ba** formation was observed, whereas >99% recovery of **4ba** was confirmed.

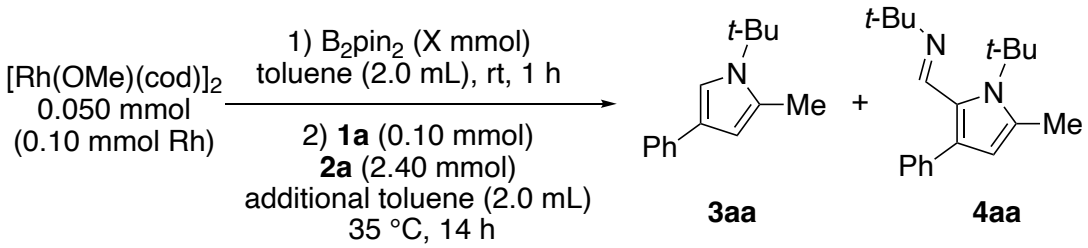
Subjcetion of pyrrole 4 to the catalytic conditions for synthesis of pyrrole 3



Imine **3aa** (124.2 mg, 0.40 mmol) was subjected to pyrrole **4aa** forming conditions similar to general procedure B using 2.0 mL of toluene. No **4aa** formation was observed, whereas >99% recovery of **3aa** was confirmed.

From these results, it is concluded that pyrrole **3** and **4** are not intermediate for the counterparts.

9. Stoichiometric experiments

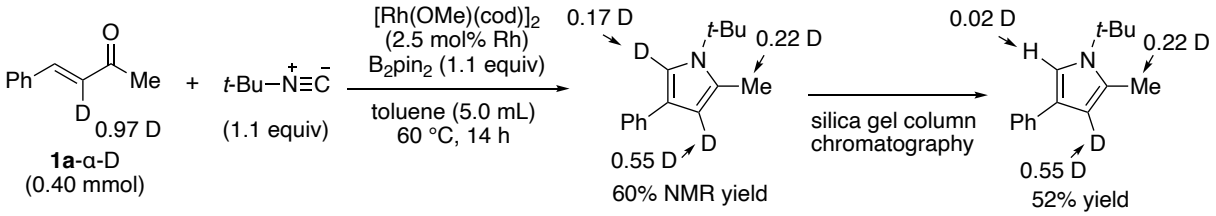


X = 0.10	21% conversion	0% (NMR)	<1% (NMR)
X = 0.20	100% conversion	20% (NMR)	51% (NMR)

To a 15 mL J. Young. Schlenk tube were added $[Rh(OMe)(cod)]_2$ (24.2 mg, 0.050 mmol, 0.10 mmol Rh) and B_2pin_2 (25.4 mg, 0.10 mmol or 50.8 mg, 0.20 mmol). The tube was purged with argon, followed by addition of toluene (2.0 mL). The solution was stirred for 1 h resulting in color change from yellow to red-brown. Then, *t*-butylisocyanide (**2a**) (271 μL, 2.40 mmol) was added to the solution to give yellow-orange solution. Finally, α,β-unsaturated ketone **1a** (14.6 mg, 0.10 mmol) and toluene (2.0 mL) were added to the mixture. The tube was sealed and stirred at 35 °C for 14 h. After cooled to rt, the reaction mixture was diluted with DCM and then transferred to 50 mL round-bottle flask. The solution was concentrated under reduced pressure to give crude mixture. NMR yields of **3aa** and **4aa** were determined by using $MeNO_2$ as an internal standard.

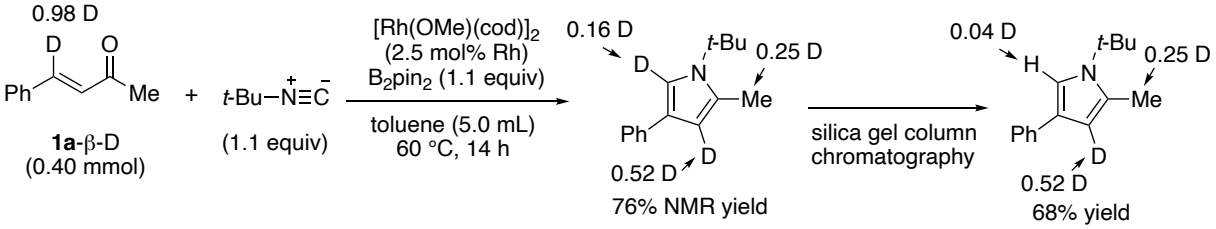
10. Deuterium labeling experiments

Reaction of 1a-α-D with 1.1 equiv of *t*-BuNC at 60 °C



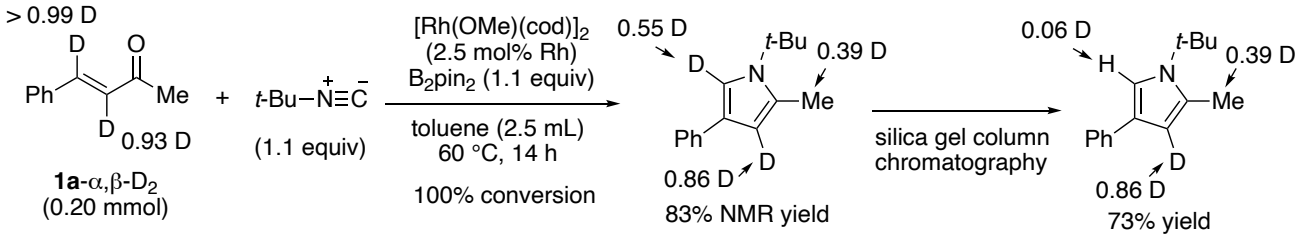
Reaction of **1a**-α-D with *t*-BuNC (**2a**) (1.1 equiv) was performed according to the general procedure A. Deuterium incorporation ratio was determined from the crude mixture and isolated **3aa** after silica gel column chromatography.

Reaction of 1a-β-D with 1.1 equiv of *t*-BuNC at 60 °C



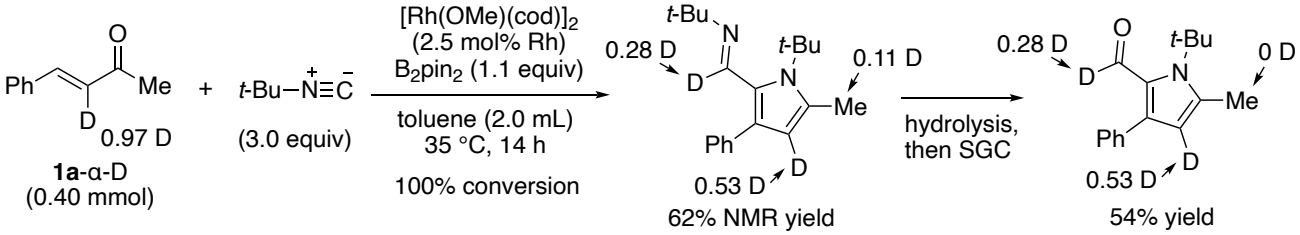
Reaction of **1a**-β-D with *t*-BuNC (**2a**) (1.1 equiv) was performed according to the general procedure A. Deuterium incorporation ratio was determined from the crude mixture and isolated **3aa** after silica gel column chromatography.

Reaction of 1a-α,β-D_2 with 1.1 equiv of *t*-BuNC at 60 °C



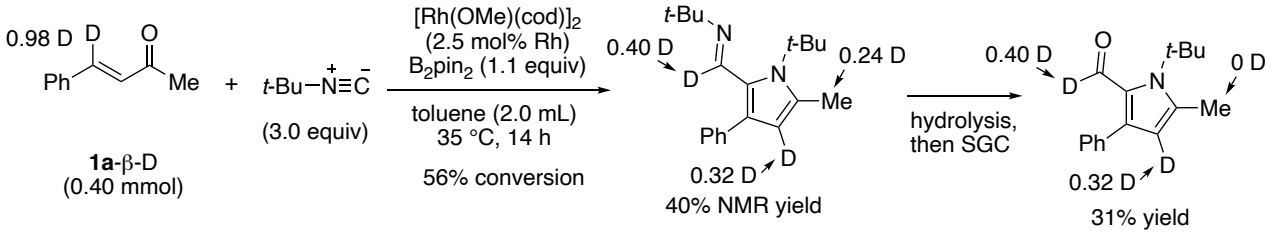
Reaction of **1a**-α,β-D_2 with *t*-BuNC (**2a**) (1.1 equiv) was performed according to the general procedure A at 0.20 mmol scale. Deuterium incorporation ratio was determined from the crude mixture and isolated **3aa** after silica gel column chromatography.

Reaction of 1a-α-D with 3.0 equiv of *t*-BuNC at 35 °C



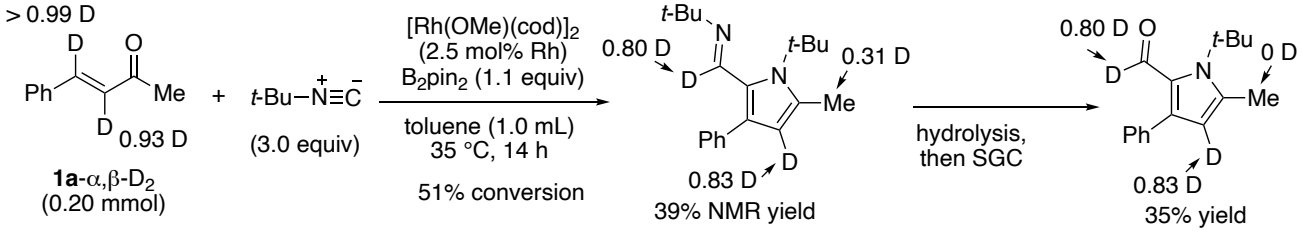
Reaction of **1a**-α-D with *t*-BuNC (**2a**) (3.0 equiv) was performed according to the general procedure B. Deuterium incorporation ratio was determined from the crude mixture including **4aa** and isolated **5aa** after hydrolysis followed by silica gel column chromatography.

Reaction of 1a-β-D with 3.0 equiv of *t*-BuNC at 35 °C



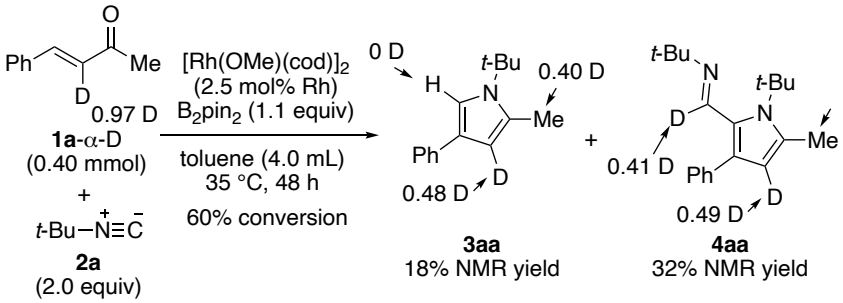
Reaction of **1a**-β-D with *t*-BuNC (**2a**) (3.0 equiv) was performed according to the general procedure B. Deuterium incorporation ratio was determined from the crude mixture including **4aa** and isolated **5aa** after hydrolysis followed by silica gel column chromatography.

Reaction of 1a-α,β-D_2 with 3.0 equiv of *t*-BuNC at 35 °C



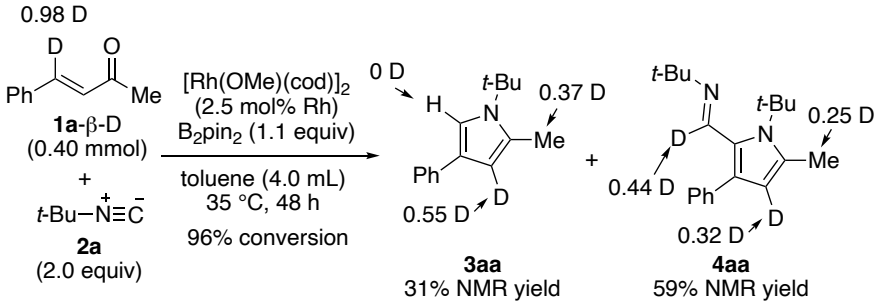
Reaction of **1a**-α,β-D_2 with *t*-BuNC (**2a**) (3.0 equiv) was performed according to the general procedure B at 0.20 mmol scale. Deuterium incorporation ratio was determined from the crude mixture including **4aa** and isolated **5aa** after hydrolysis followed by silica gel column chromatography.

Reaction of 1a-α-D with 2.0 equiv of *t*-BuNC at 35 °C



Reaction of **1a**-α-D with *t*-BuNC (**2a**) (2.0 equiv) was performed according to the general procedure B. Deuterium incorporation ratio was determined from the crude mixture including **3aa** and **4aa**.

Reaction of 1a-β-D with 2.0 equiv of *t*-BuNC at 35 °C



Reaction of **1a**-β-D with *t*-BuNC (**2a**) (2.0 equiv) was performed according to the general procedure B. Deuterium incorporation ratio was determined from the crude mixture including **3aa** and **4aa**.

Possible mechanism for deuterium exchange in pyrrole 4 synthesis

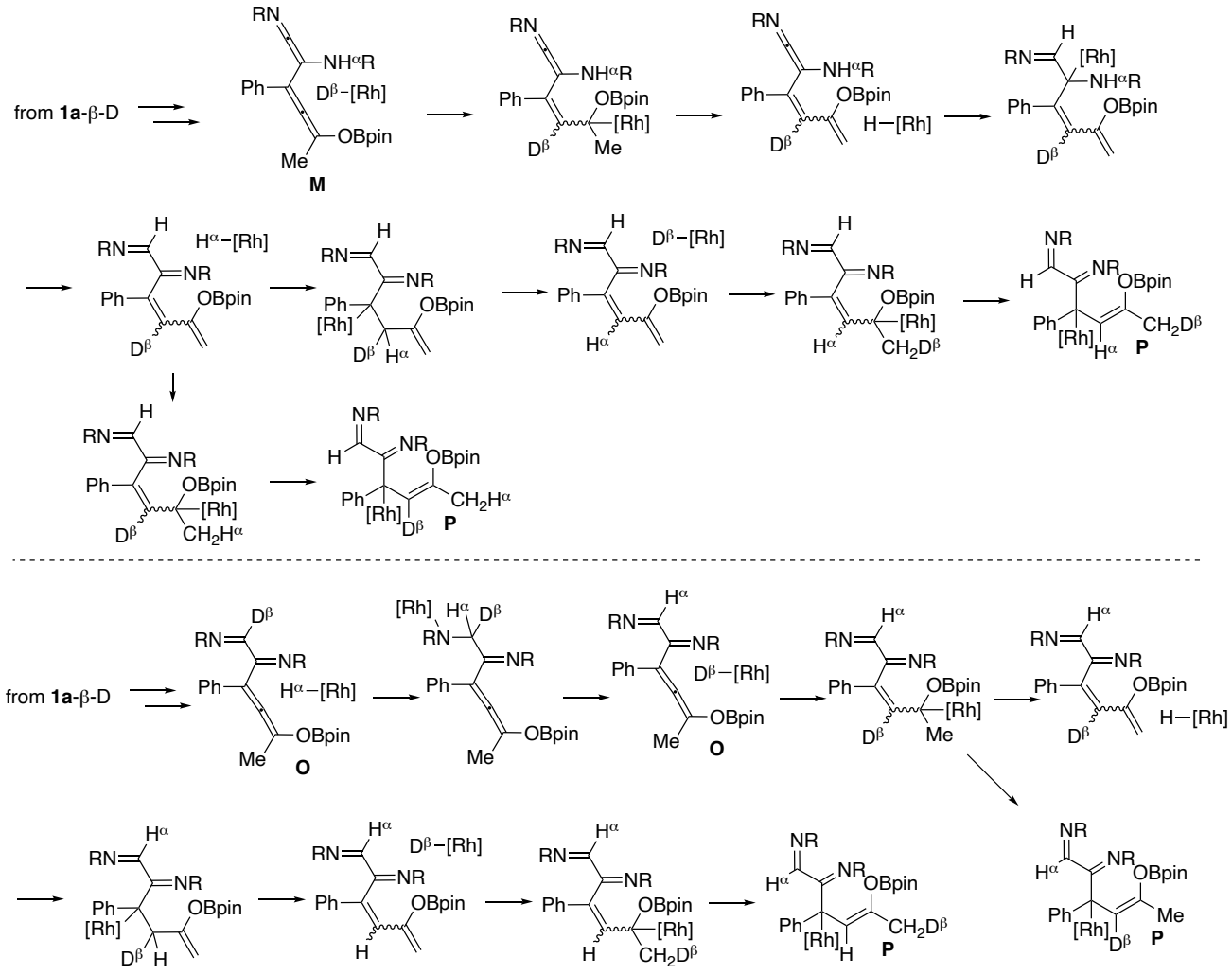


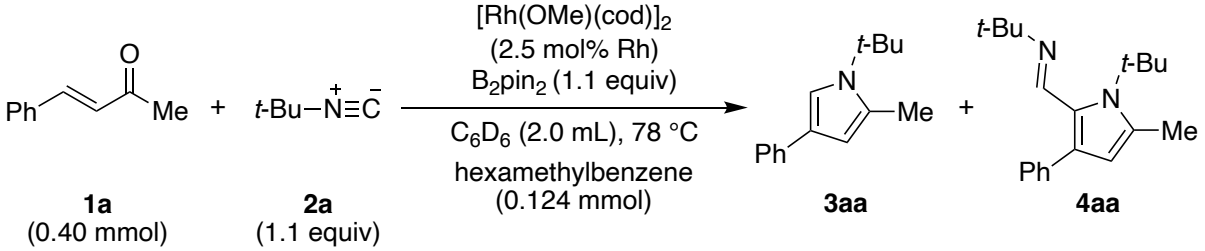
Figure S5. Deuterium scrambling in pyrrole **4** synthesis.

11. Tracing reaction time course in NMR equipment

To a 15 mL J. Young Schlenk tube were added $[Rh(OMe)(cod)]_2$ (2.4 mg, 0.0050 mmol) and B_2pin_2 (111.7 mg, 0.44 mmol). The tube was purged with argon for three times. C_6D_6 (1.0 mL, degassed with freeze-pump-thaw method) was added to the tube. The solution was stirred at rt for 1 h. *t*-BuNC (**2a**) (49.8 μL, 0.44 mmol), benzalacetone (**1a**) (58.5 mg, 0.40 mmol), and hexamethylbenzene (20.2 mg, 0.124 mmol, internal standard, δ 2.131 ppm) was successively added to the solution in this order. Finally, degassed C_6D_6 (1.0 mL) was added. The solution (0.8 mL) was transferred to NMR tube equipped with J. Young cock in glove box under argon atmosphere. The NMR tube was surely closed and heated to 78 °C in NMR equipment. The reaction was traced with ^{1}H NMR.

1 h of an induction period was observed for the reaction of **1a** with **2a** (1.1 equiv) at 78 °C in C_6D_6. A peak assigned to methyl group of MeOBpin was observed at 3.51 ppm after 10 min. Literature data for ^{1}H NMR of MeOBpin: (400 MHz, C_6D_6, 293 K): δ 1.04 (s, 12H, CH_3-Bpin), 3.50 (s, 3 H, $-OCH_3$). [13]

Table S3. Time profile of the reaction of **1a** with **2a** (1.1 equiv) at 78 °C in C_6D_6 traced with ^{1}H NMR



1a (0.40 mmol) + **2a** (1.1 equiv) → **3aa** + **4aa**

		NMR yields (%)[a]	
time (h)	Conversion (%)[a]	**3aa**	**4aa**
0	0	0	0
0.5	4	0	0
1	7	0	0
1.25	37	21	2
2	69	51	5
2.5	76	56	8
3	82	59	11
6	95	59	14
7	96	60	14
8	100	60	15

[a] Determined by ^{1}H NMR using hexamethylbenzene as an internal standard.

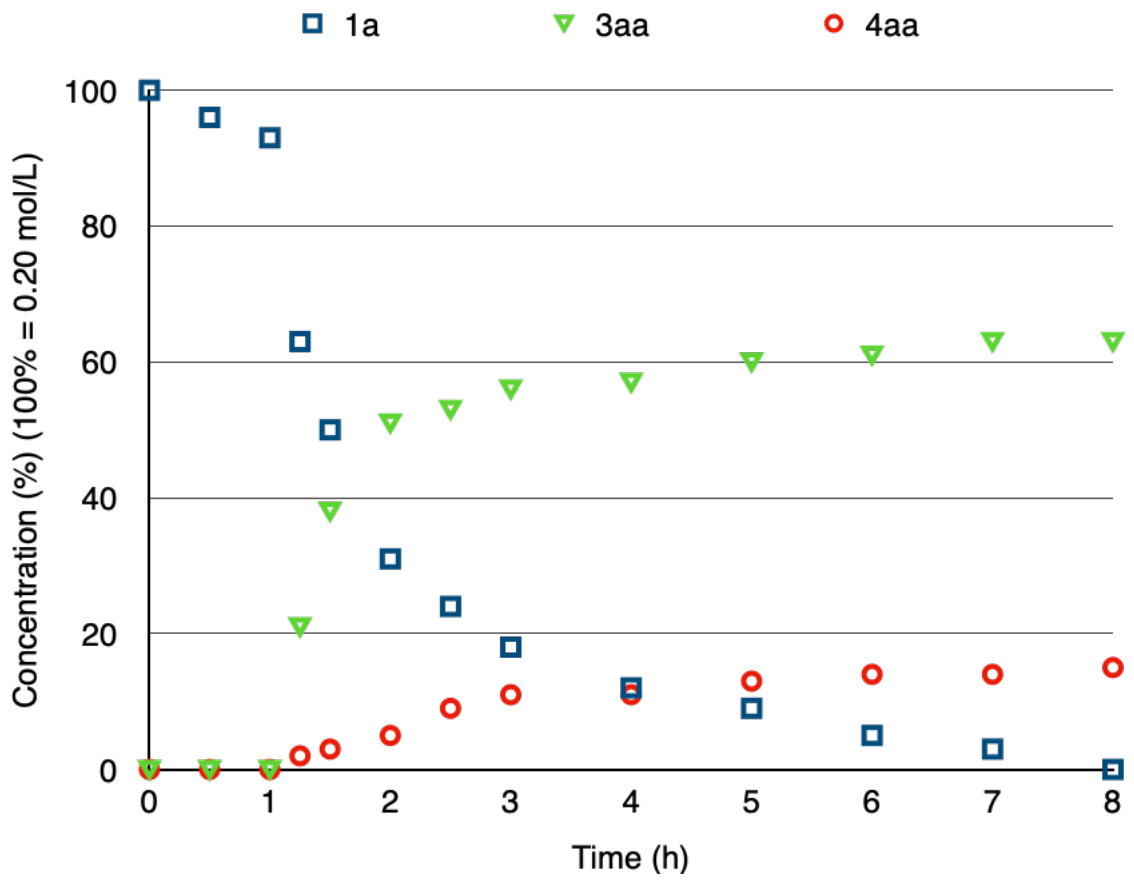
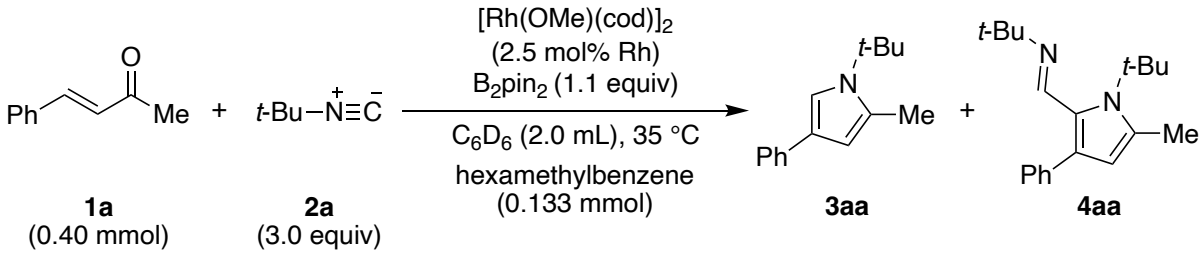


Figure S6. Time course of reaction at 35 °C in C_6D_6

To a 15 mL J. Young Schlenk tube were added $[Rh(OMe)(cod)]_2$ (2.4 mg, 0.0050 mmol) and B_2pin_2 (111.7 mg, 0.44 mmol). The tube was purged with argon for three times. C_6D_6 (1.0 mL, degassed with freeze-pump-thaw method) was added to the tube. The solution was stirred at rt for 1 h. *t*-BuNC (**2a**) (136 μL, 1.20 mmol), benzalacetone (**1a**) (58.5 mg, 0.40 mmol), and hexamethylbenzene (21.6 mg, 0.133 mmol, internal standard, δ 2.131 ppm) was successively added to the solution in this order. Finally, degassed C_6D_6 (1.0 mL) was added. The solution (0.8 mL) was transferred to NMR tube equipped with J. Young cock in glove box under argon atmosphere. The NMR tube was surely closed and heated to 35 °C in NMR equipment. The reaction was traced with ^{1}H NMR. 4 h of an induction period was observed. A peak assigned to methyl group of MeOBpin was observed at 3.51 ppm after 10 min. Literature data for ^{1}H NMR of MeOBpin: (400 MHz, C_6D_6, 293 K): δ 1.04 (s, 12H, CH_3-Bpin), 3.50 (s, 3 H, $-OCH_3$).[13]

Table S4. Time course of the reaction of **1a** with **2a** (3.0 equiv) at 35 °C in C_6D_6



1a (0.40 mmol) + **2a** (3.0 equiv) → **3aa** + **4aa**

time (h)	Conversion (%)[a]	NMR yields (%)[a]	
		3aa	**4aa**
0	0	0	0
1	2	0	0
2	7	0	0
3	12	0	0
4	23	2	6
5	49	3	24
6	71	3	39
7	84	4	50
8	93	4	57
9	99	4	65
10	100	4	65

[a] Determined by ^{1}H NMR using hexamethylbenzene as an internal standard.

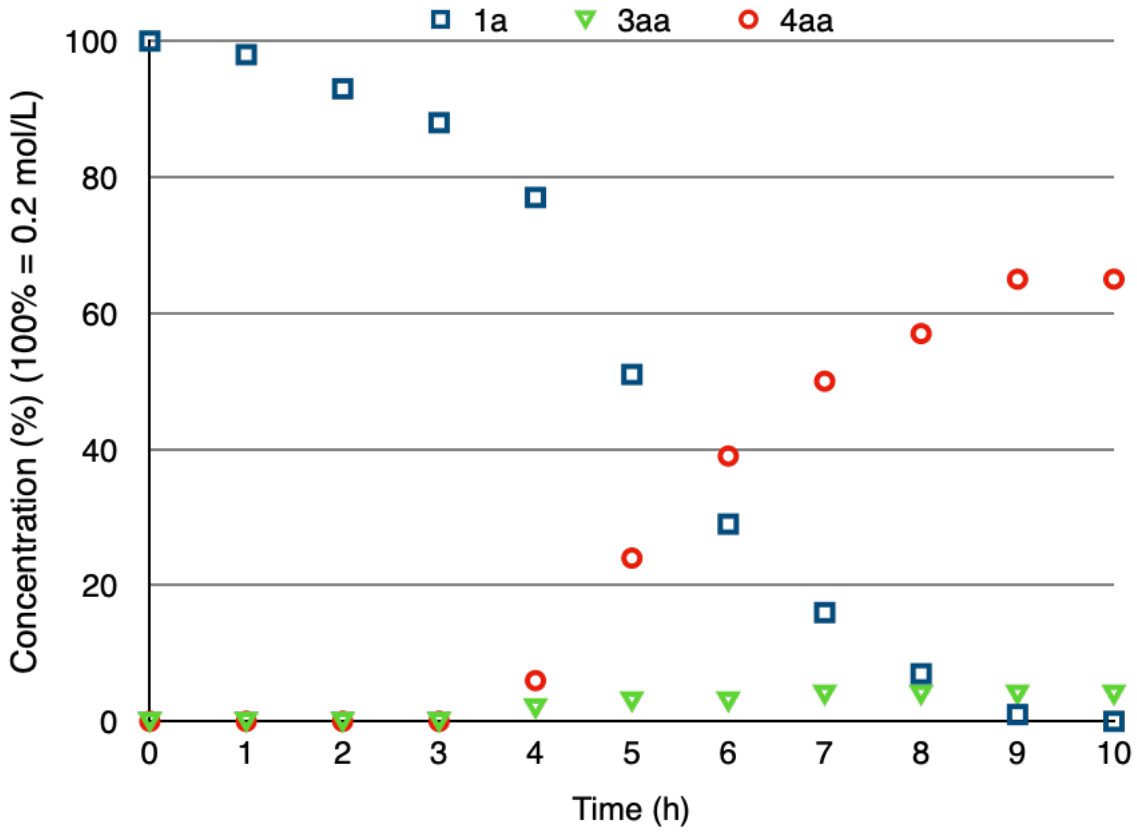
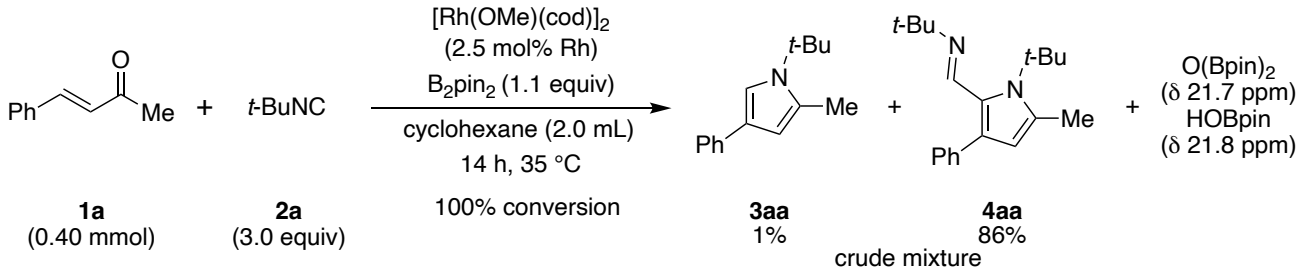


Figure S7. Time course of reaction at 35 °C in C_6D_6

12. ^{11}B NMR of the crude mixture

Broad peak around 21.5-21.7 ppm was observed in ^{11}B NMR (C_6D_6, rt, 128.3 MHz) spectrum of the crude mixture of the catalytic reaction (Figure S8). The peak should be assigned to $O(Bpin)_2$ (δ 21.7 ppm) and/or HOBpin (δ 21.8 ppm).[13] $BF_3{\cdot}OEt_2$ was used as external reference for chemical shift (δ 0.0 ppm).



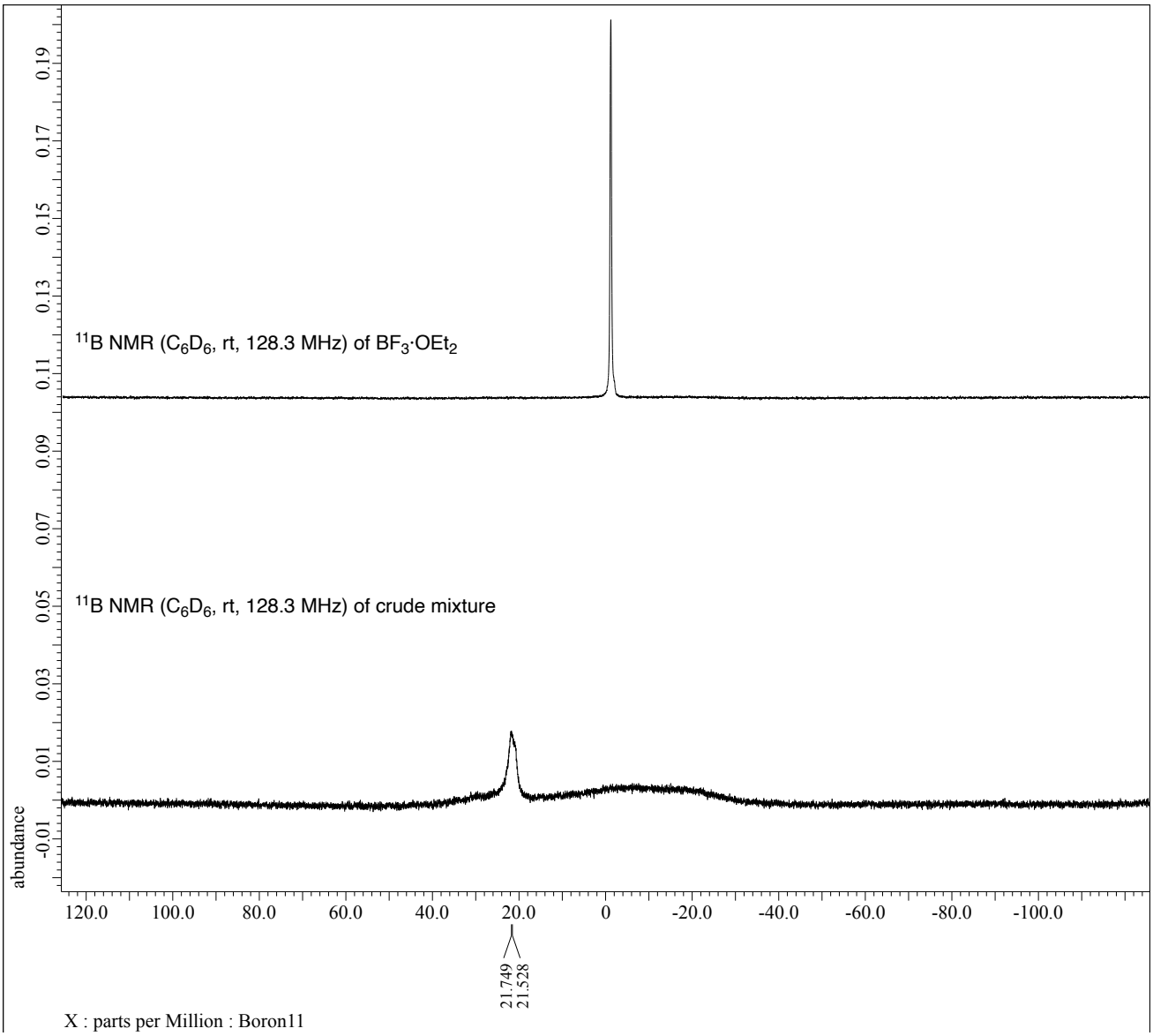


Figure S8. ^{11}B NMR spectra of crude mixture compared to $BF_3{\cdot}OEt_2$ as an external reference.

13. X-ray crystallographic data

Crystallographic data of **2ab**, **5da**, and **8ba** were collected on a Rigaku/Saturn 70 CCD diffractometer and processed with CrystalClear (Rigaku, Tokyo, Japan). Calculations were performed with the Olex2 software package (Ver. 1.2.10, OlexSys Ltd., Durham, UK).[14] The structures were solved by *SHELXT*[15] and refined by full-matrix least-squares (*SHELXL*) against F^2.[16]

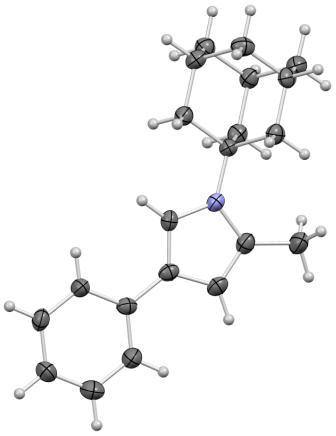


Figure S9. ORTEP illustration with 50% probability level and structure of **2ab**.

Table S5. Crystal data of **2ab**.

CCDC number	2269832
Empirical Formula	$C_{21}H_{25}N$
Formula Weight	291.42
Crystal Color, Habit	colourless, block
Crystal System	monoclinic
Crystal Size (mm^3)	0.1 × 0.1 × 0.1
Lattice Parameters	
a (Å)	9.960(10)
b (Å)	14.289(14)
c (Å)	12.521(13)
α (°)	90
β (°)	113.237(12)
γ (°)	90
V ($Å^3$)	1637(3)
Space Group	$P2_1/n$ (#14)
Z value	4
D_{calc} (g cm^{-3})	1.182
F_{000}	632
Radiation	MoKα (λ = 0.71075 Å) graphite monochromated
Temperature (°C)	–105.0
θ range for data collection	$3.3° < \theta < 27.5°$
No. of Reflections Measured	Total: 13109
Structure Solution	Direct Methods (SHELXT ver. 2015)
Refinement	Full-matrix least-squares on F^2 (SHELXL ver. 2015)
No. Observations (All reflections)	3613
No. Variables	200
No. Restraints	0
Reflection/Parameter Ratio	18.07
Residuals: R_1; wR_2 (I > 2.00σ(I))	0.0907; 0.1505

Residuals: *R; wR*$_2$ (All reflections)	0.1983; 0.1979
Goodness of Fit Indicator	1.030
Max Shift/Error in Final Cycle	0.000
Maximum peak in Final Diff. Map (e^- Å^{-3})	0.23
Minimum peak in Final Diff. Map (e^- Å^{-3})	–0.26

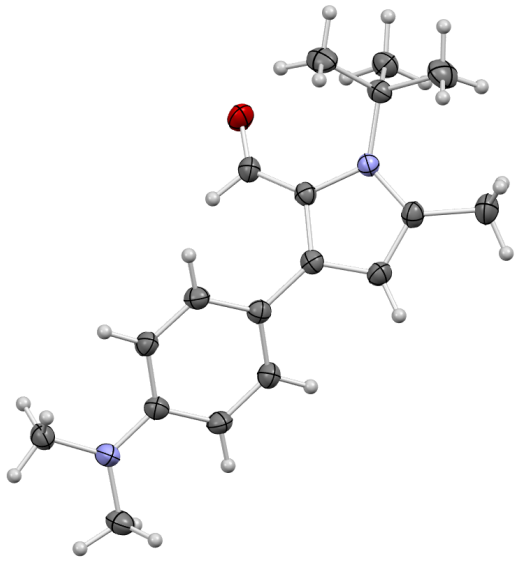


Figure S10. ORTEP illustration with 50% probability level and structure of **5da**.

Table S6. Crystal data of **5da**

CCDC number	2269833
Empirical Formula	$C_{18}H_{24}N_2O$
Formula Weight	284.39
Crystal Color, Habit	colourless, block
Crystal System	monoclinic
Crystal Size (mm^3)	0.2 × 0.2 × 0.2
Lattice Parameters	
a (Å)	5.6949(16)
b (Å)	23.640(7)
c (Å)	11.681(3)
α (°)	90
β (°)	96.821(4)
γ (°)	90
V (Å^3)	1561.5(8)
Space Group	$C2_1/c$ (#14)
Z value	4
D_{calc} (g cm^{-3})	1.210
F_{000}	616
Radiation	MoKα (λ = 0.71075 Å) graphite monochromated
Temperature (°C)	–100.0
θ range for data collection	3.4° < *θ* < 27.5°
No. of Reflections Measured	Total: 12352
Structure Solution	Direct Methods (SHELXT ver. 2015)
Refinement	Full-matrix least-squares on F^2 (SHELXL ver. 2015)
No. Observations (All reflections)	3507
No. Variables	196
No. Restraints	0

Reflection/Parameter Ratio	17.89
Residuals: R_1; wR_2 (I > 2.00σ(I))	0.0471; 0.1065
Residuals: R; wR_2 (All reflections)	0.0627; 0.1147
Goodness of Fit Indicator	1.026
Max Shift/Error in Final Cycle	0.001
Maximum peak in Final Diff. Map (e^- Å^{-3})	0.223
Minimum peak in Final Diff. Map (e^- Å^{-3})	–0.167

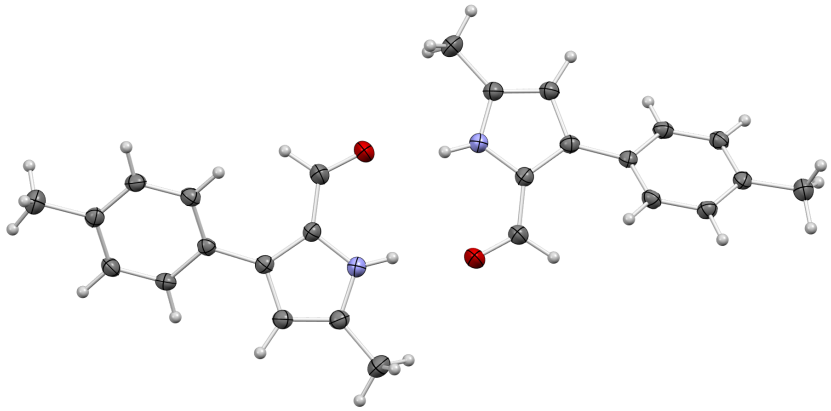


Figure S11. ORTEP illustration with 50% probability level and structure of **8ba**.

Table S7. Crystal data of **8ba**

CCDC number	2269834
Empirical Formula	C_{13}H13NO
Formula Weight	199.24
Crystal Color, Habit	colourless, block
Crystal System	triclinic
Crystal Size (mm^3)	0.2 × 0.2 × 0.3
Lattice Parameters	
a (Å)	9.347(5)
b (Å)	9.721(6)
c (Å)	12.090(7)
α (°)	87.159(17)
β (°)	78.143(15)
γ (°)	81.332(16)
V (Å^3)	1062.6(11)
Space Group	P-1 (#2)
Z value	4
D_{calc} (g cm^{-3})	1.245
F_{000}	424
Radiation	MoKα (λ = 0.71075 Å) graphite monochromated
Temperature (°C)	–100.0
θ range for data collection	3.1° < θ < 27.5°
No. of Reflections Measured	Total: 8691
Structure Solution	Direct Methods (SHELXT ver. 2015)
Refinement	Full-matrix least-squares on F^2 (SHELXL ver. 2015)
No. Observations (All reflections)	4677
No. Variables	331
No. Restraints	0
Reflection/Parameter Ratio	14.13
Residuals: R_1; wR_2 (I > 2.00σ(I))	0.0450; 0.1119

Residuals: *R; wR2* (All reflections)	0.0659; 0.1189
Goodness of Fit Indicator	0.948
Max Shift/Error in Final Cycle	0.001
Maximum peak in Final Diff. Map (e^- Å^{-3})	0.278
Minimum peak in Final Diff. Map (e^- Å^{-3})	–0.225

14. References

1. K. A. Waibel, R. Nickisch, N. Möhl, R. Seim and M. A. R. Meier, *Green Chem.*, 2020, **22**, 933-941.
2. K. Zumbansen, A. Döhring and B. List, *Adv. Synth. Cata.*, 2010, **352**, 1135-1138.
3. V. Dhayalan, C. Samann and P. Knochel, *Chem. Commun.*, 2015, **51**, 3239-3242.
4. L. Zhang, R. J. Clark and L. Zhu, *Chem. Eur. J.*, 2008, **14**, 2894-2903.
5. T. Ramar, M. A. M. Subbaiah and A. Ilangovan, *J. Org. Chem.*, 2022, **87**, 4508-4523.
6. J. M. Dickinson, J. A. Murphy, C. W. Patterson and N. F. Wooster, *J. Chem. Soc., Perkin Trans.*, 1990, 1179-1184.
7. A. R. Pinhas, A. G. Samuelson, R. Risemberg, E. V. Arnold, J. Clardy and B. K. Carpenter, *J. Am. Chem. Soc.*, 1981, **103**, 1668-1675.
8. V. G. Landge, K. K. Shrestha, A. J. Grant and M. C. Young, *Org. Lett.*, 2020, **22**, 9745-9750.
9. P. Seguineau and J. Villieras, *Tetrahedron Letters*, 1988, **29**, 477-480.
10. T. C. Malig, D. Yu and J. E. Hein, *J. Am. Chem. Soc.*, 2018, **140**, 9167-9173.
11. K. Tanaka and T. Shoji, *Org. Lett.*, 2005, **7**, 3561-3563.
12. T. N. Poudel and Y. R. Lee, *Org. Lett.*, 2015, **17**, 2050-2053.
13. T. Bolaño, M. A. Esteruelas, M. P. Gay, E. Oñate, I. M. Pastor and M. Yus, *Organometallics*, 2015, **34**, 3902-3908.
14. O. V. Dolomanov, L. J. Bourhis, R. J. Gildea, J. A. K. Howard and H. Puschmann, *J. Appl. Crystallogr.*, 2009, **42**, 339-341.
15. G. Sheldrick, *Acta Crystallogr. A*, 2015, **71**, 3-8.
16. G. Sheldrick, *Acta Crystallogr. C*, 2015, **71**, 3-8.

15. NMR spectra

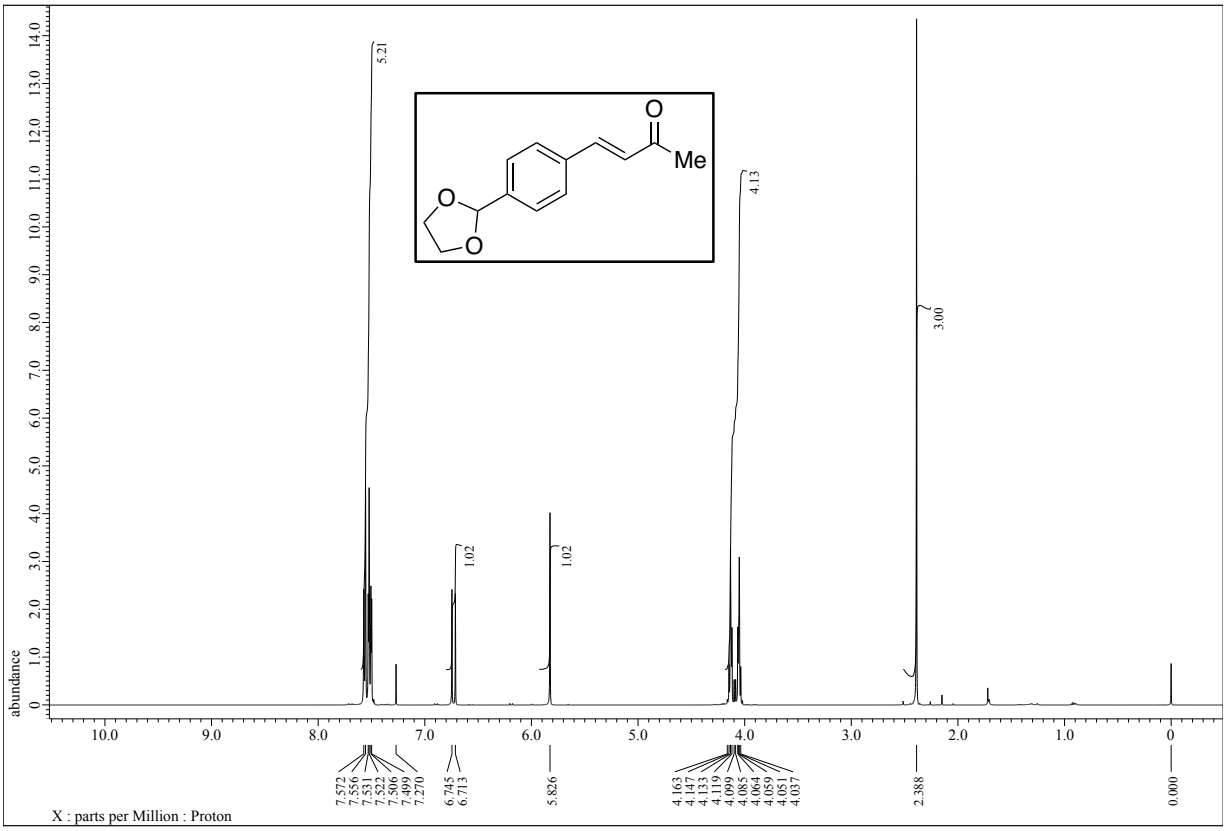


Figure S12. ^{1}H NMR (500 MHz, $CDCl_3$) spectrum of **1j**.

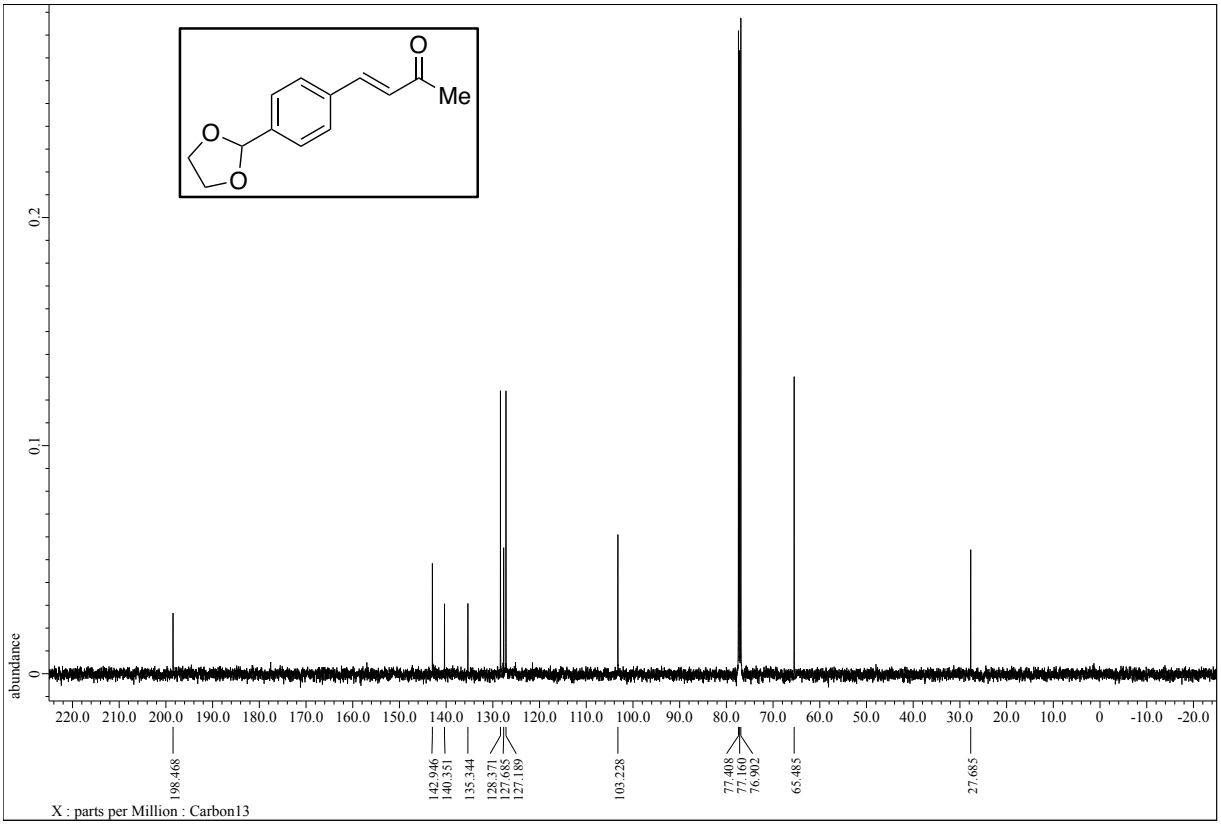


Figure S13. ^{13}C NMR (125.8 MHz, $CDCl_3$) spectrum of **1j**.

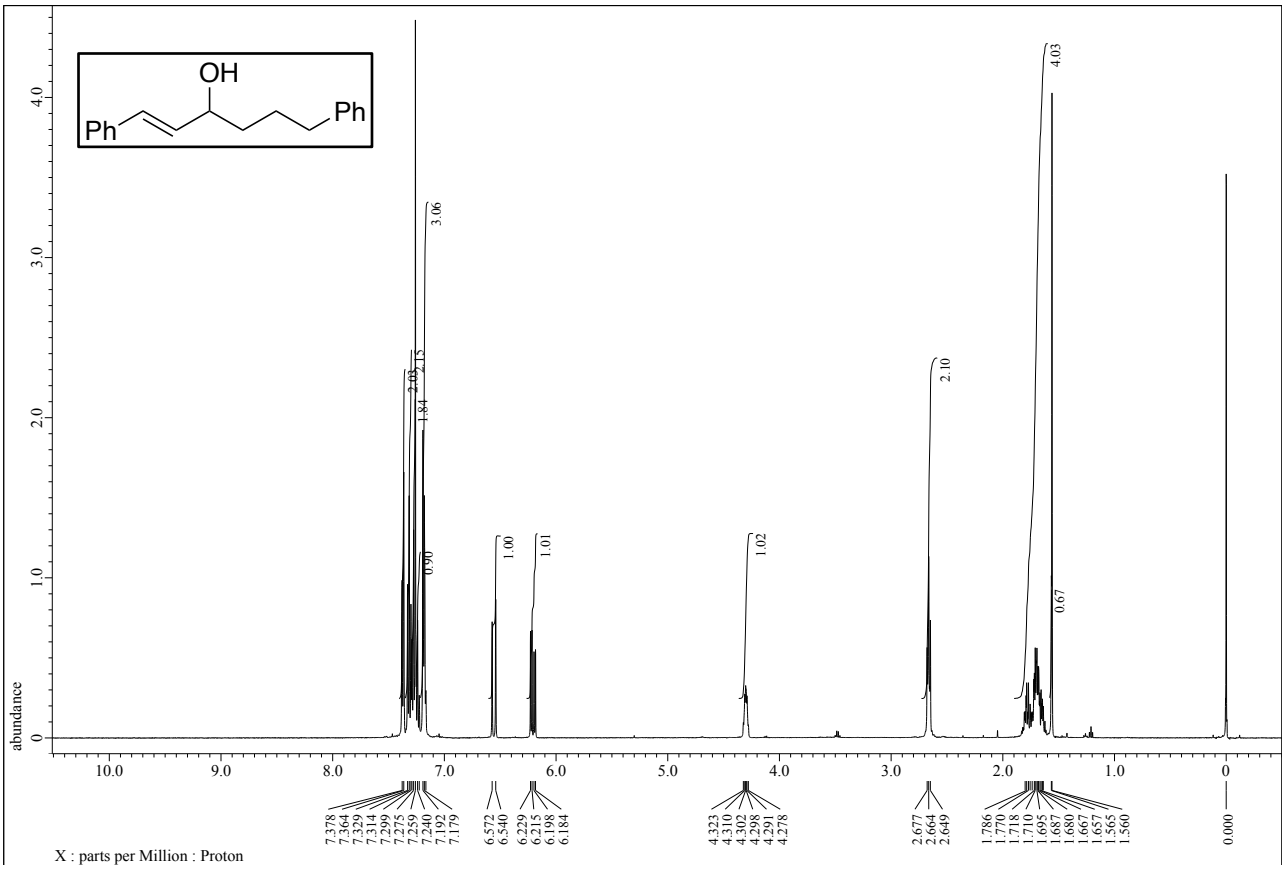


Figure S14. ^{1}H NMR (500 MHz, $CDCl_3$) spectrum of (*E*)-1,6-diphenylhex-1-en-3-ol.

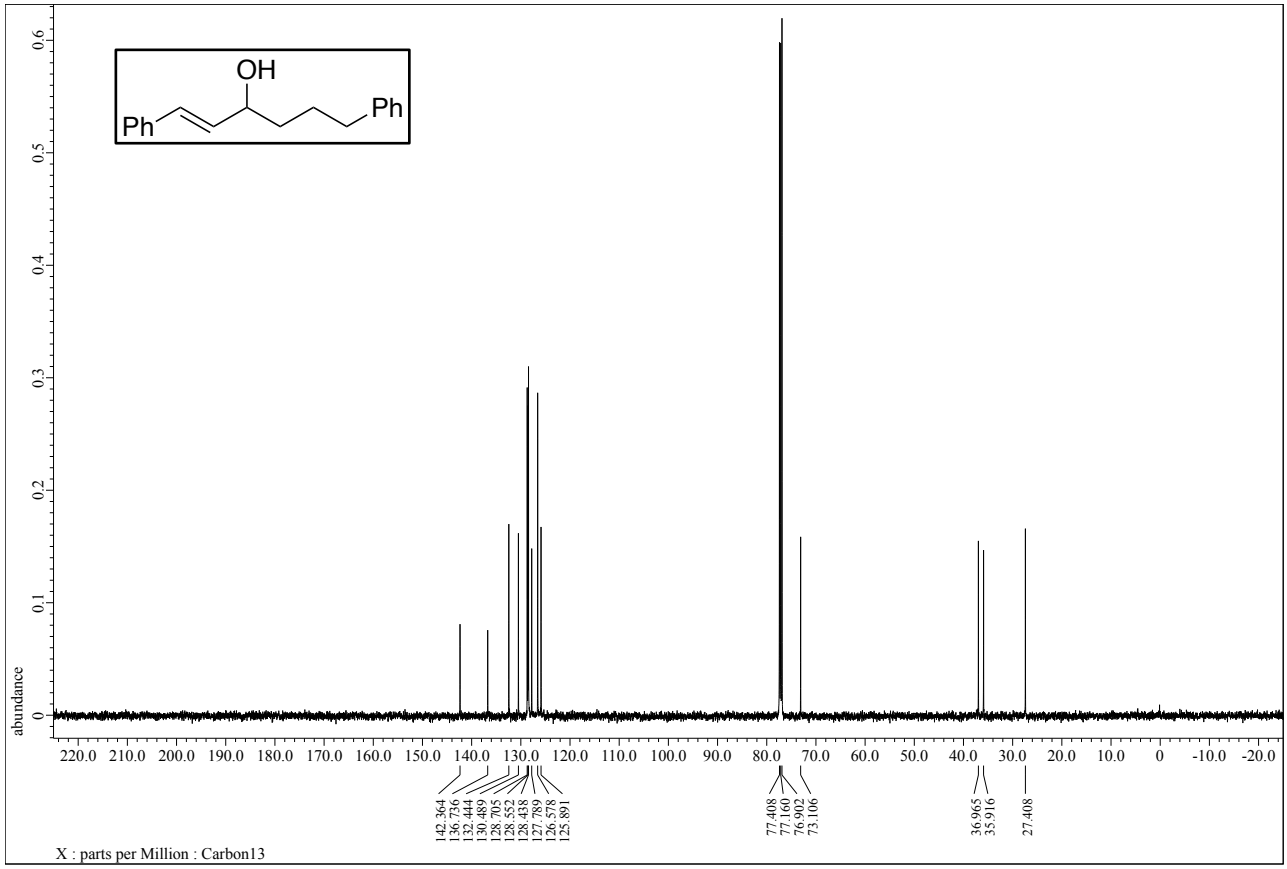


Figure S15. ^{13}C NMR (125.8 MHz, $CDCl_3$) spectrum of (*E*)-1,6-diphenylhex-1-en-3-ol.

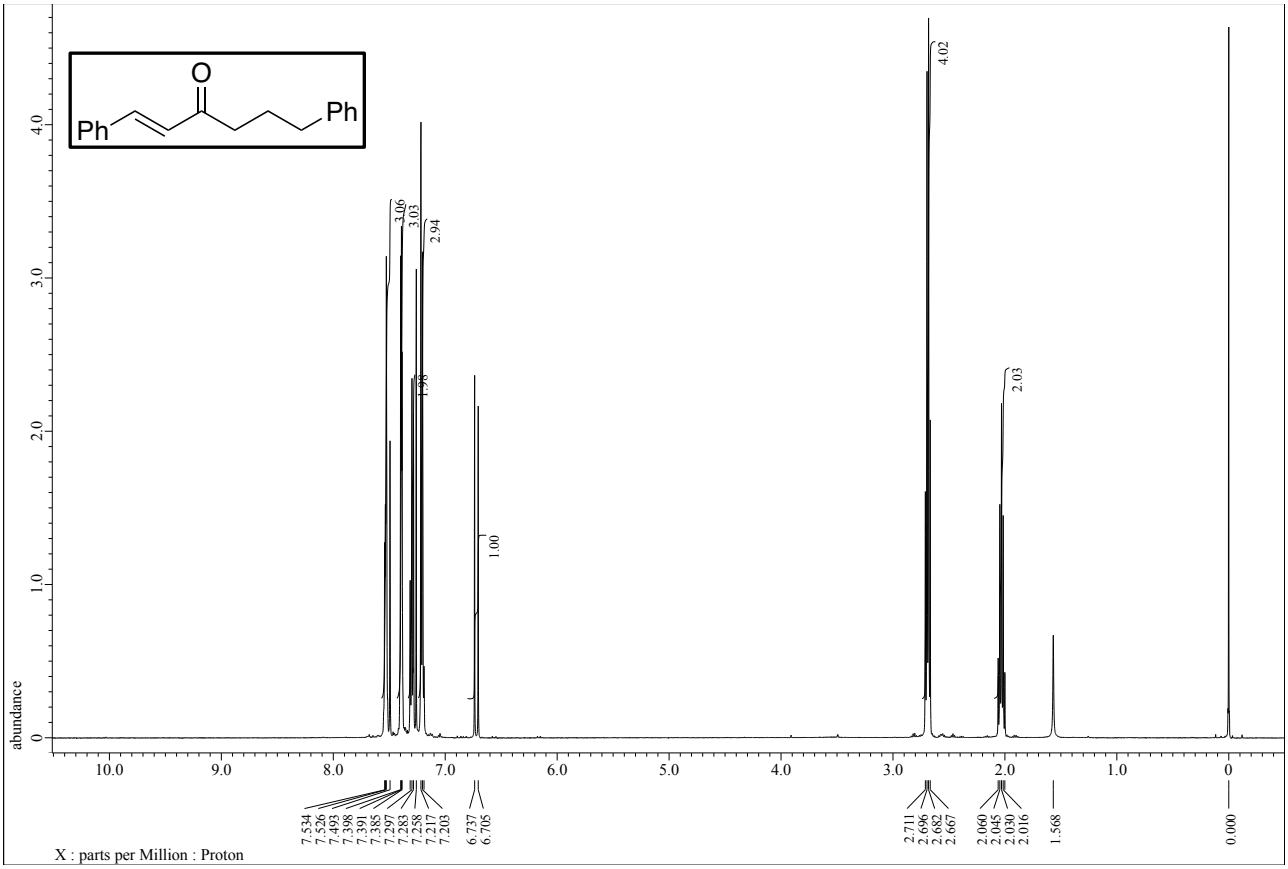


Figure S16. ^{1}H NMR (500 MHz, $CDCl_3$) spectrum of **1k**.

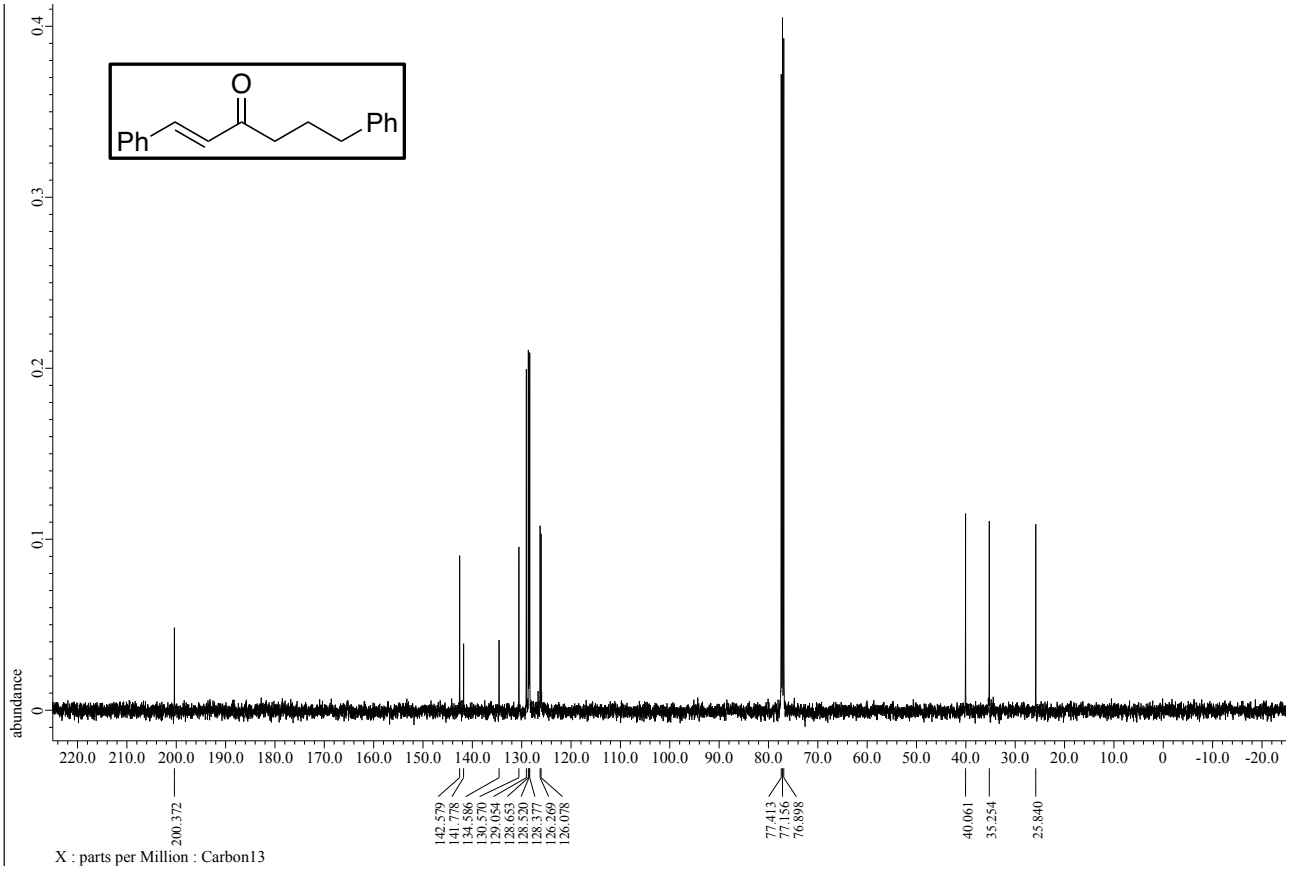


Figure S17. ^{13}C NMR (125.8 MHz, $CDCl_3$) spectrum of **1k**.

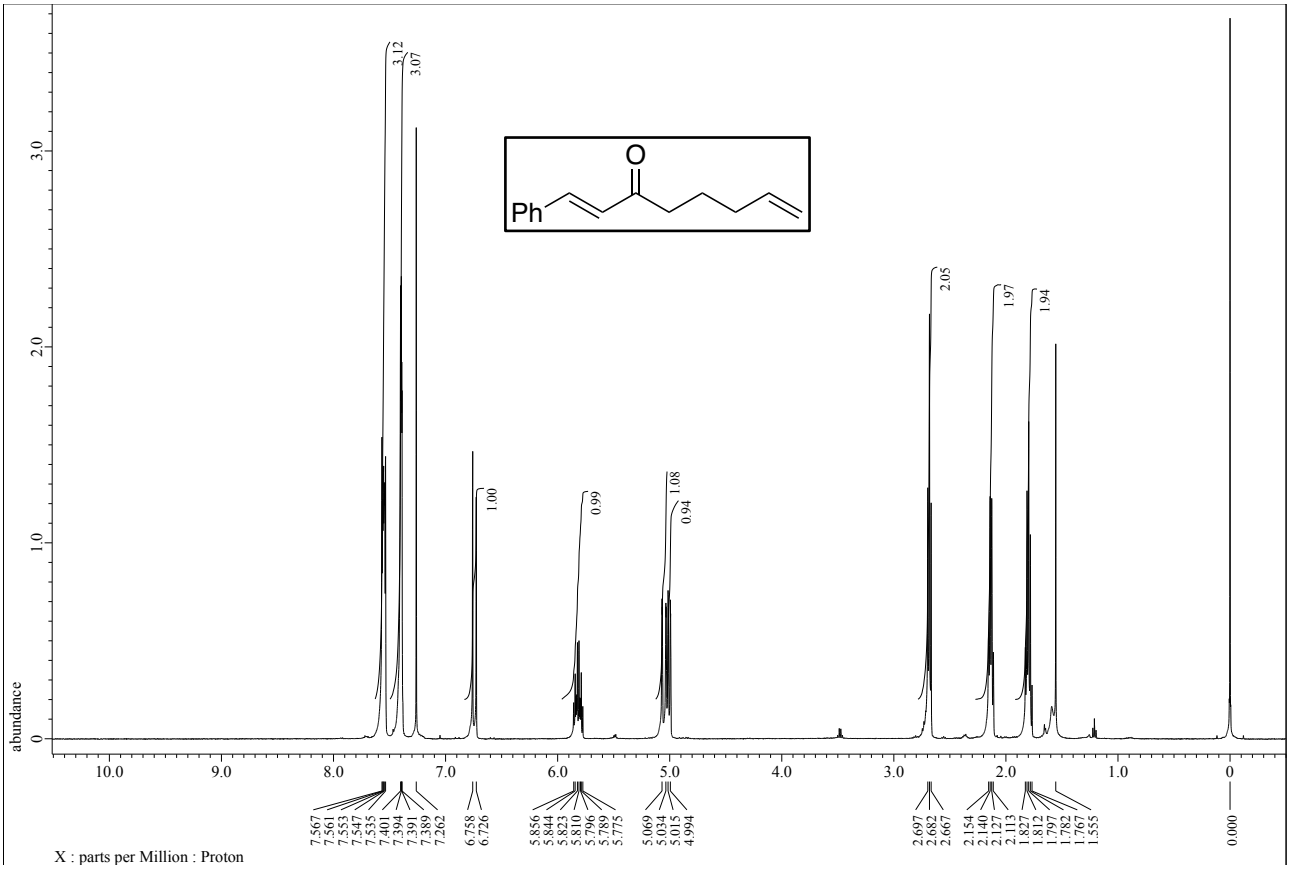


Figure S18. ^{1}H NMR (500 MHz, $CDCl_3$) spectrum of **1l**.

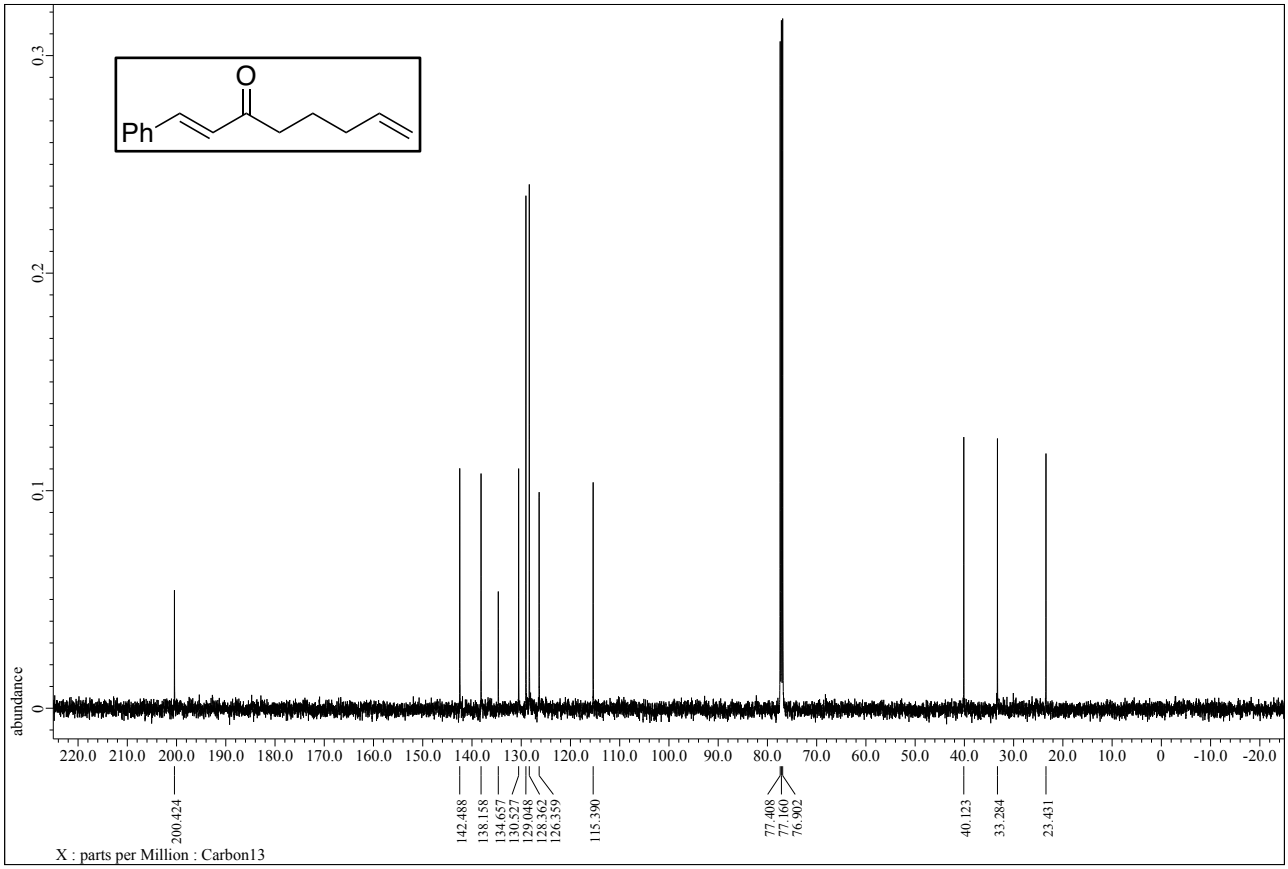


Figure S19. ^{13}C NMR (125.8 MHz, $CDCl_3$) spectrum of **1l**.

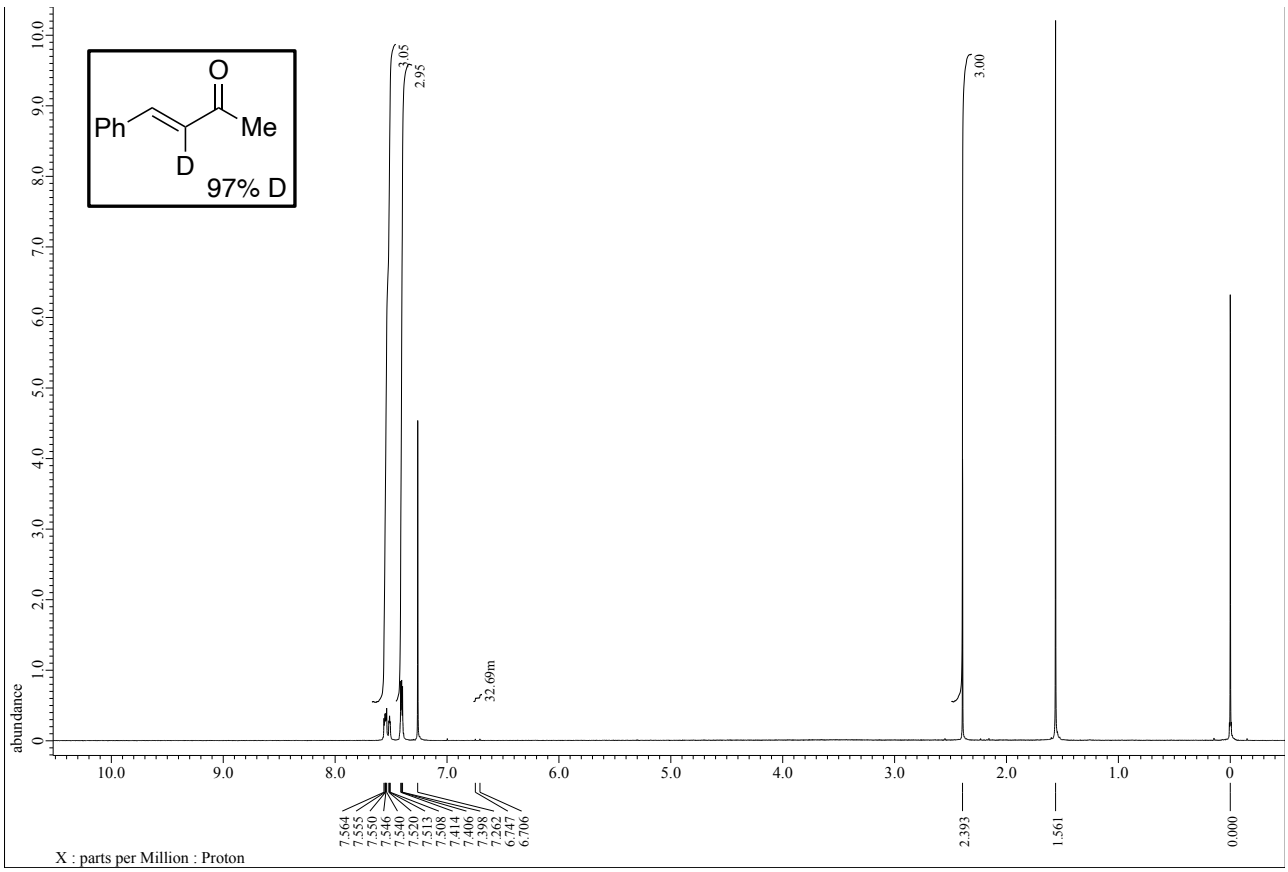


Figure S20. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **1a-α-D**.

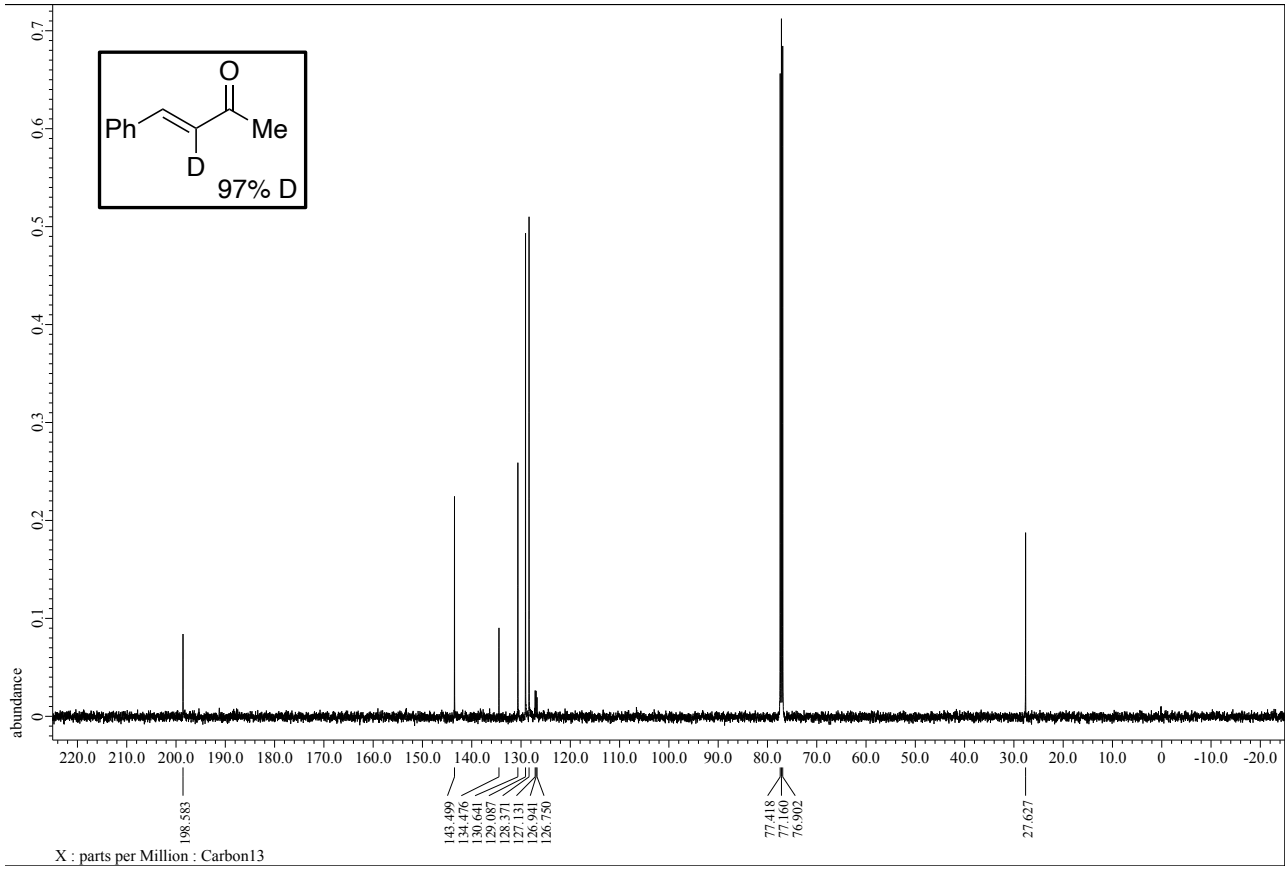


Figure S21. ^{13}C NMR (125.8 MHz, $CDCl_3$) spectrum of **1a-α-D**.

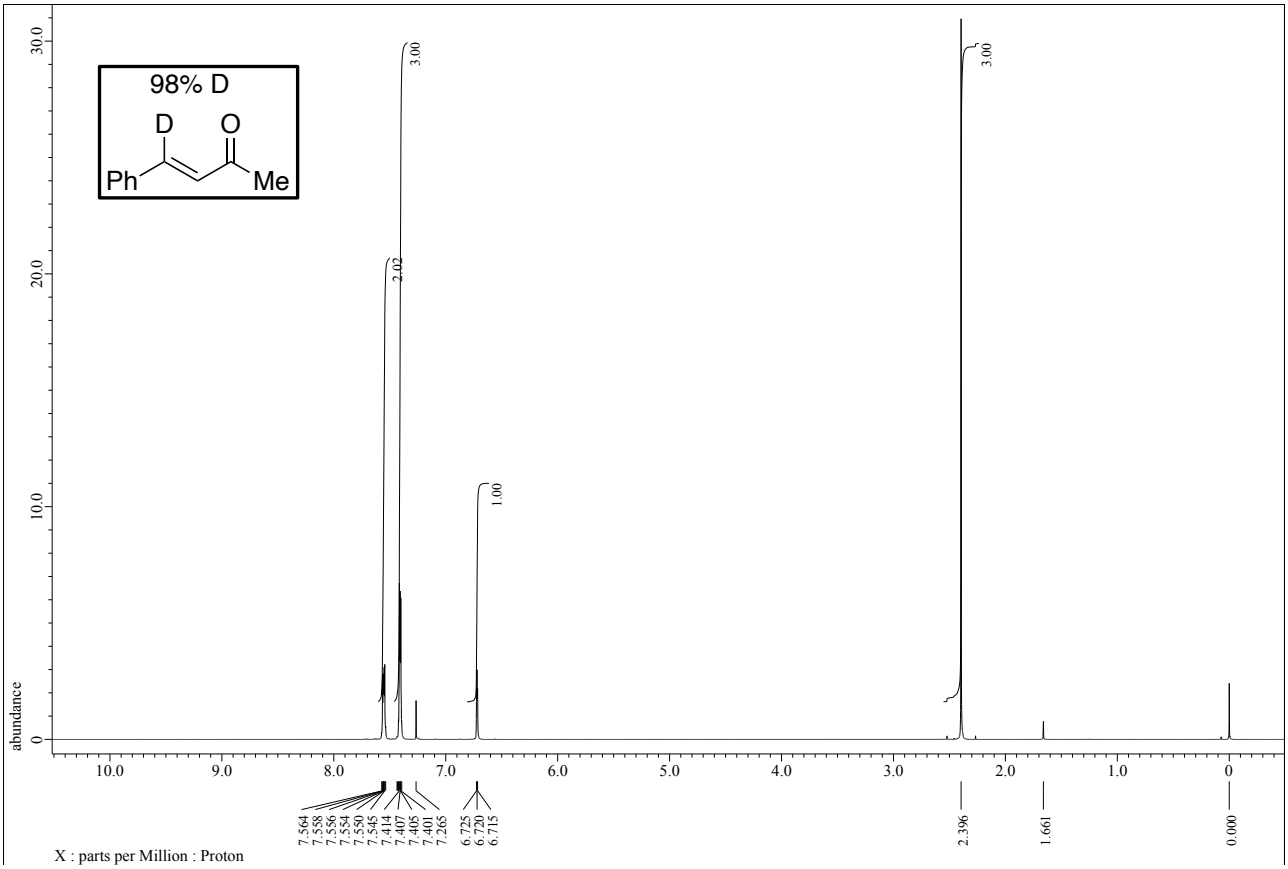


Figure S22. ^{1}H NMR (500 MHz, $CDCl_3$) spectrum of **1a-β-D**.

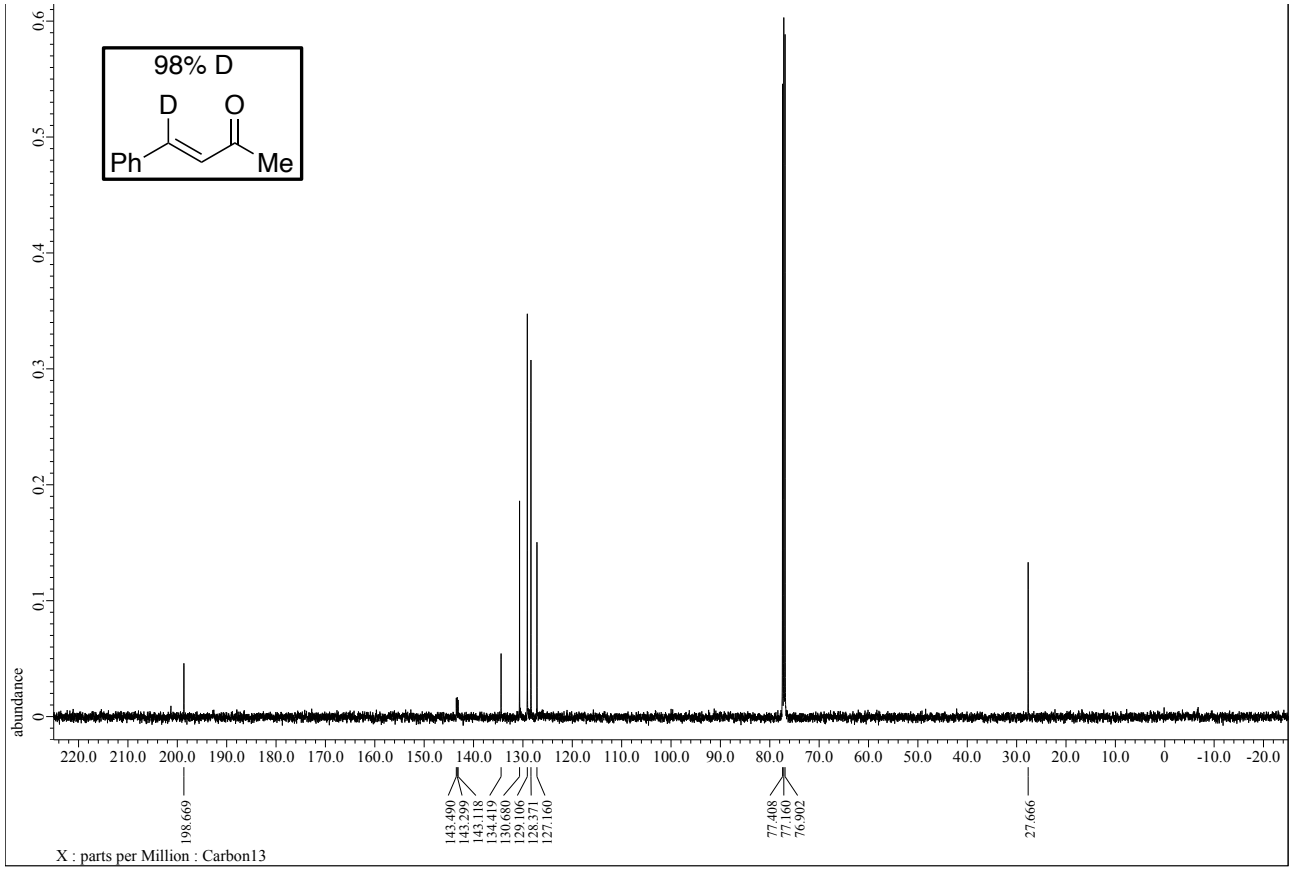


Figure S23. ^{13}C NMR (125.8 MHz, $CDCl_3$) spectrum of **1a-β-D**.

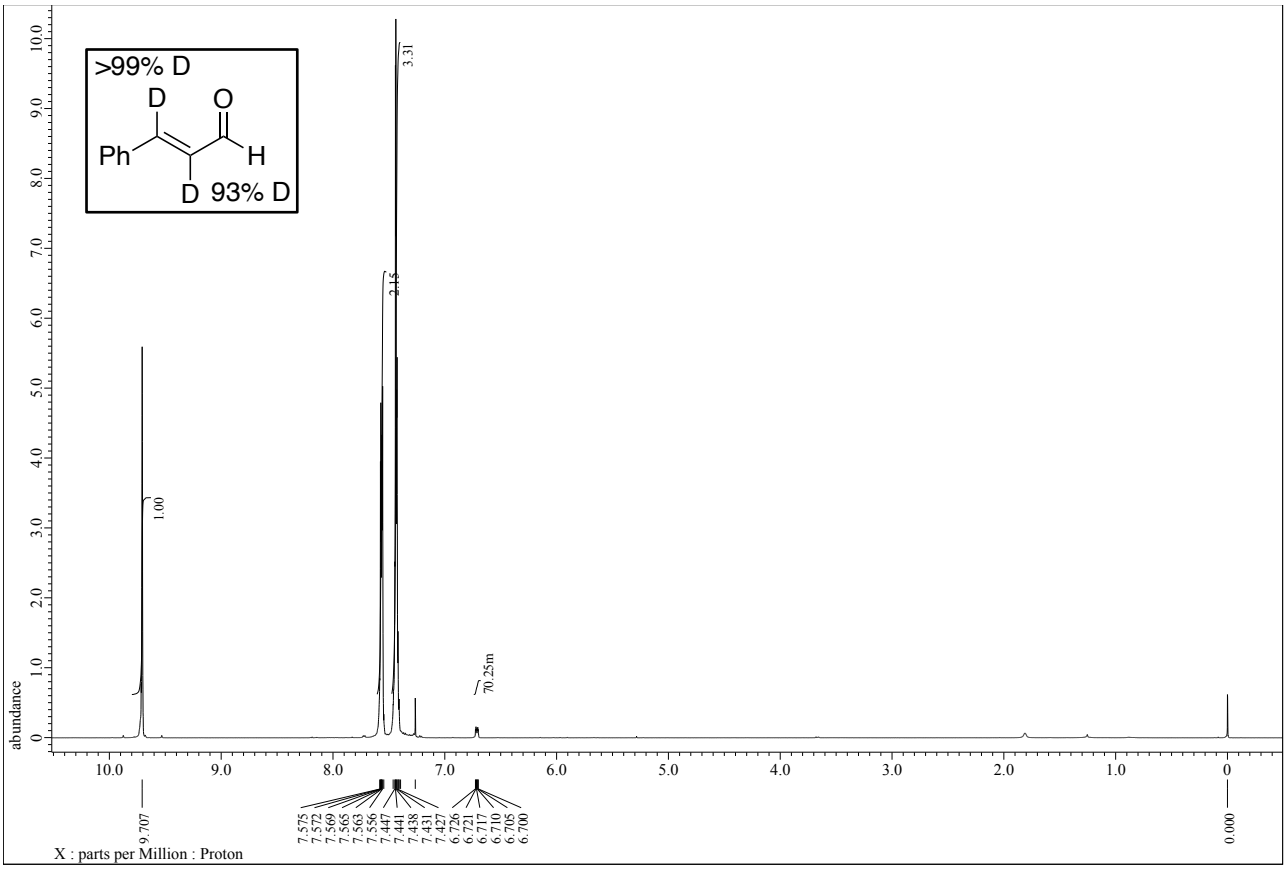


Figure S24. ^{1}H NMR (500 MHz, $CDCl_3$) spectrum of (*E*)-cinnamaldehyde-2,3-d_2.

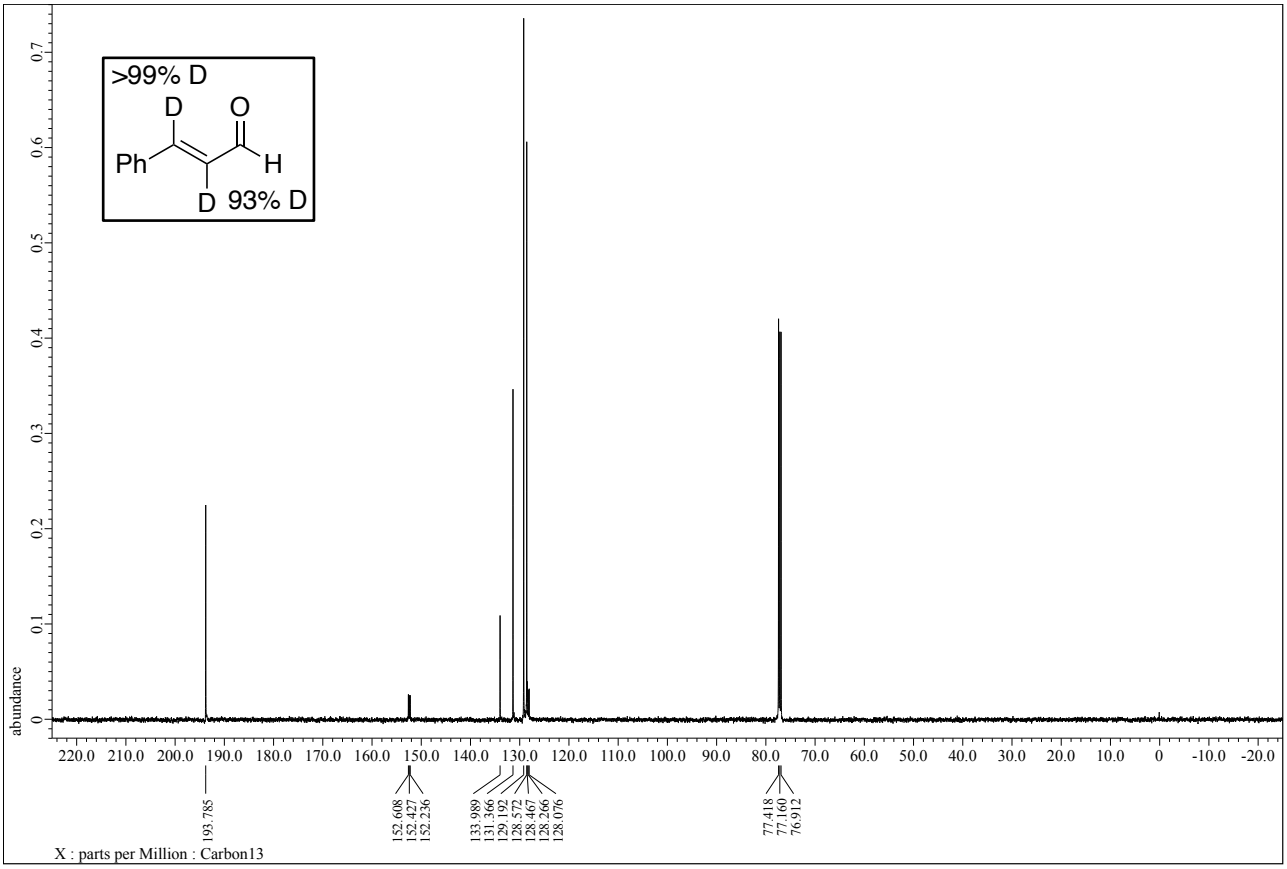


Figure S25. ^{13}C NMR (125.8 MHz, $CDCl_3$) spectrum of (*E*)-cinnamaldehyde-2,3-d_2.

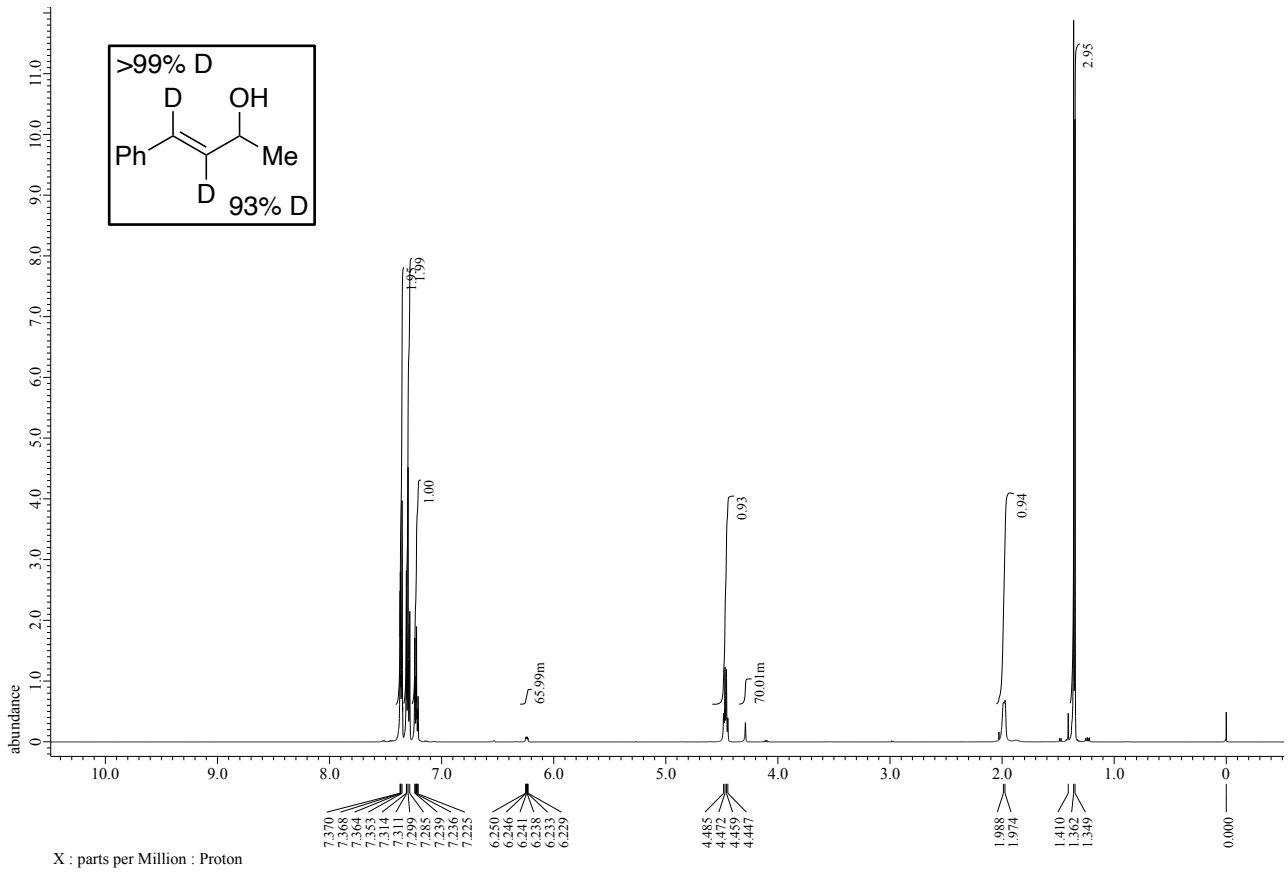


Figure S26. ^{1}H NMR (500 MHz, $CDCl_3$) spectrum of (*E*)-4-phenylbut-3-en-3,4-d_2-2-ol.

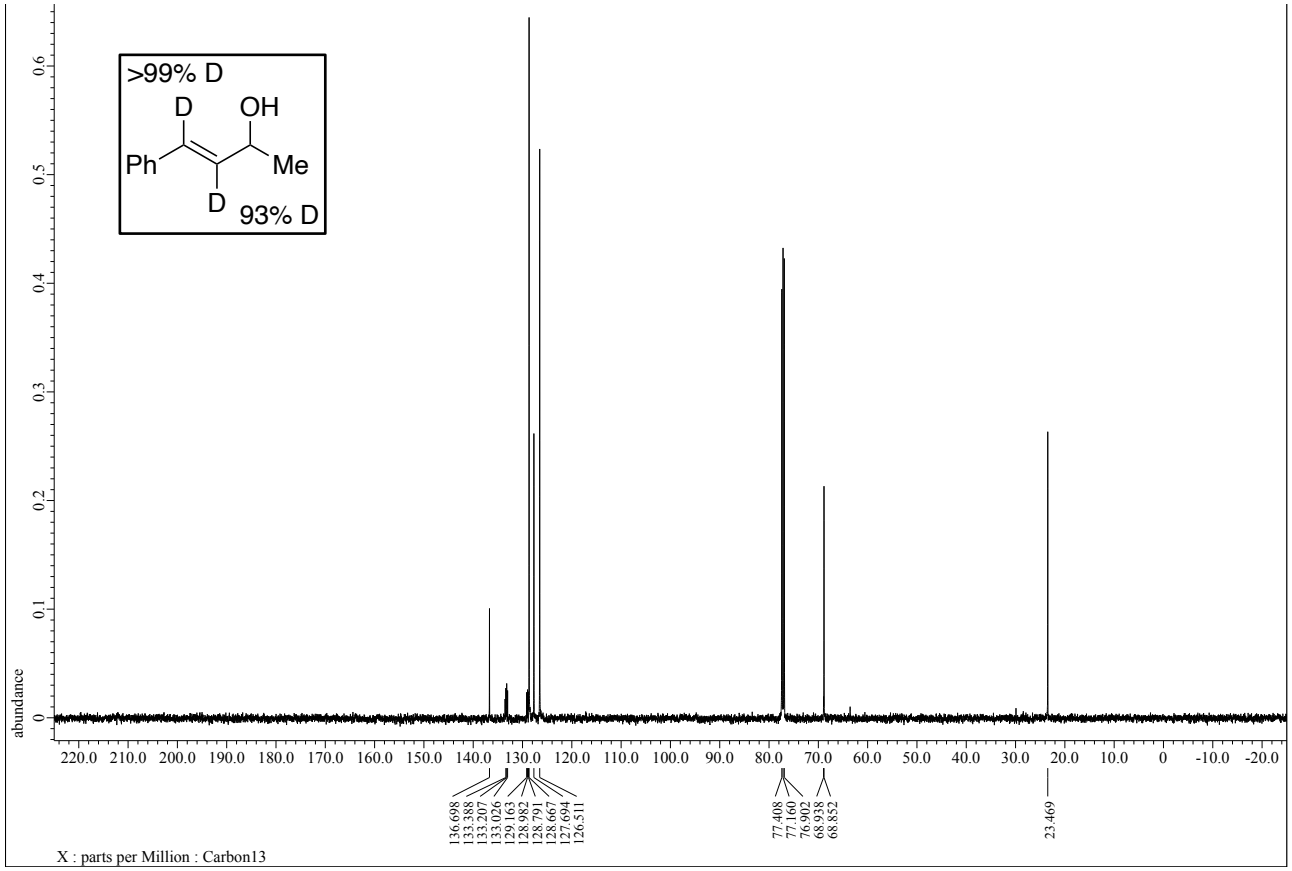


Figure S27. ^{13}C NMR (125.8 MHz, $CDCl_3$) spectrum of (*E*)-4-phenylbut-3-en-3,4-d_2-2-ol.

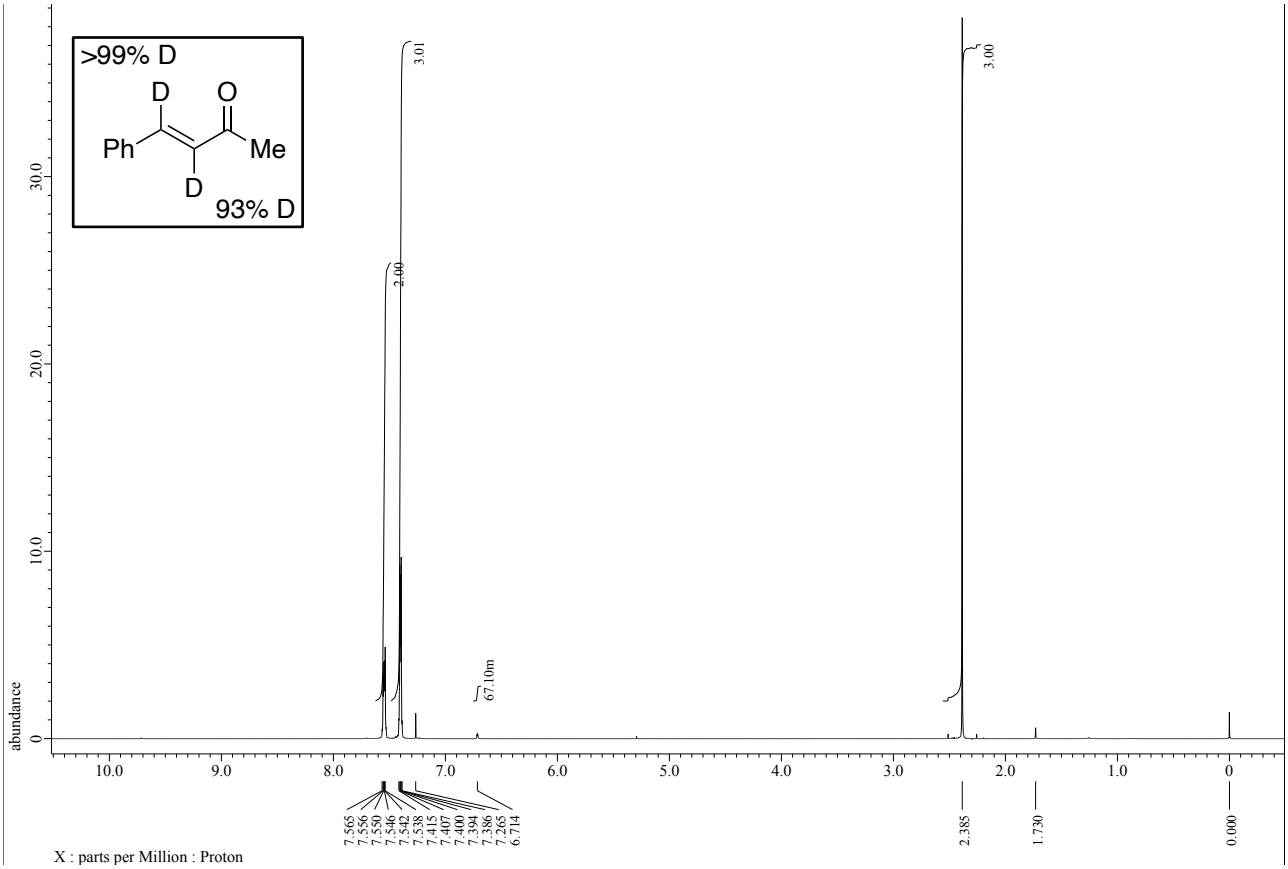


Figure S28. ^{1}H NMR (500 MHz, $CDCl_3$) spectrum of **1a-α,β-D$_2$**.

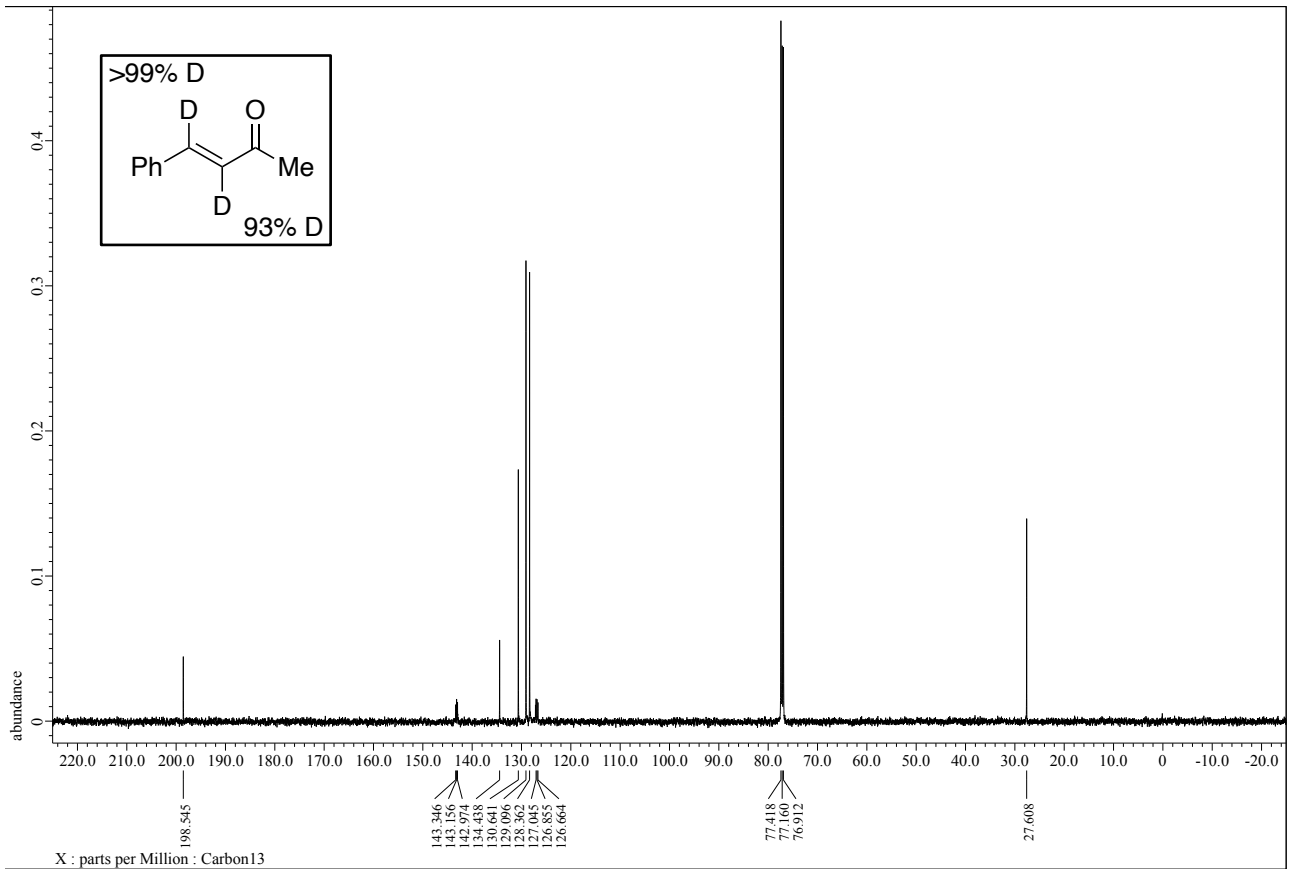


Figure S29. ^{13}C NMR (125.8 MHz, $CDCl_3$) spectrum of **1a-α,β-D$_2$**.

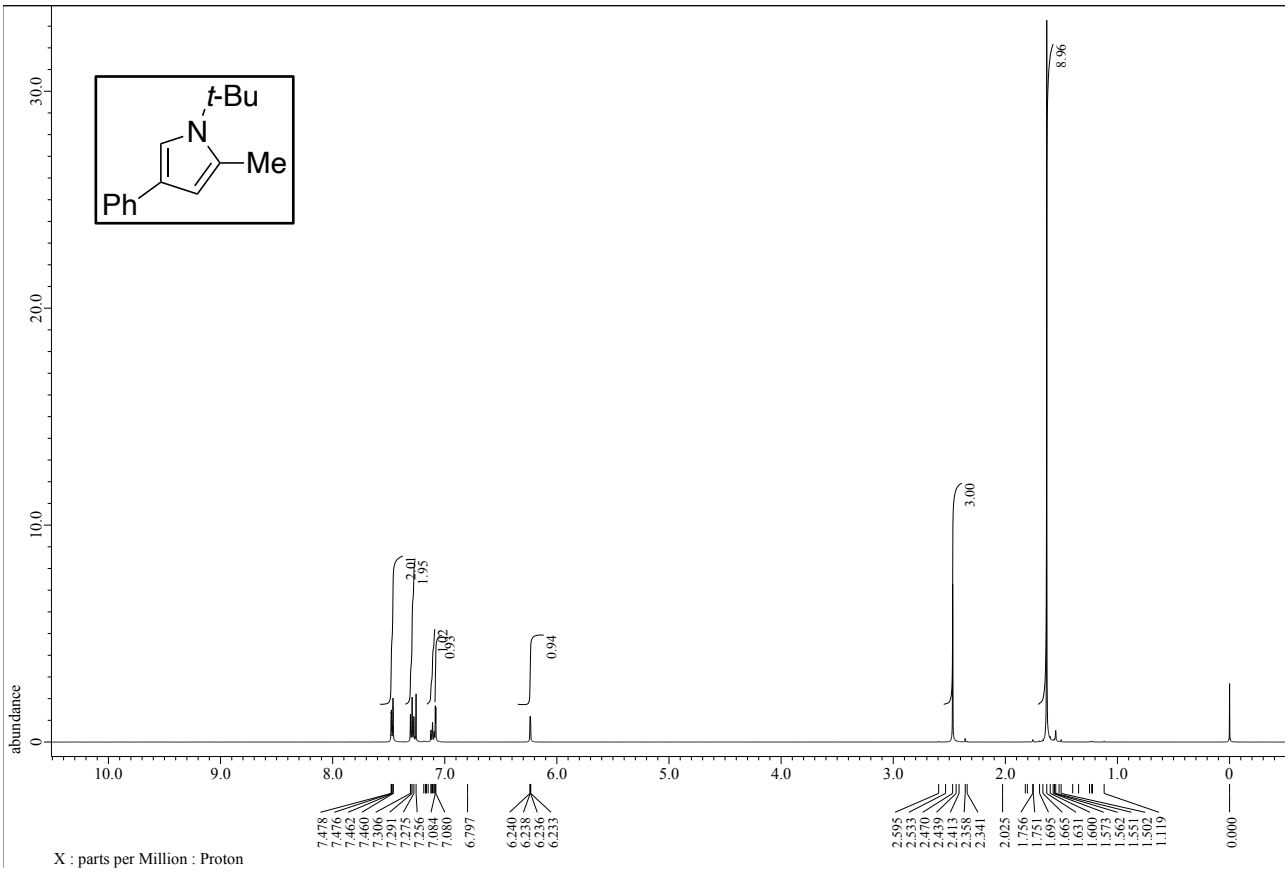


Figure S30. ^{1}H NMR (500 MHz, $CDCl_3$) spectrum of **3aa**.

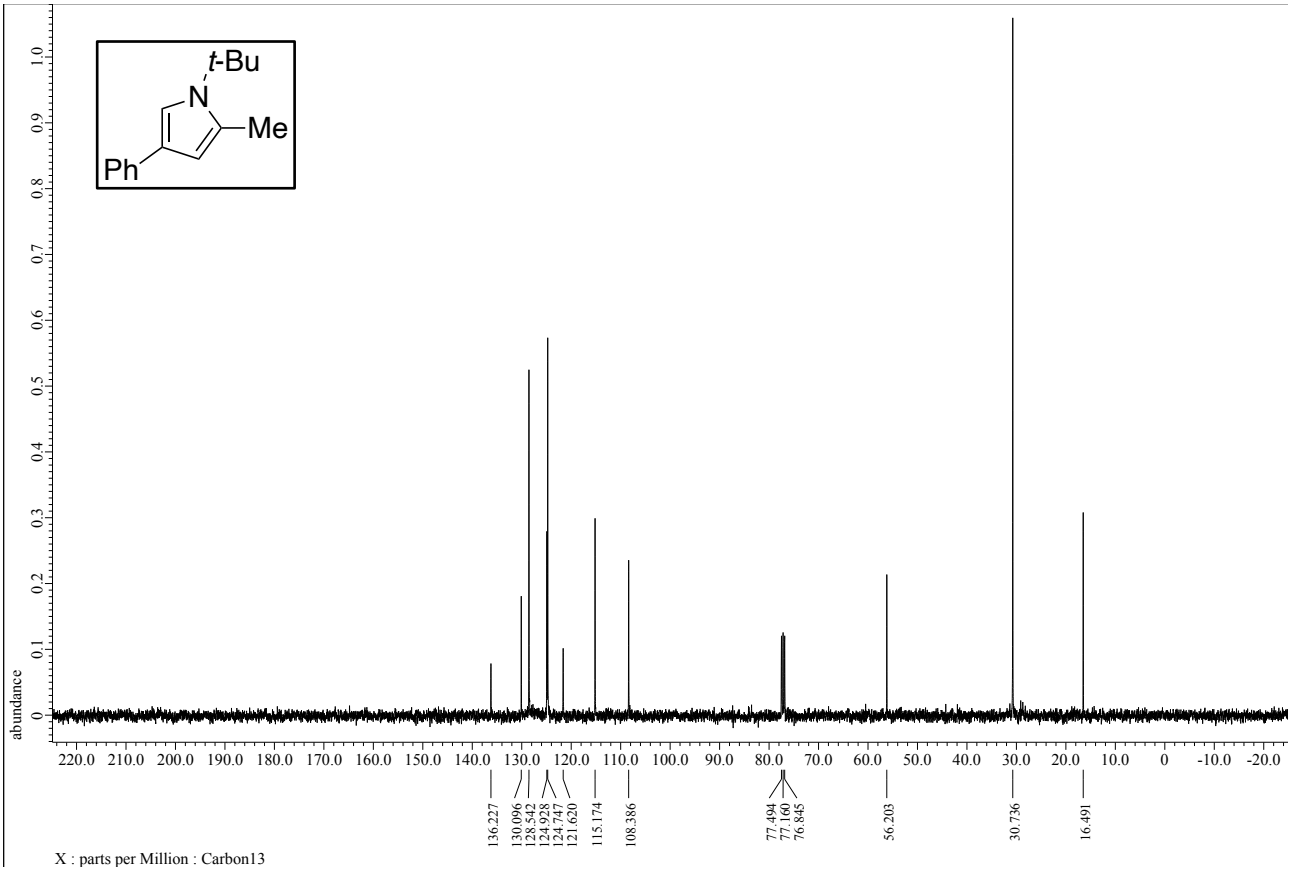


Figure S31. ^{13}C NMR (100.5 MHz, $CDCl_3$) spectrum of **3aa**.

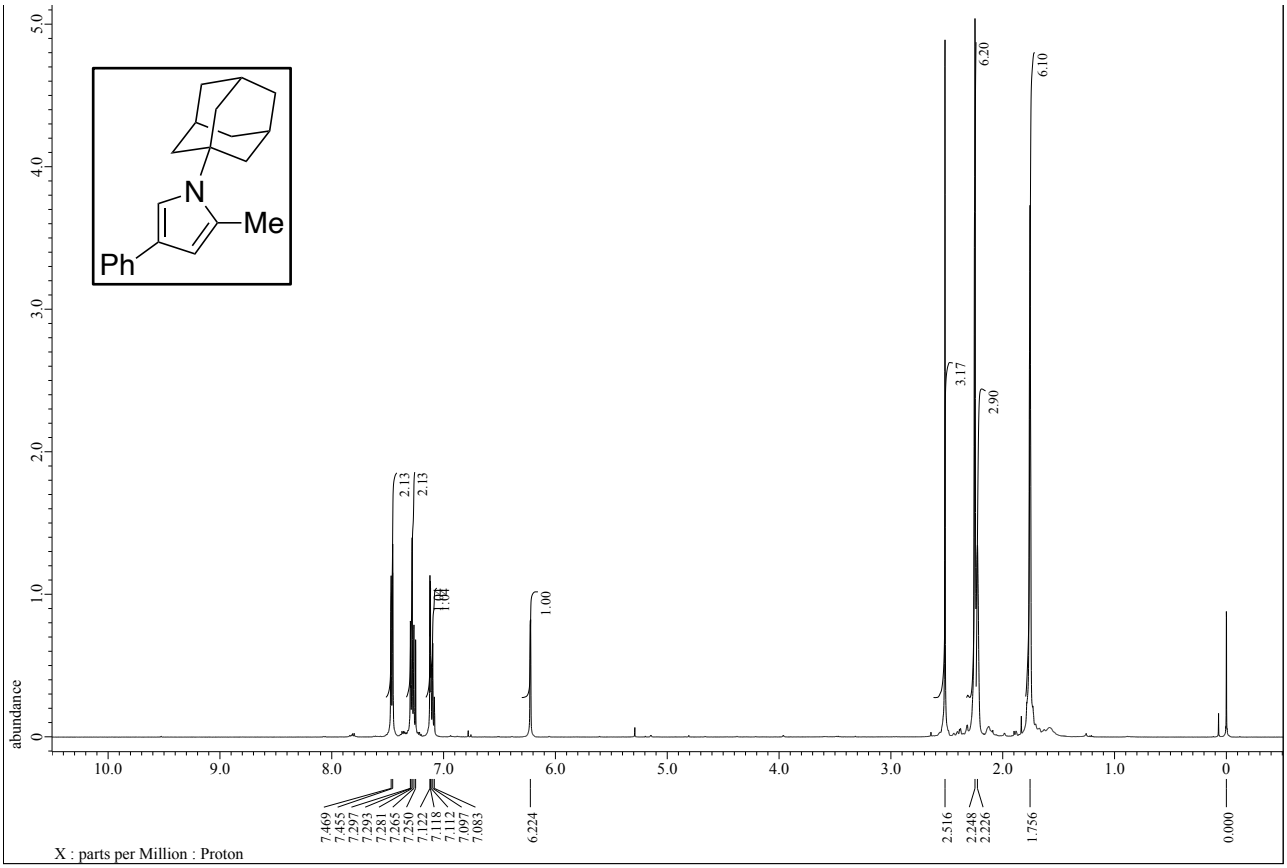


Figure S32. ^{1}H NMR (500 MHz, $CDCl_3$) spectrum of **3ab**.

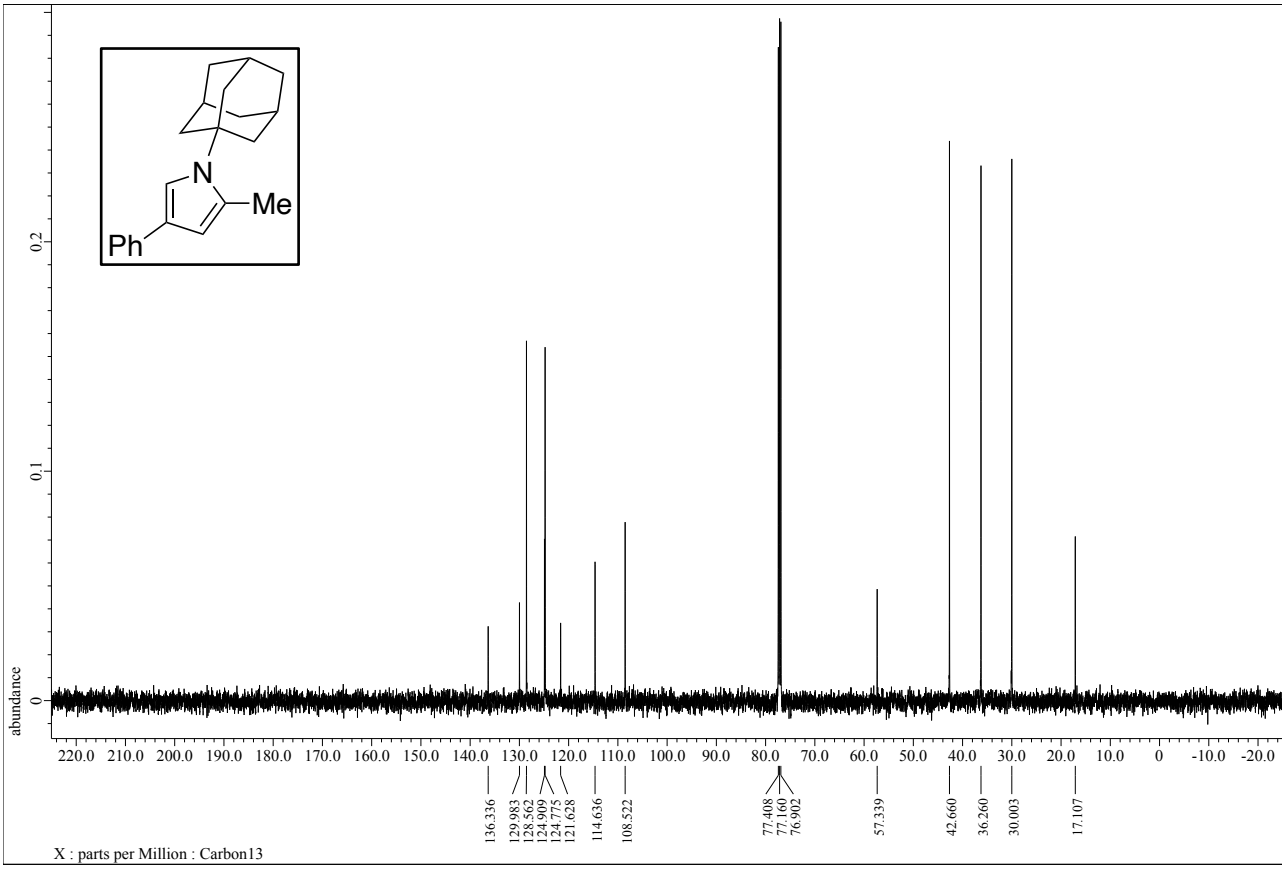


Figure S33. ^{13}C NMR (125.8 MHz, $CDCl_3$) spectrum of **3ab**.

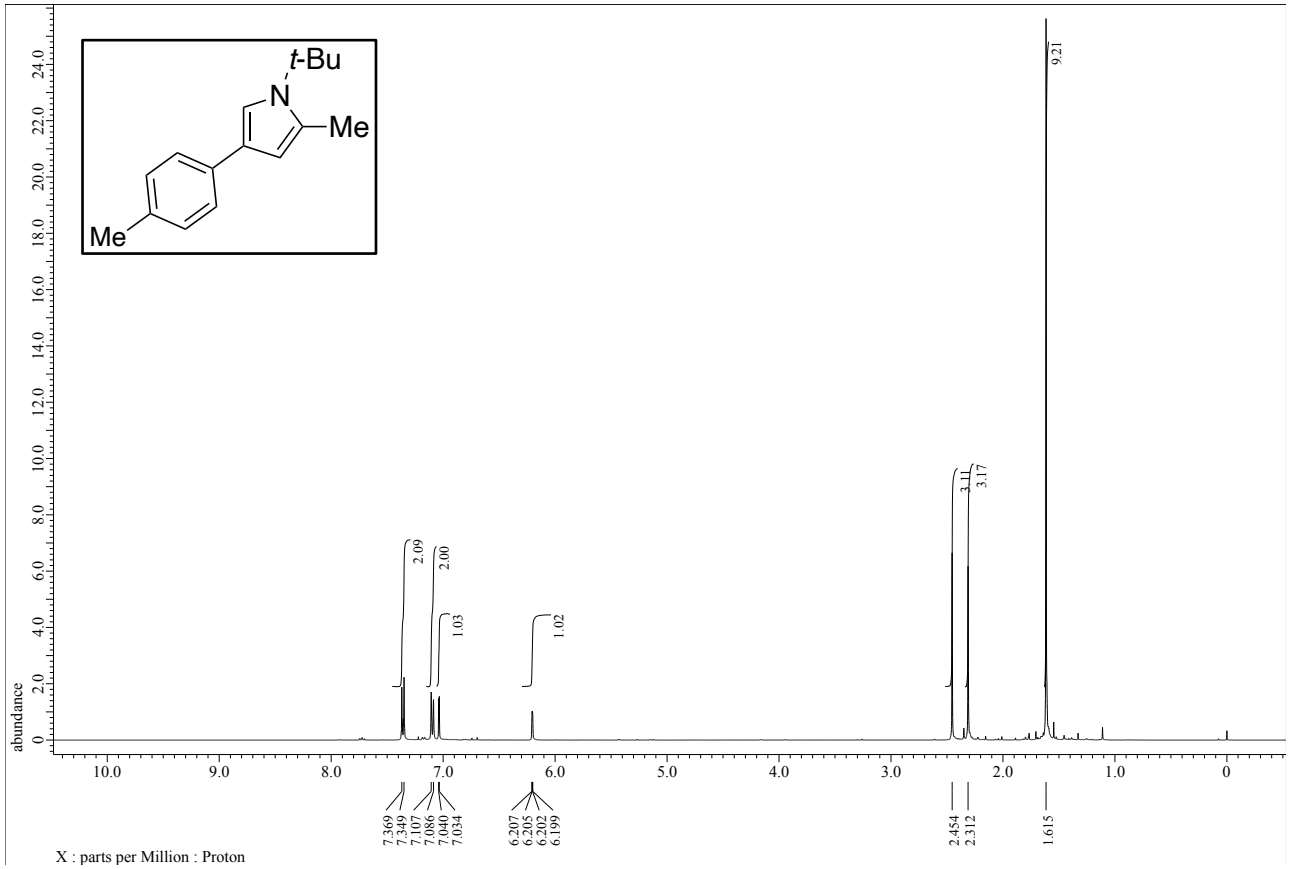


Figure S34. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **3ba**.

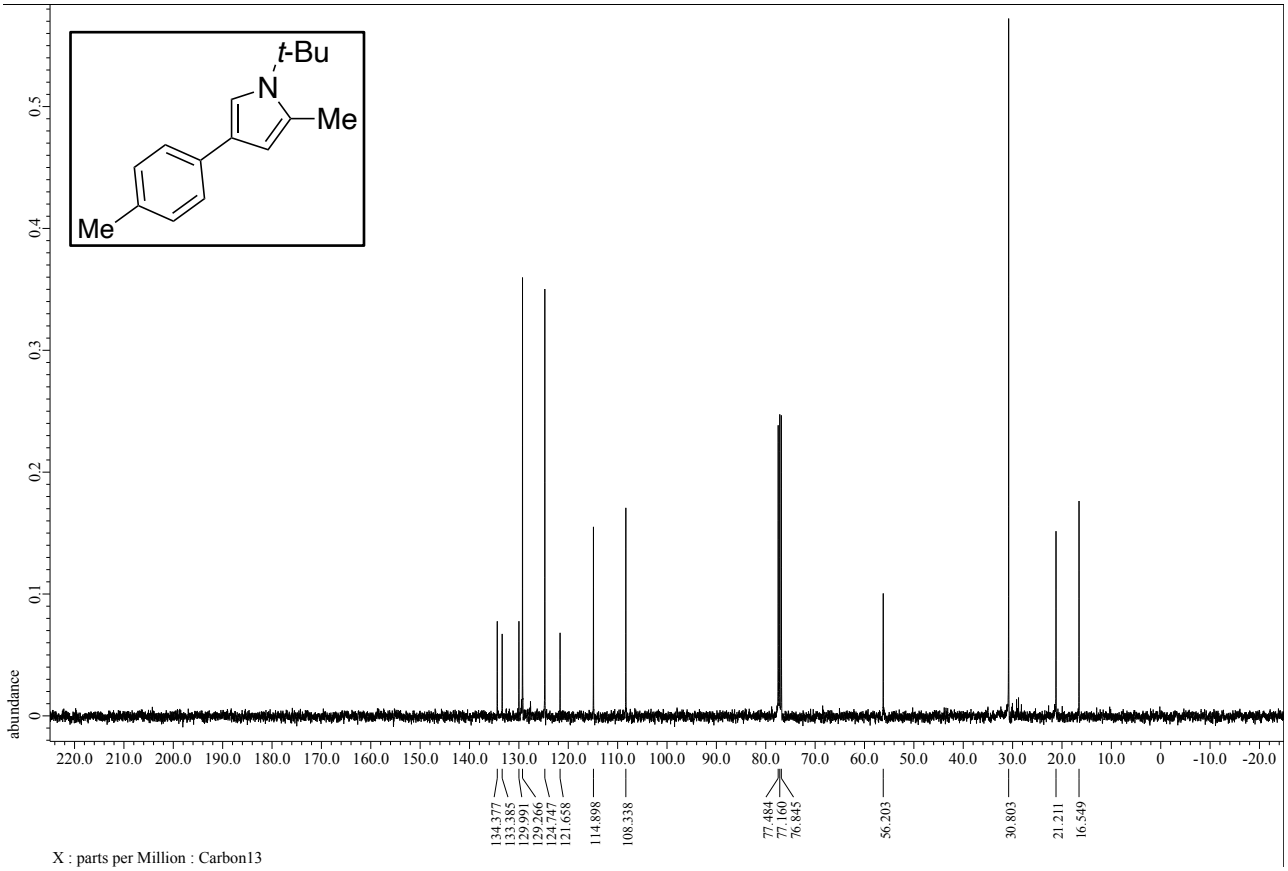


Figure S35. ^{13}C NMR (100.5 MHz, $CDCl_3$) spectrum of **3ba**.

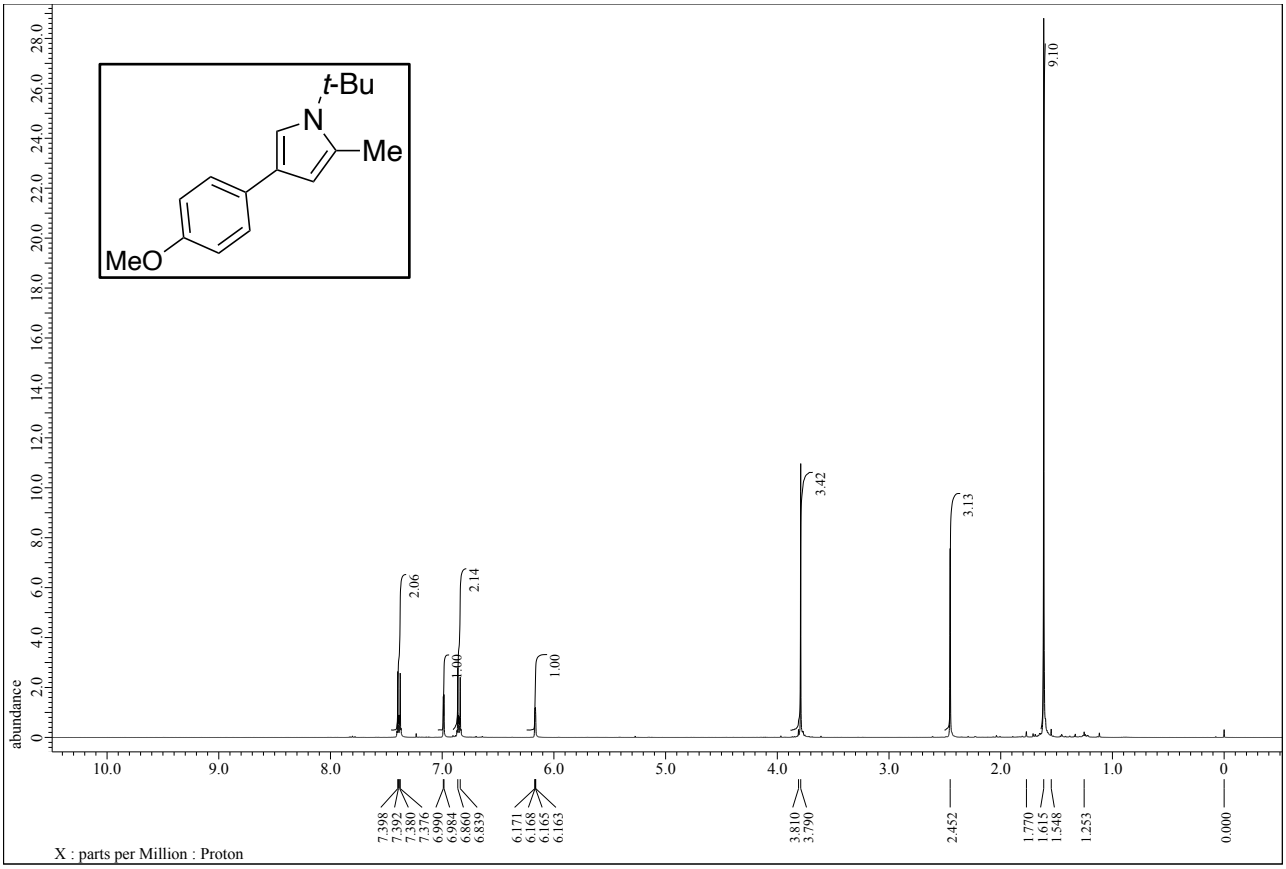


Figure S36. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **3ca**.

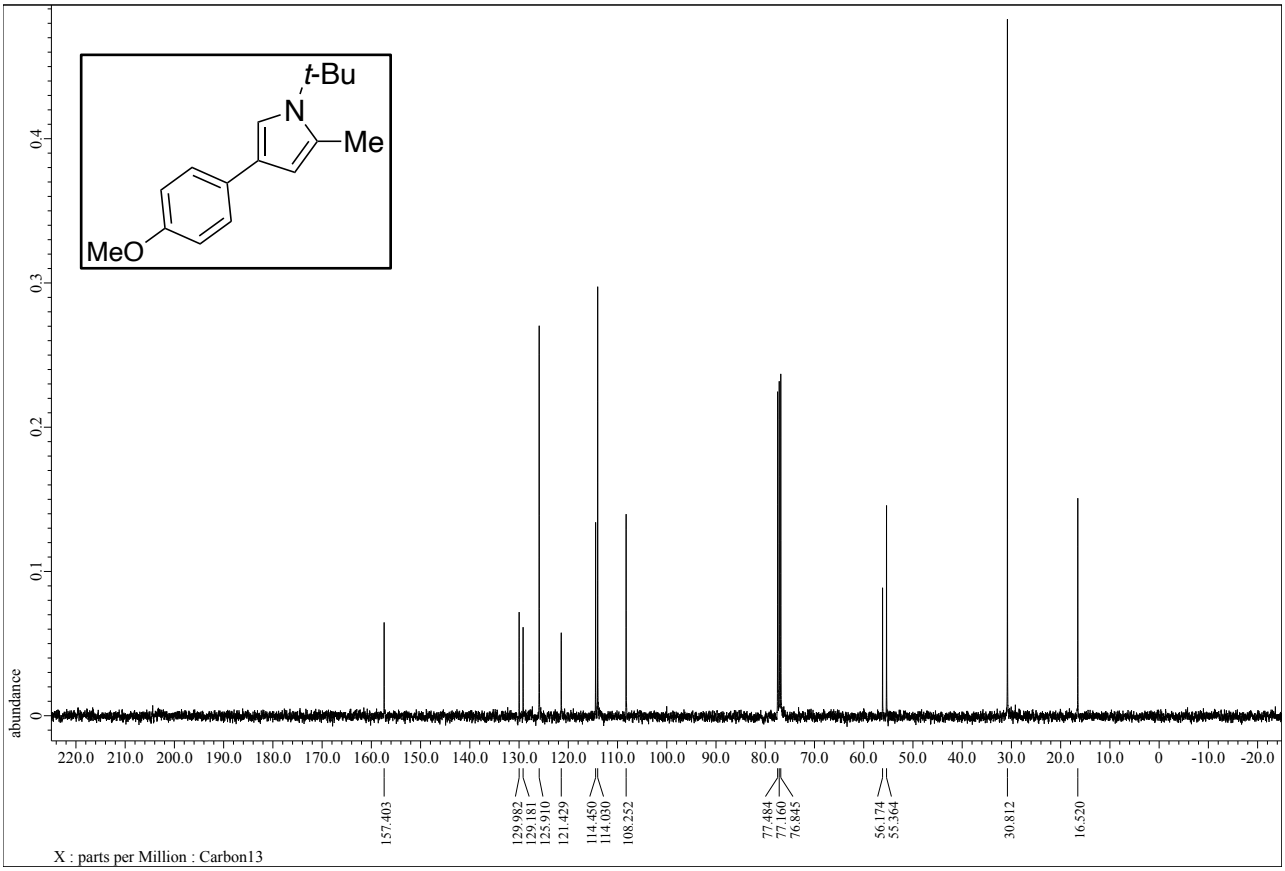


Figure S37. ^{13}C NMR (100.5 MHz, $CDCl_3$) spectrum of **3ca**.

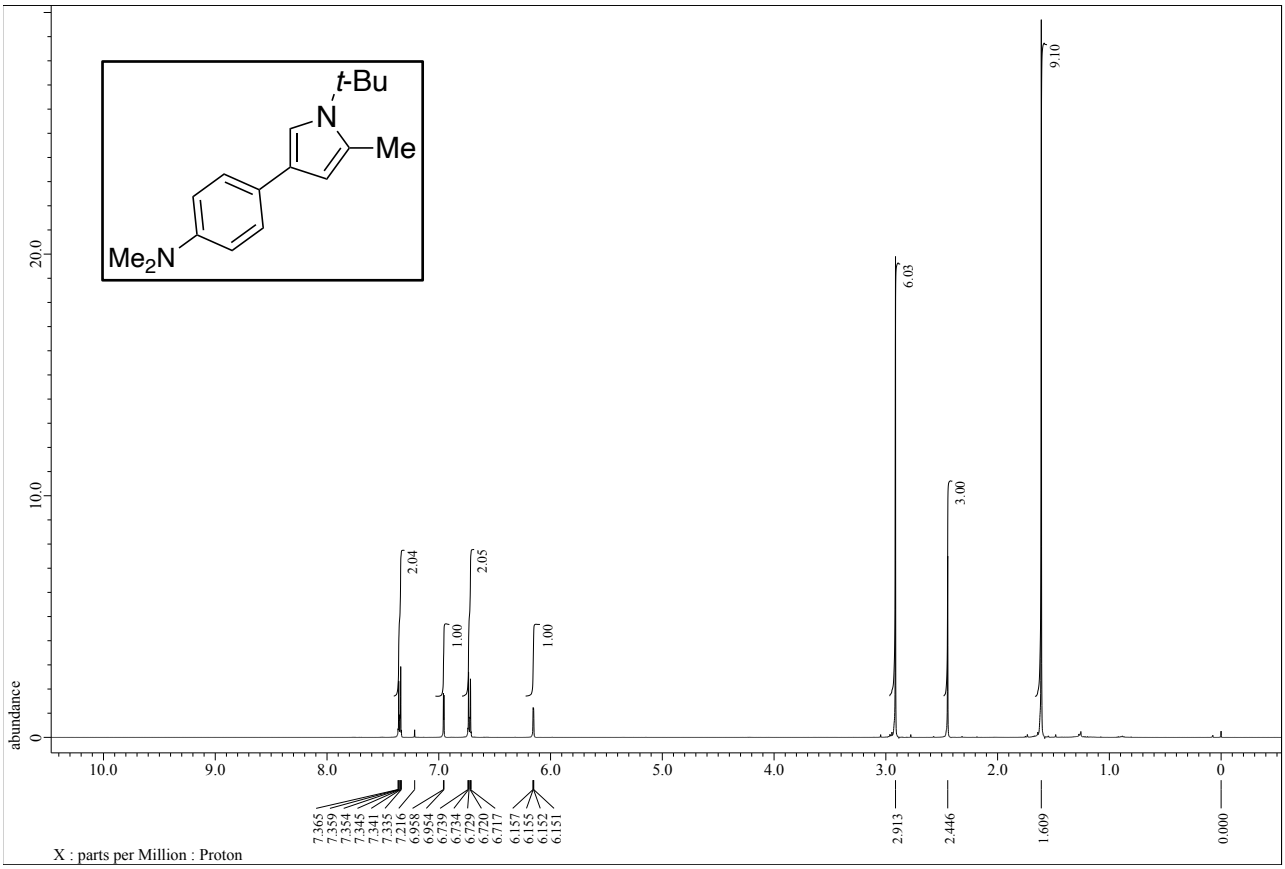


Figure S38. ^{1}H NMR (500 MHz, $CDCl_3$) spectrum of **3da**.

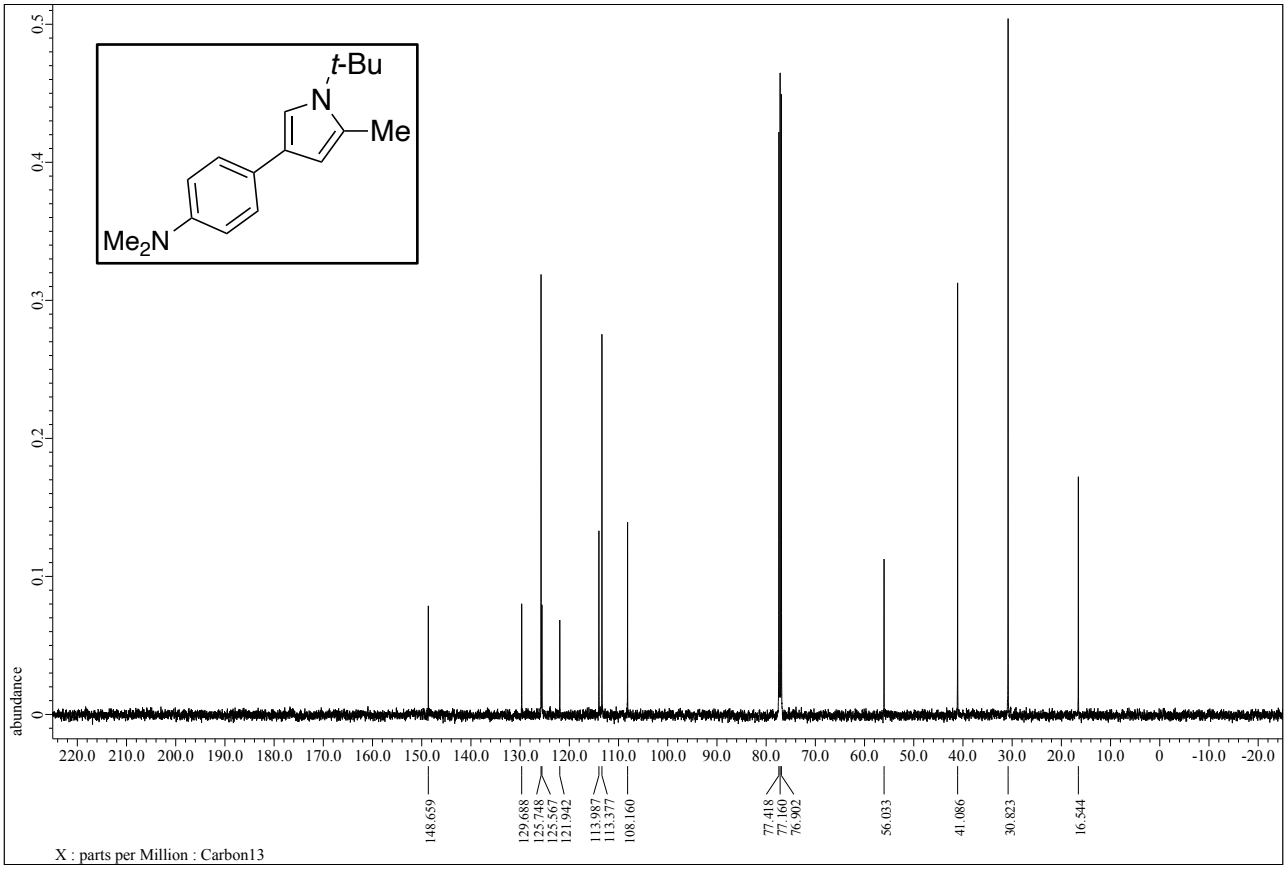


Figure S39. ^{13}C NMR (125.8 MHz, $CDCl_3$) spectrum of **3da**.

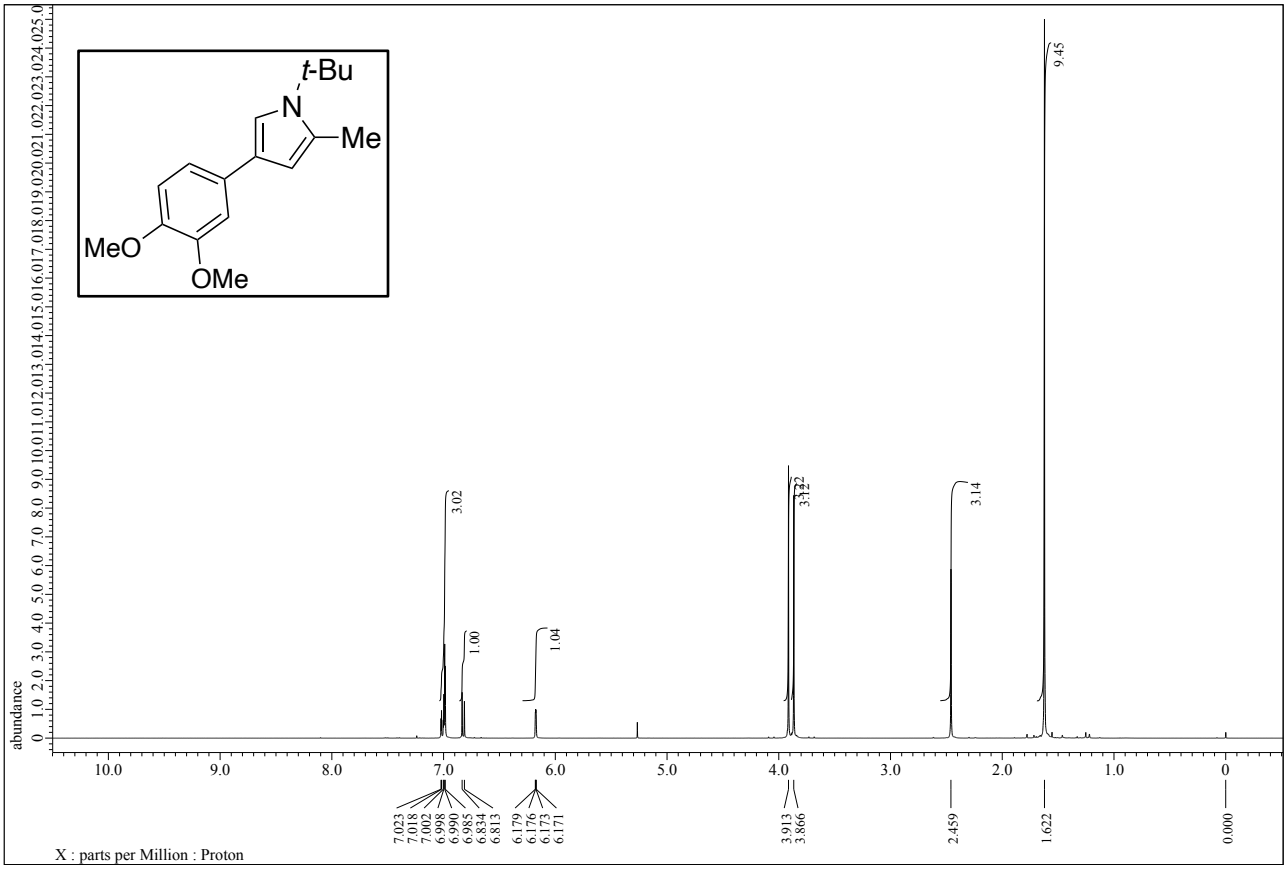


Figure S40. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **3ea**.

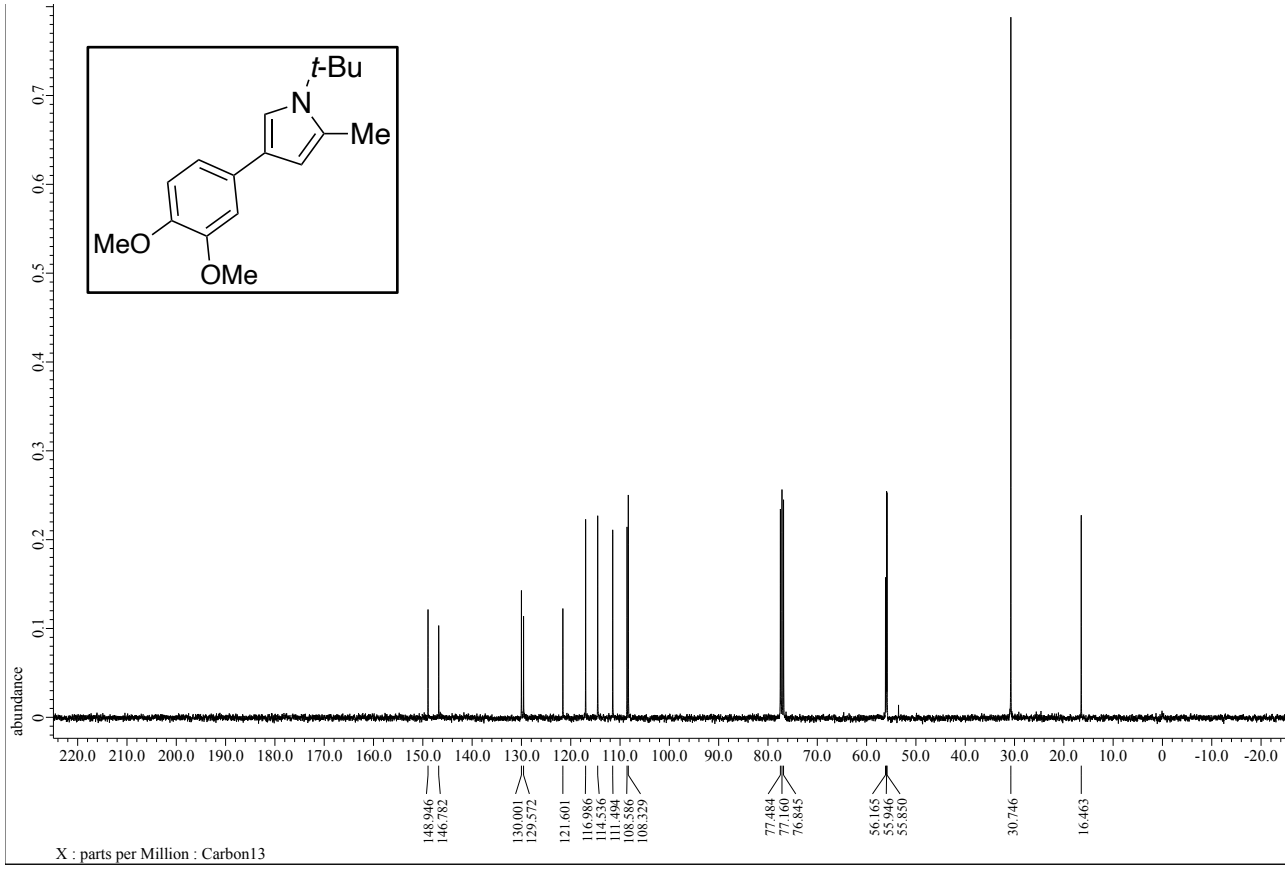


Figure S41. ^{13}C NMR (100 MHz, $CDCl_3$) spectrum of **3ea**.

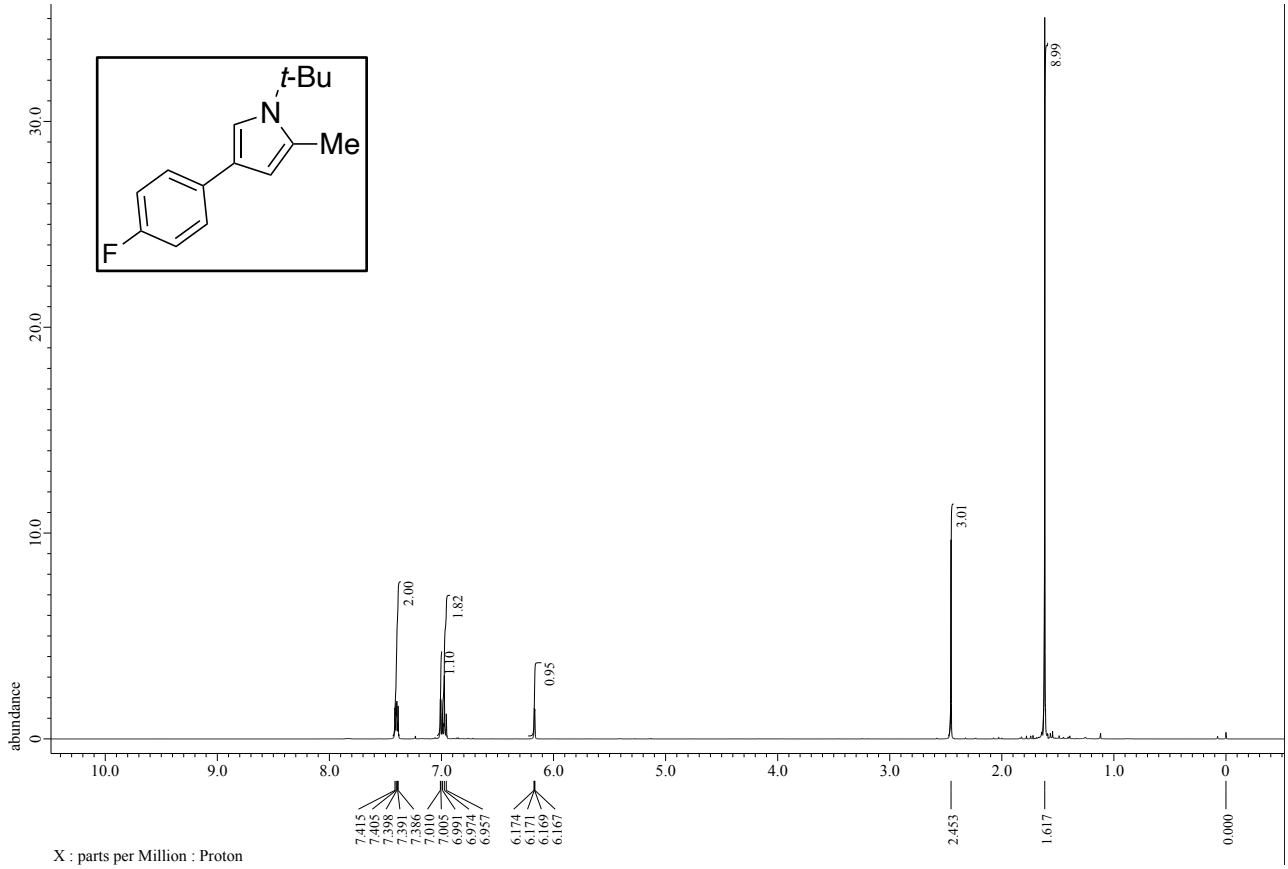


Figure S42. ^{1}H NMR (500 MHz, $CDCl_3$) spectrum of **3fa**.

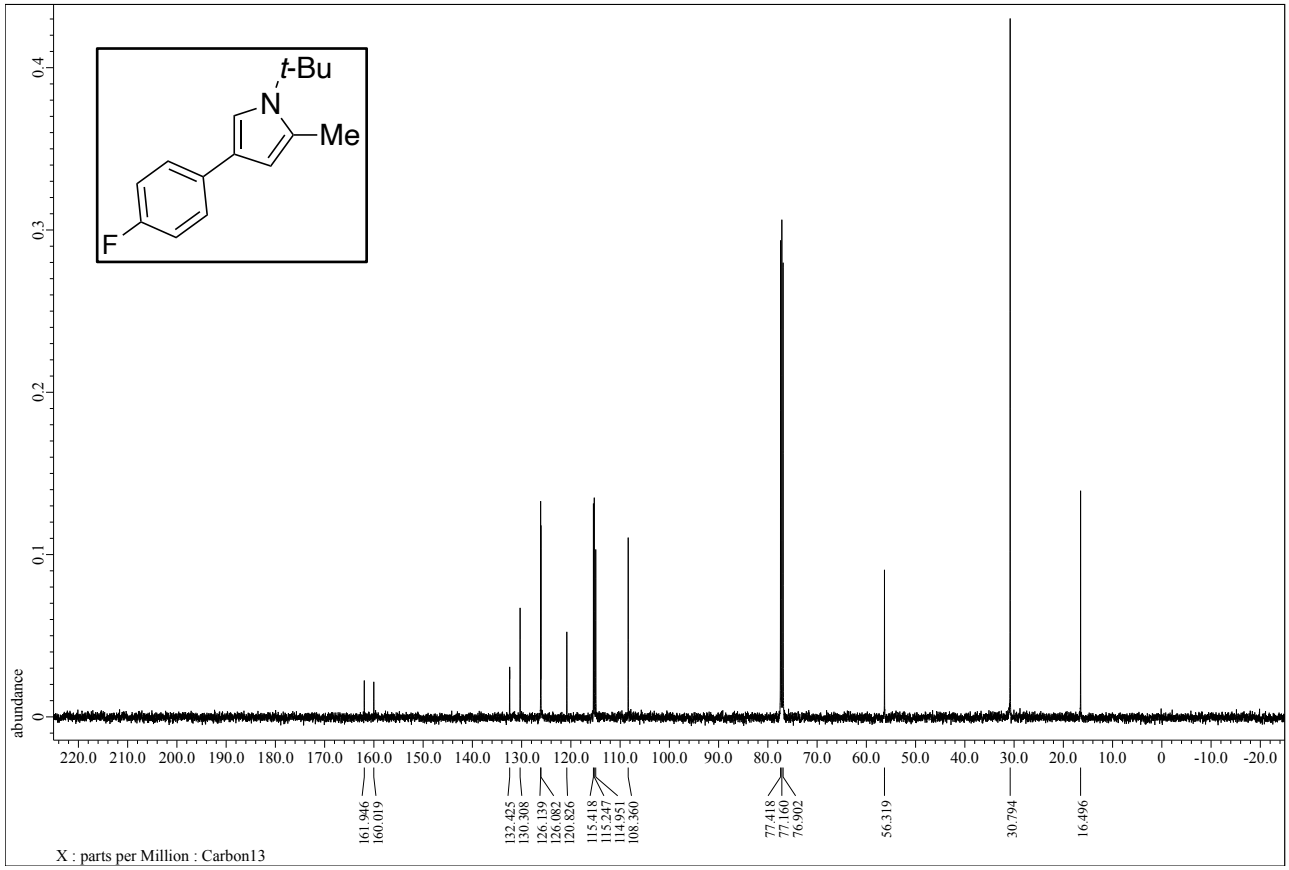


Figure S43. ^{13}C NMR (125.8 MHz, $CDCl_3$) spectrum of **3fa**.

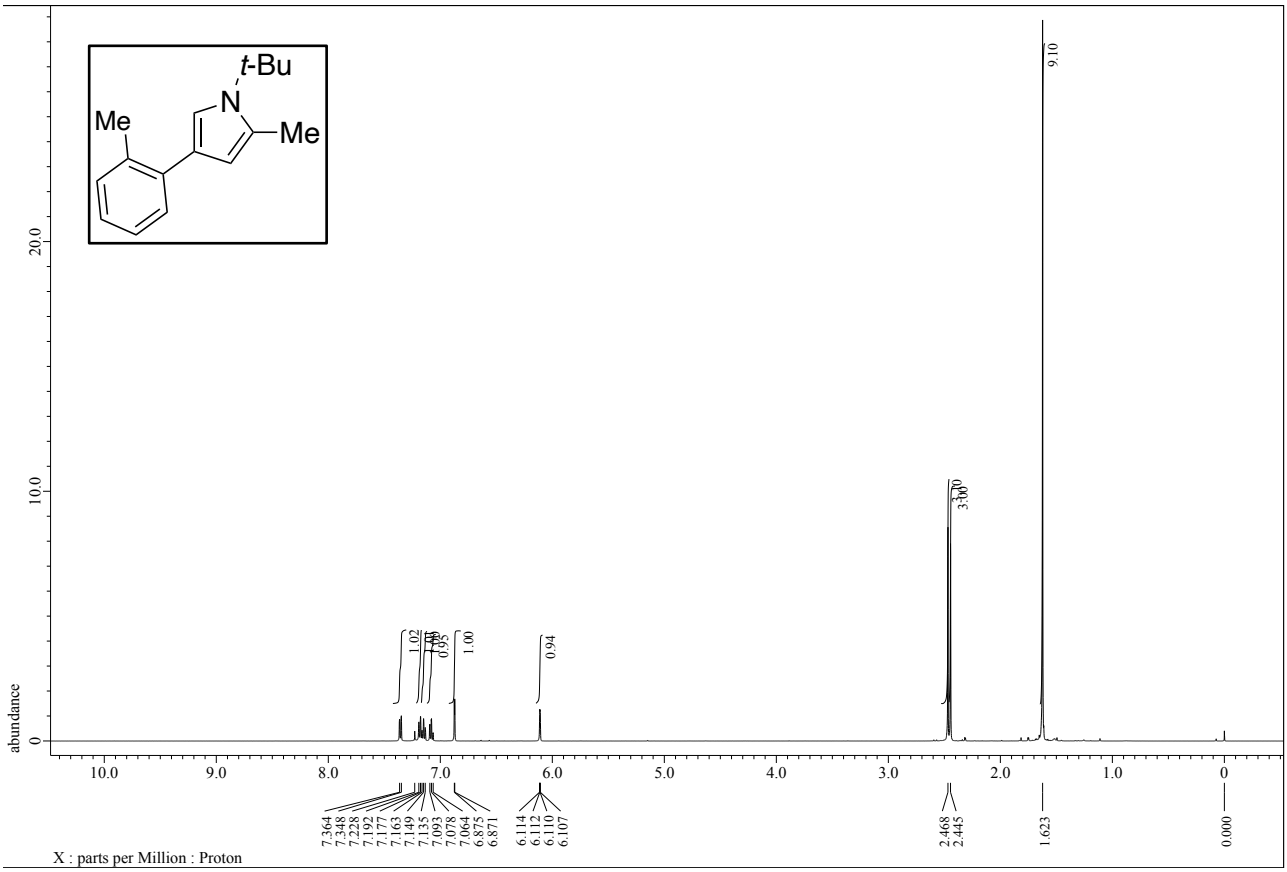


Figure S44. ^{1}H NMR (500 MHz, $CDCl_3$) spectrum of **3ga**.

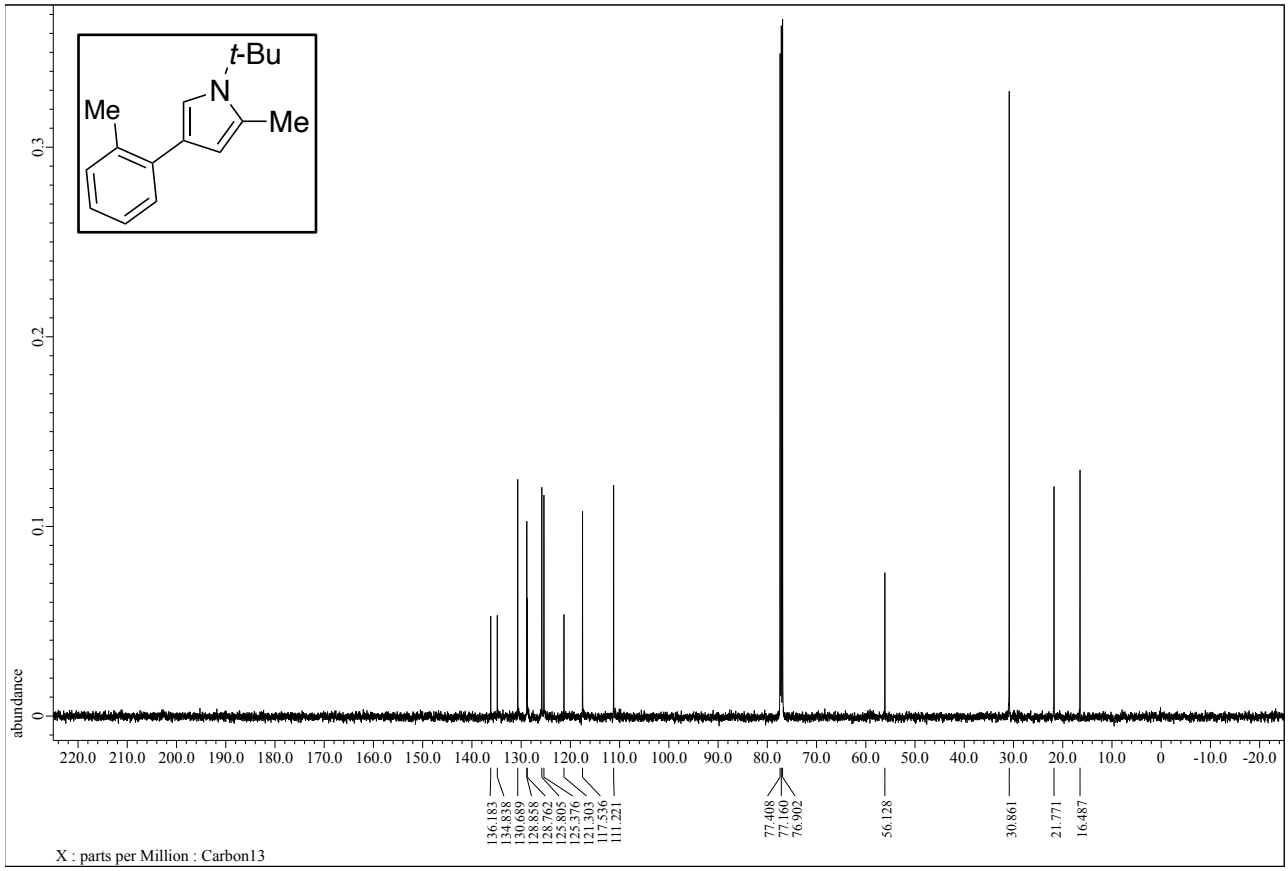


Figure S45. ^{13}C NMR (125.8 MHz, $CDCl_3$) spectrum of **3ga**.

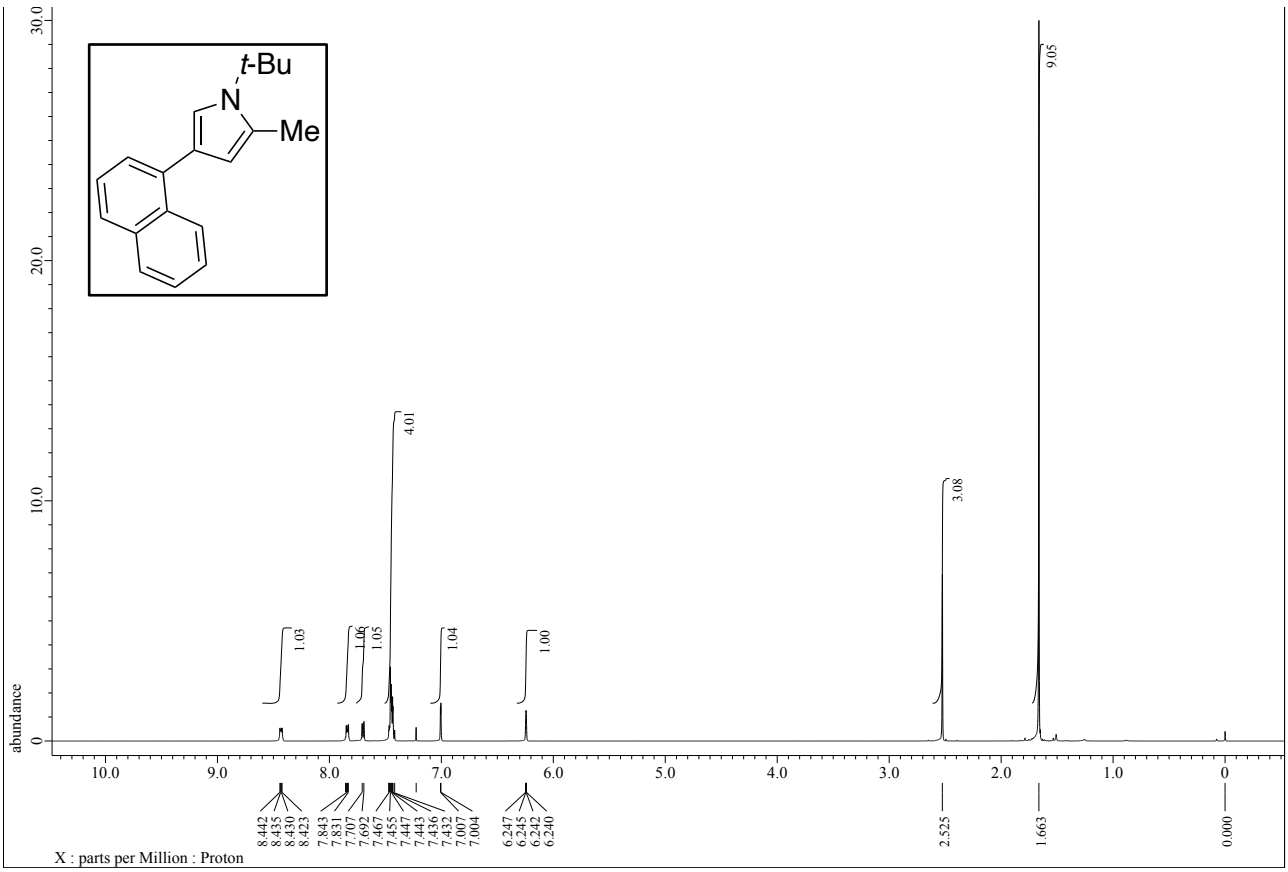


Figure S46. ^{1}H NMR (500 MHz, $CDCl_3$) spectrum of **3ha**.

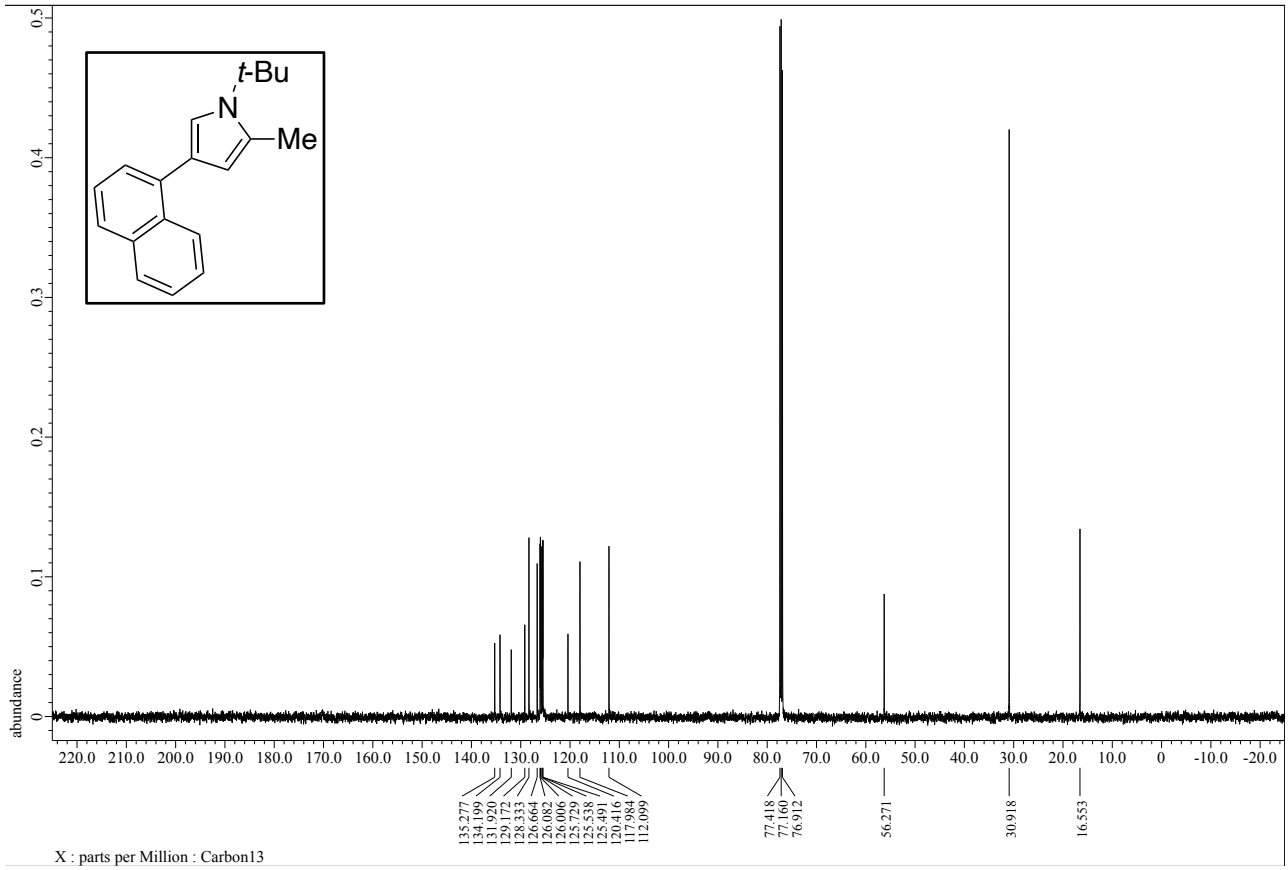


Figure S47. ^{13}C NMR (125.8 MHz, $CDCl_3$) spectrum of **3ha**.

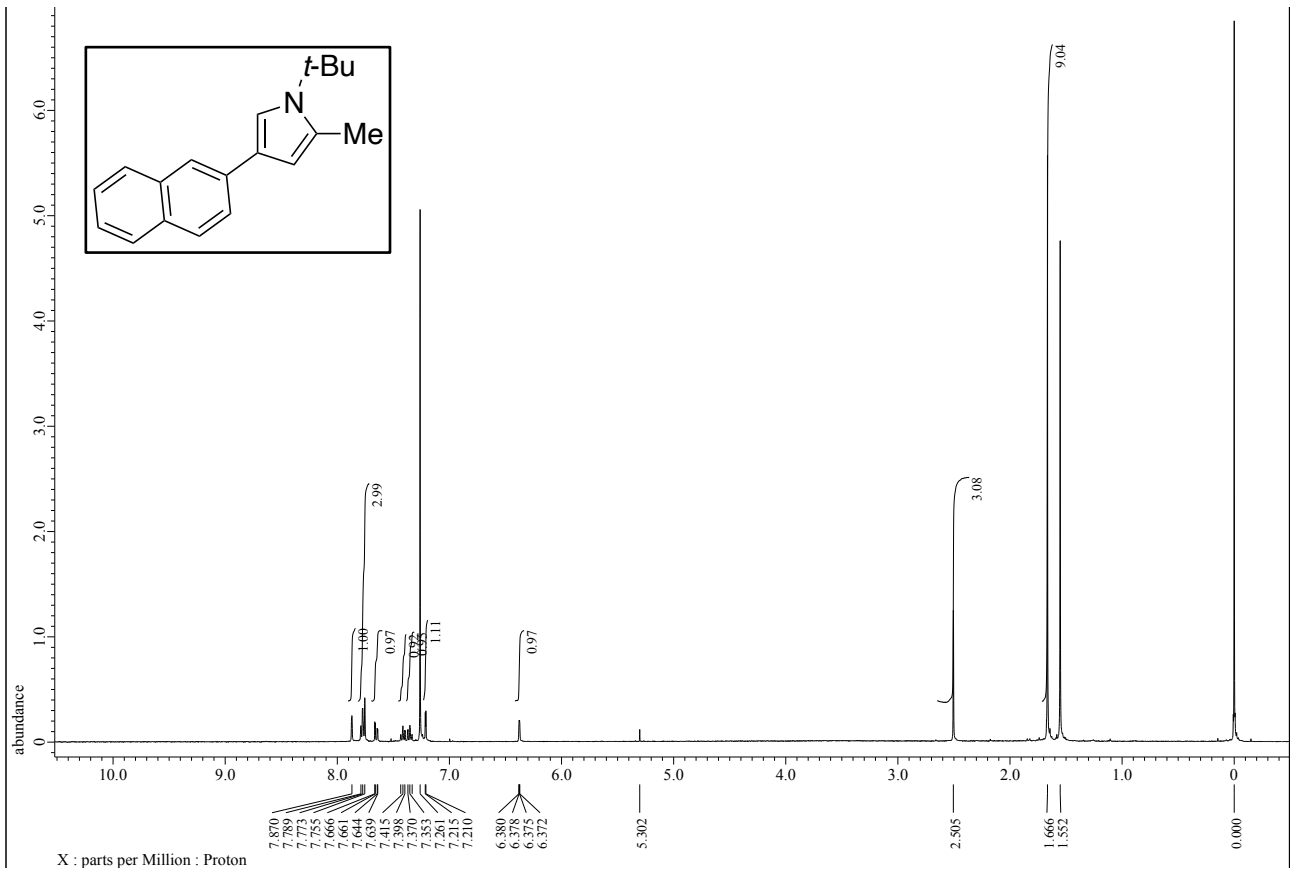


Figure S48. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **3ia**.

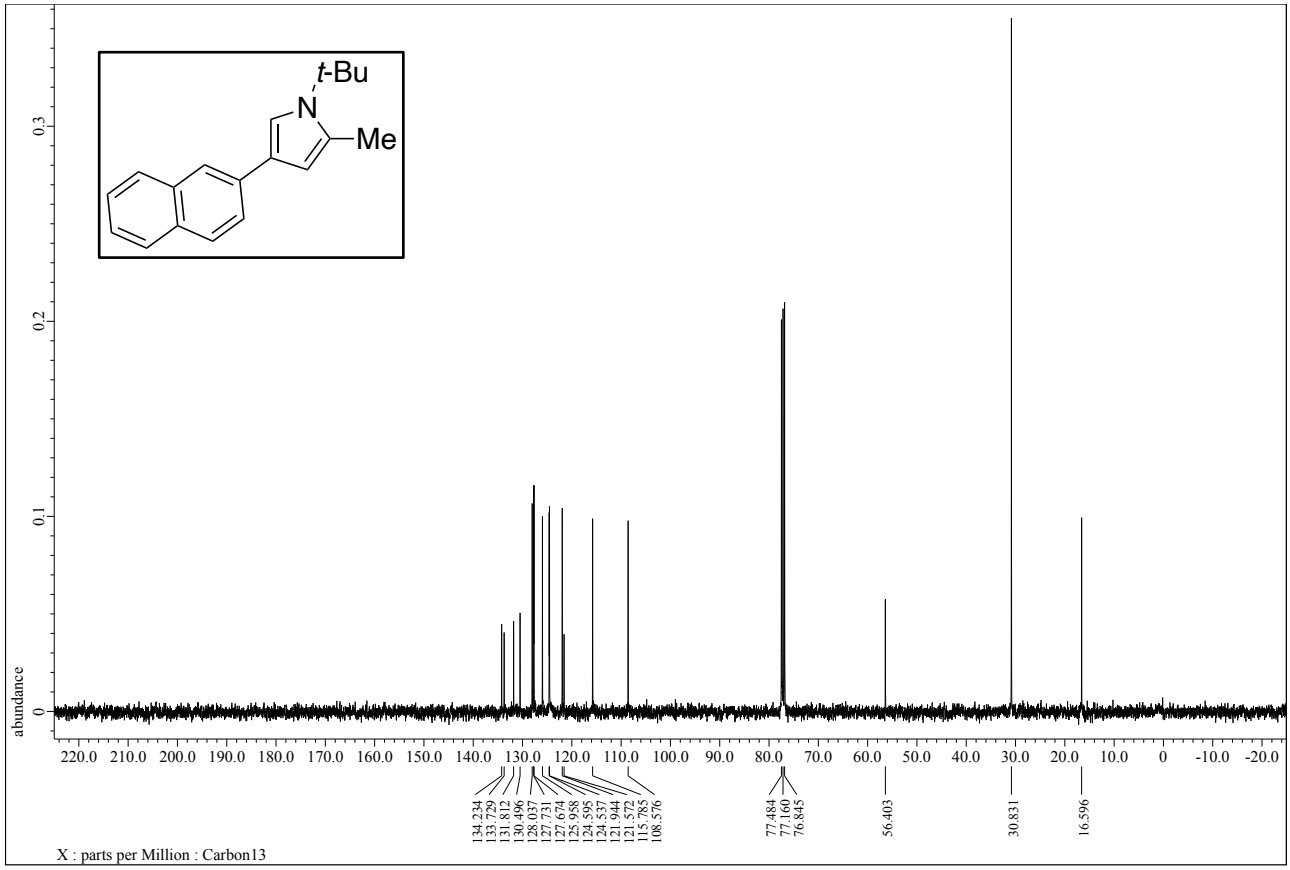


Figure S49. ^{13}C NMR (100.5 MHz, $CDCl_3$) spectrum of **3ia**.

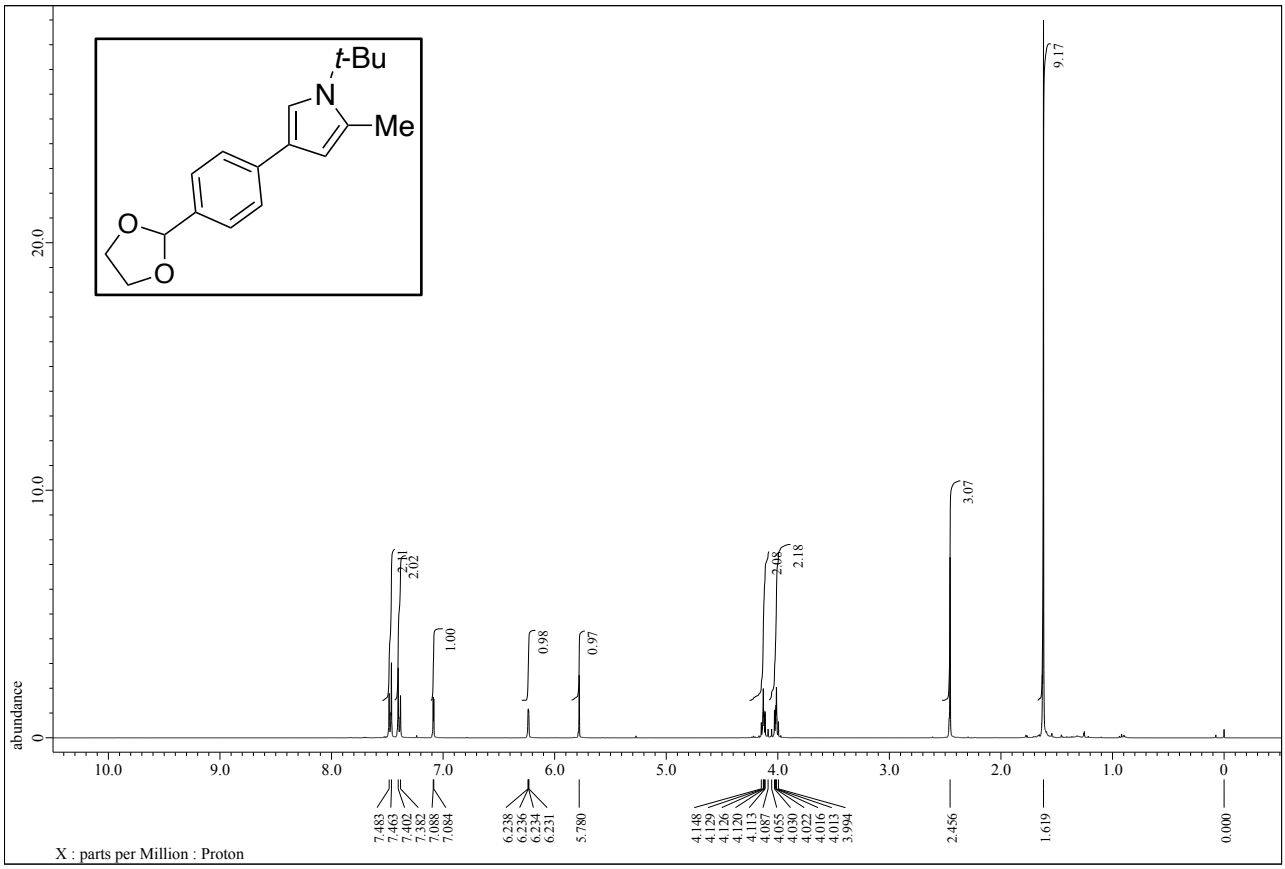


Figure S50. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **3ja**.

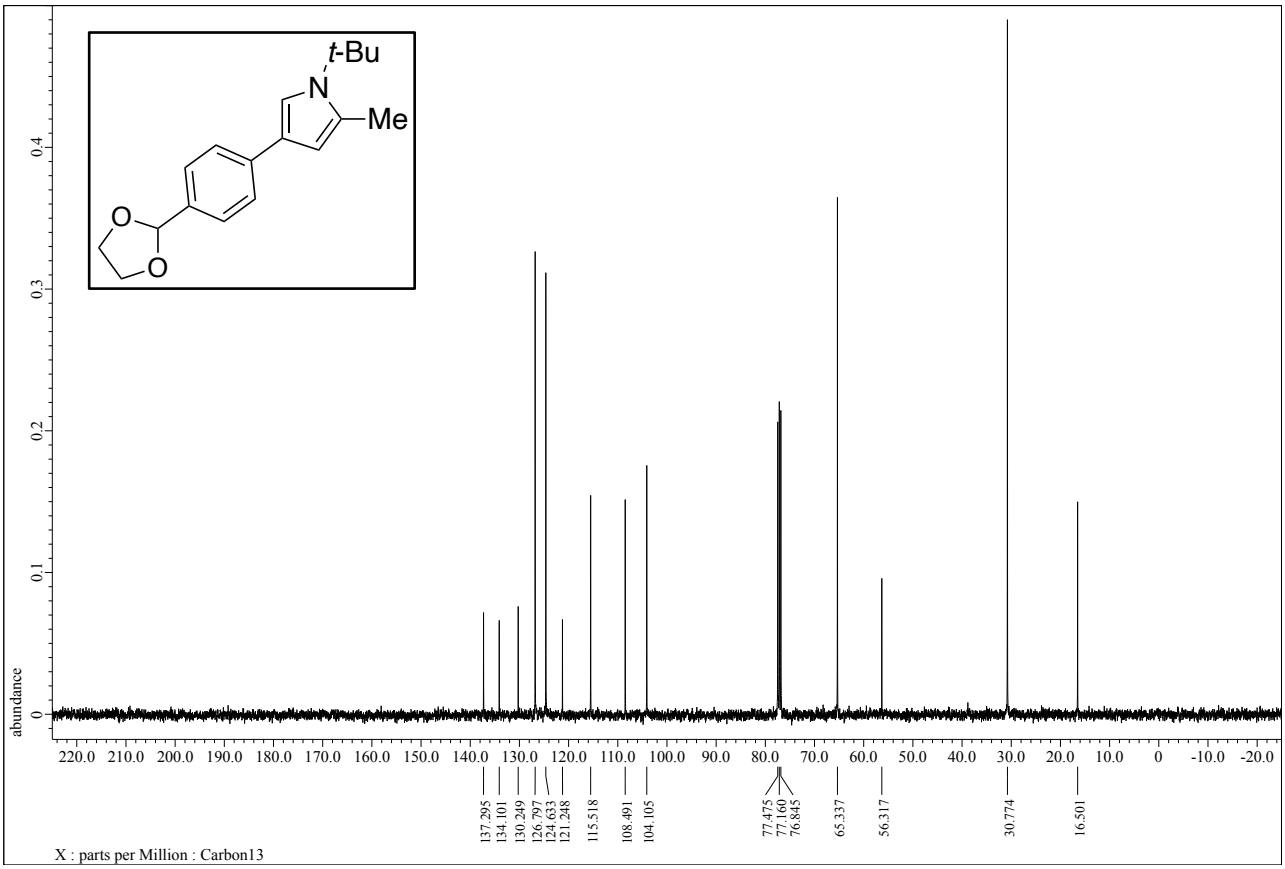


Figure S51. ^{13}C NMR (100.5 MHz, $CDCl_3$) spectrum of **3ja**.

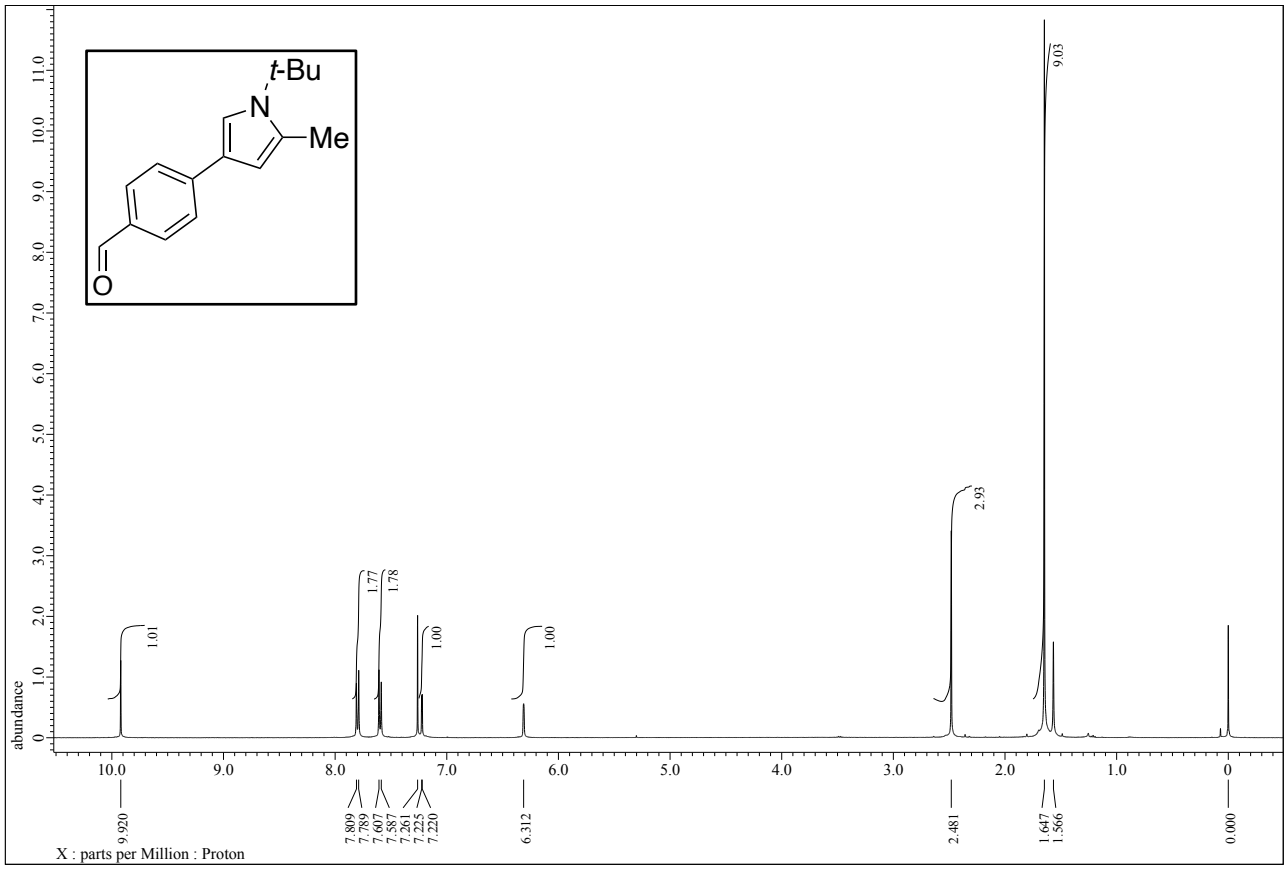


Figure S52. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **6ja**.

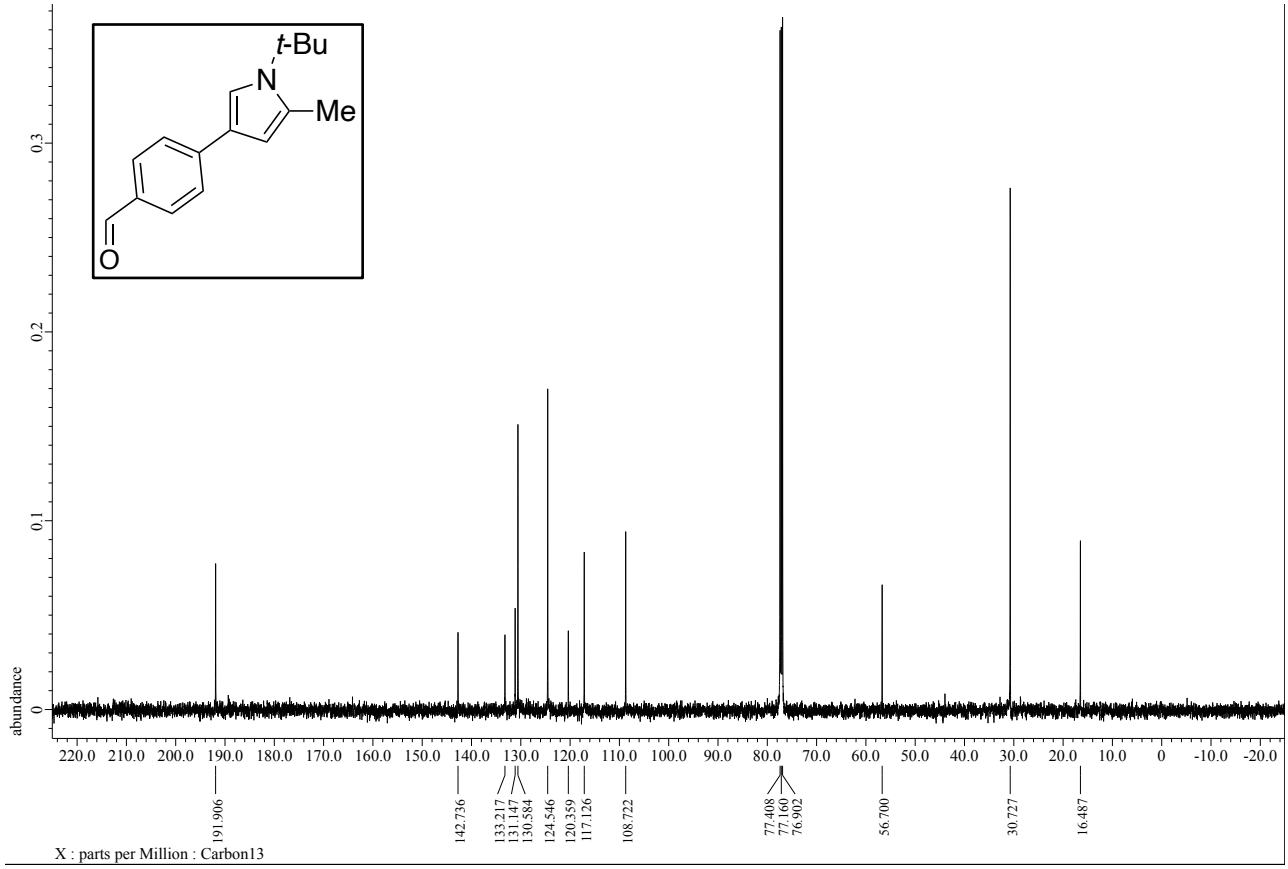


Figure S53. ^{13}C NMR (125.8 MHz, $CDCl_3$) spectrum of **6ja**.

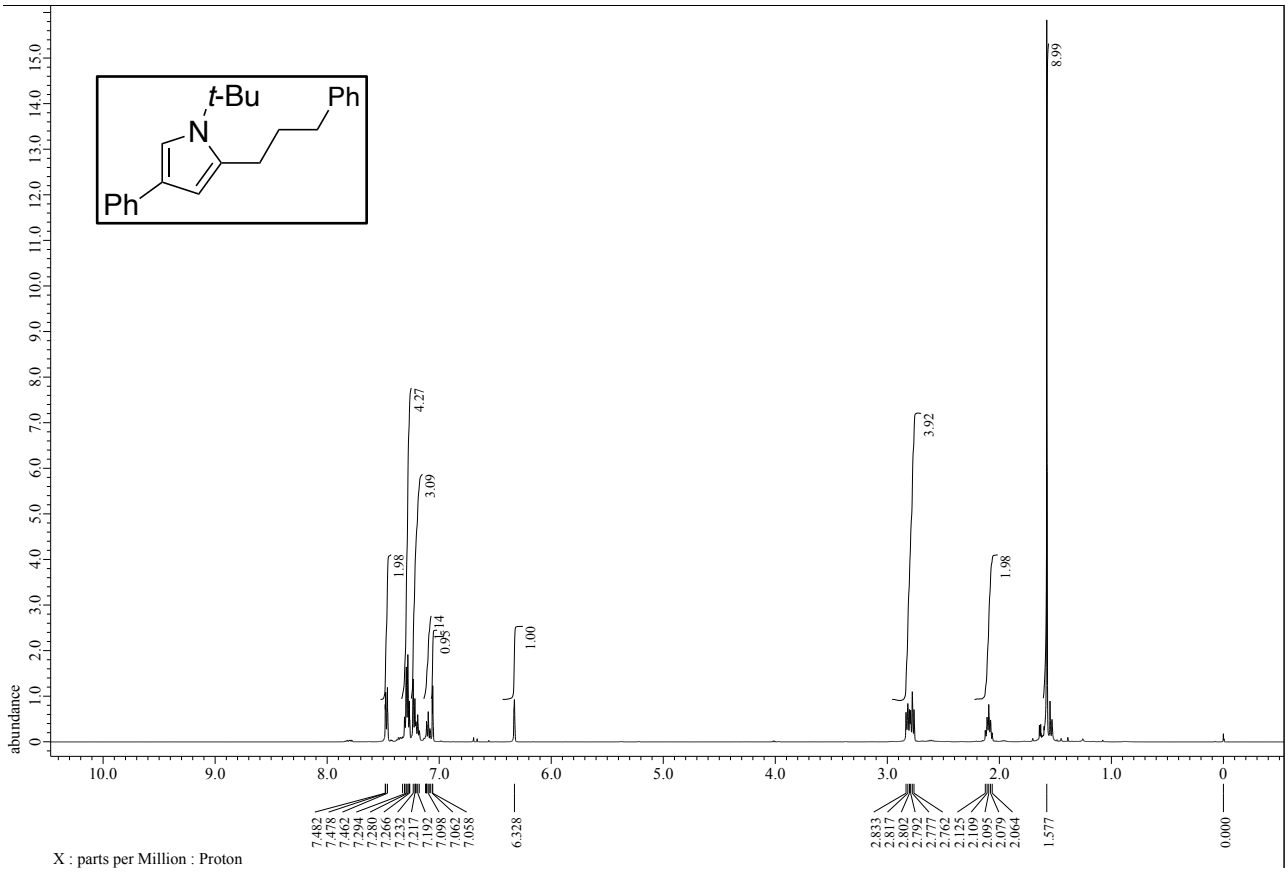


Figure S54. ^{1}H NMR (500 MHz, $CDCl_3$) spectrum of **3ka**.

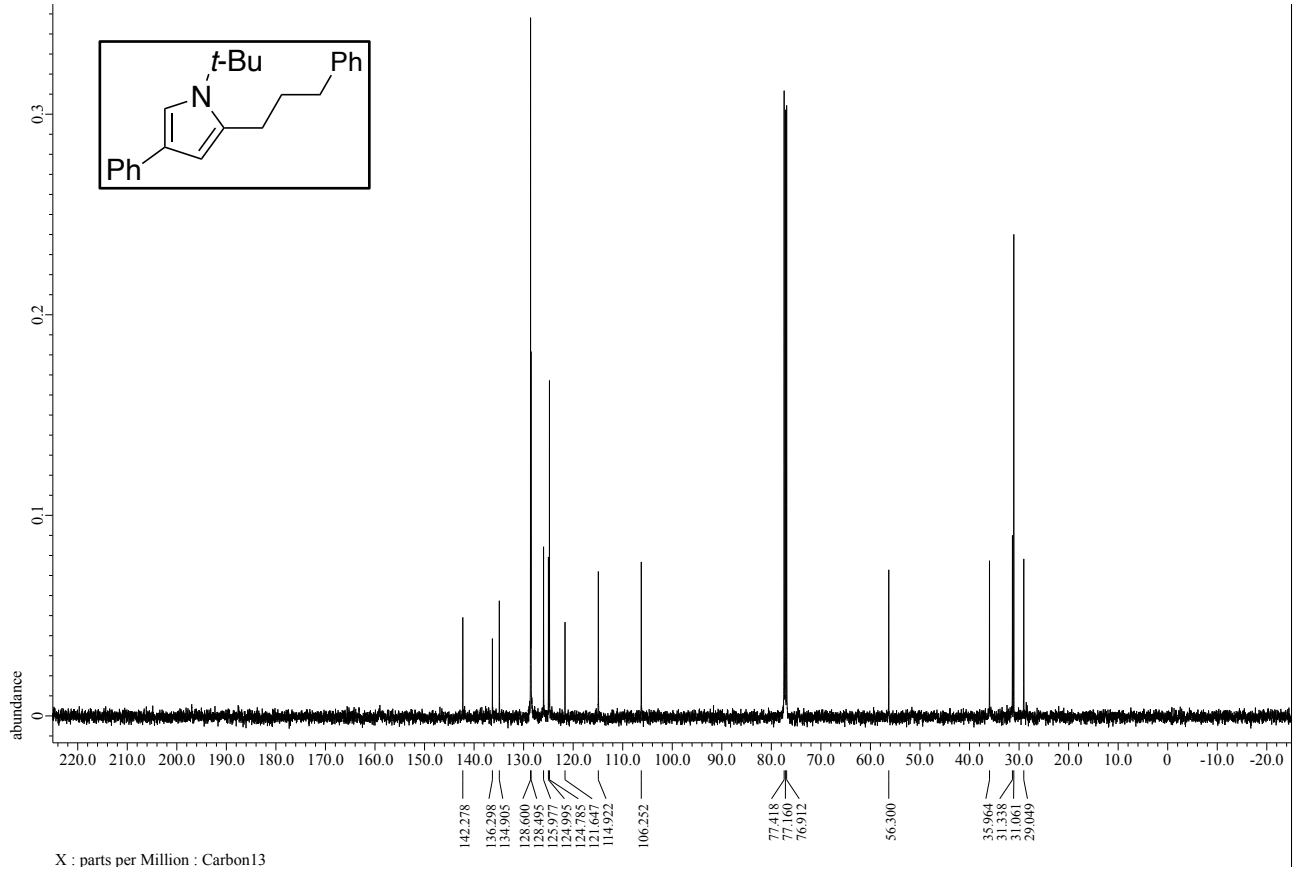


Figure S55. ^{13}C NMR (125.8 MHz, $CDCl_3$) spectrum of **3ka**.

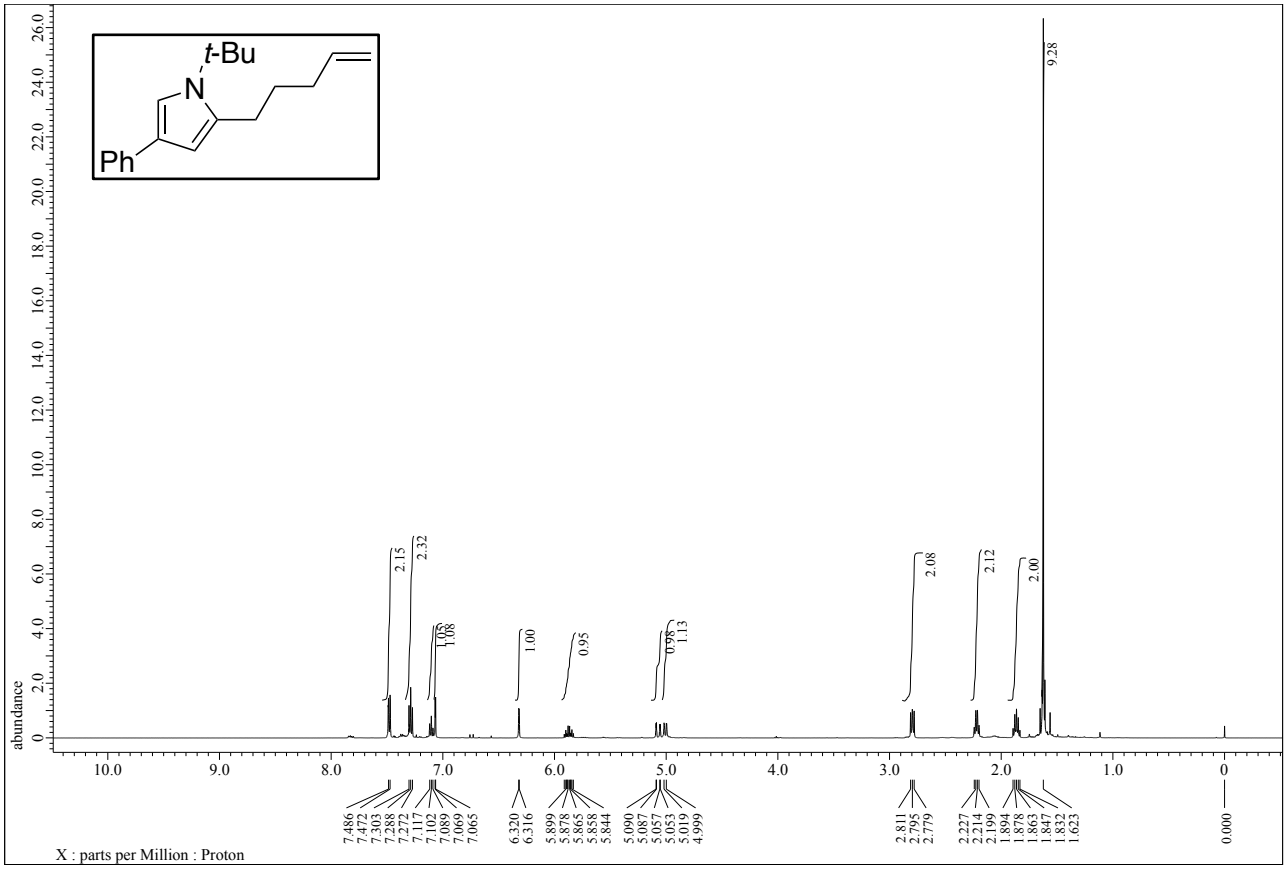


Figure S56. ^{1}H NMR (500 MHz, $CDCl_3$) spectrum of **3la**.

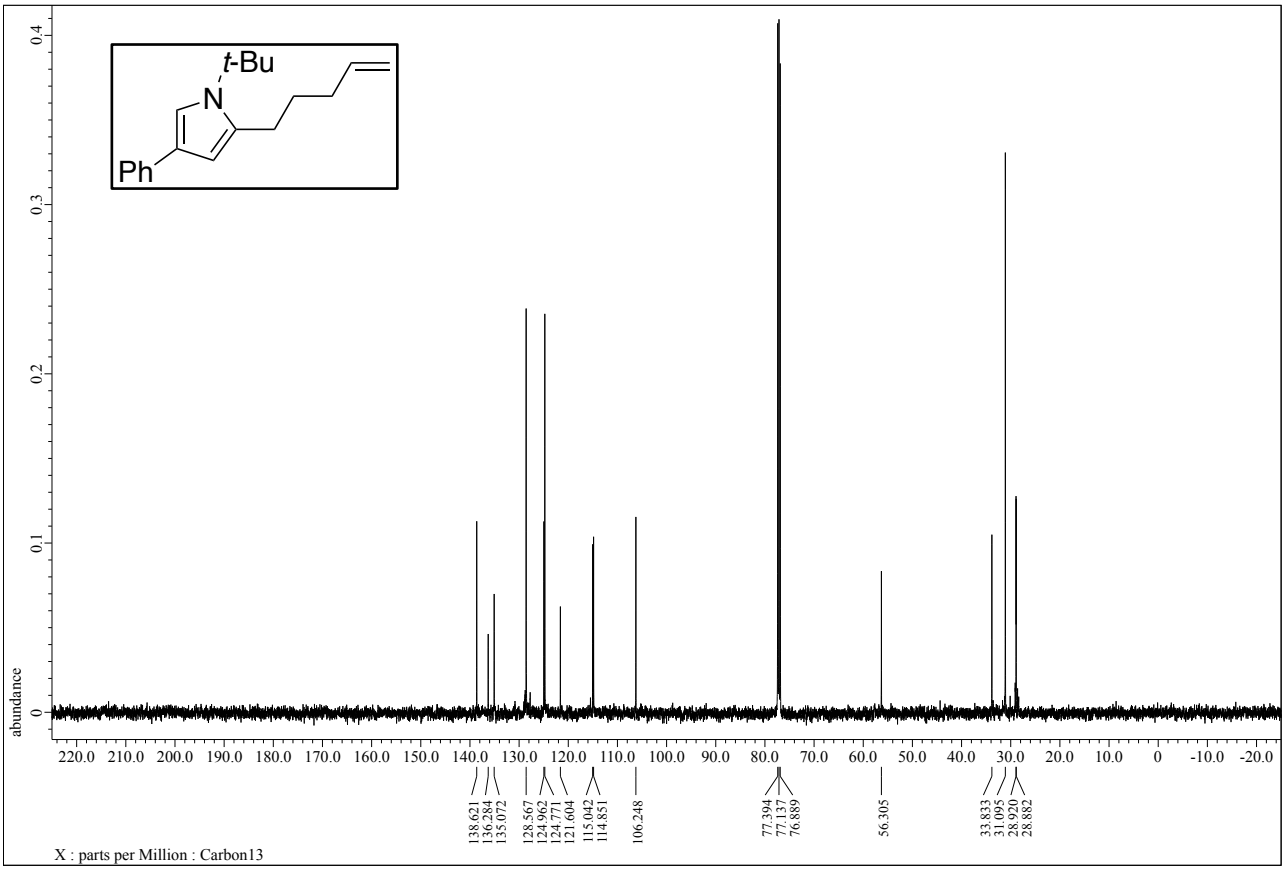


Figure S57. ^{13}C NMR (125.8 MHz, $CDCl_3$) spectrum of **3la**.

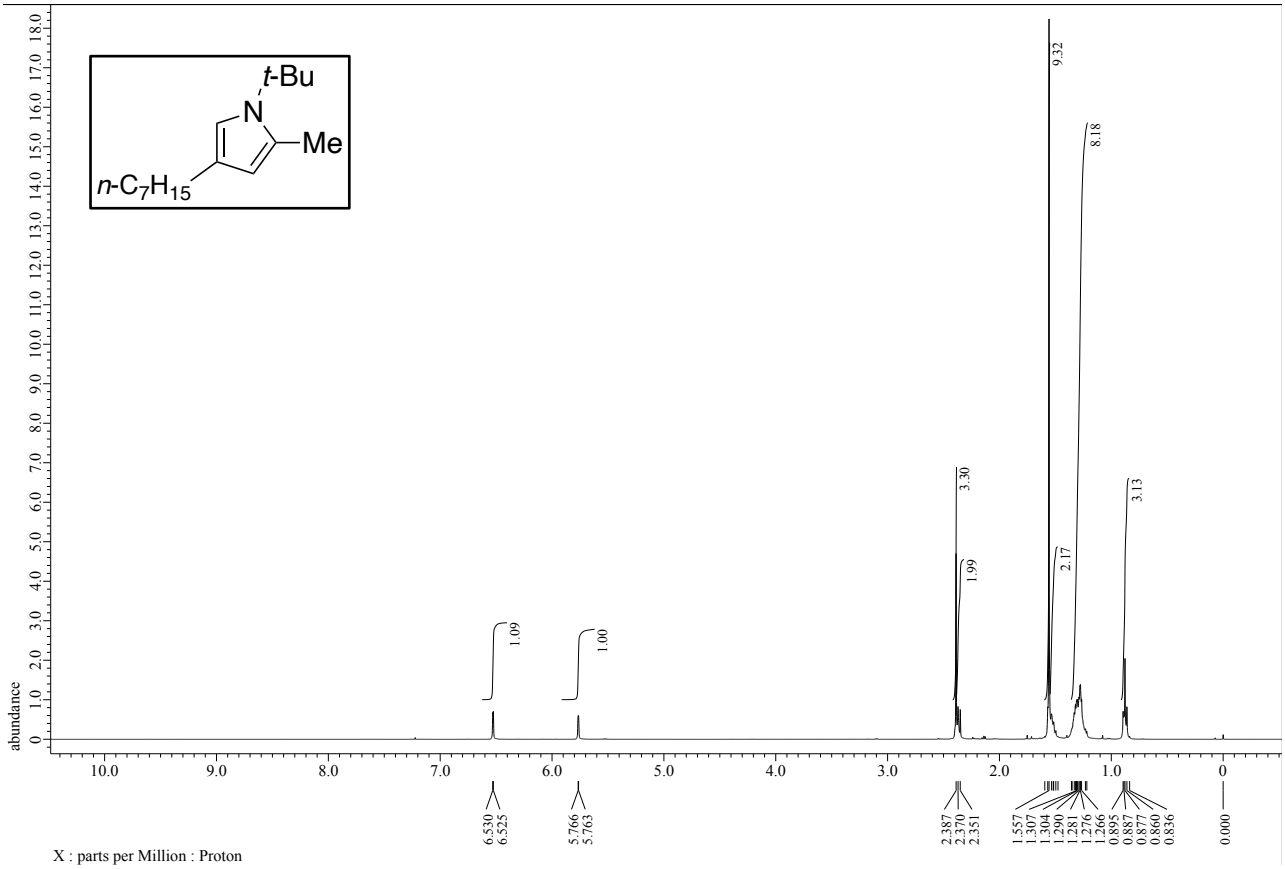


Figure S58. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **3ma**.

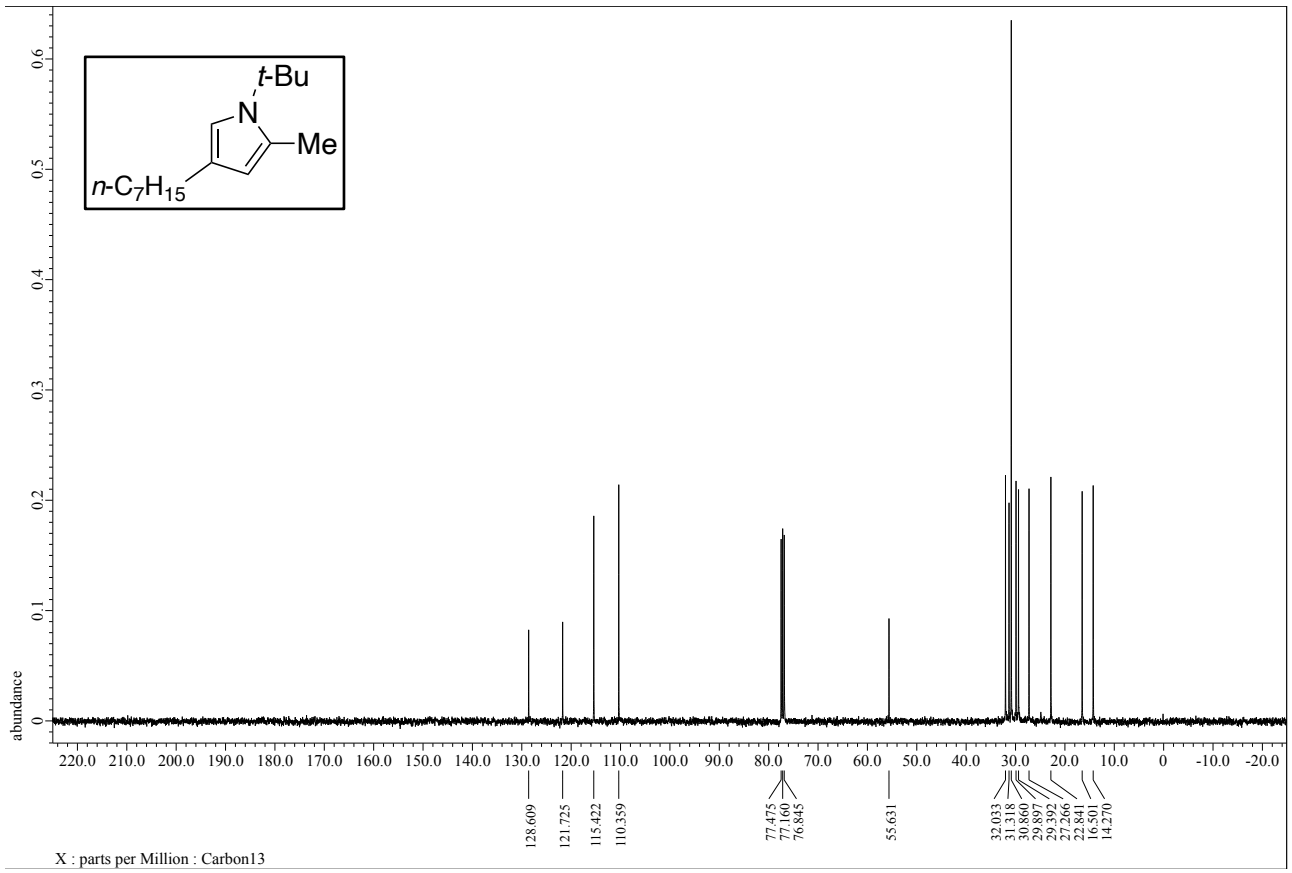


Figure S59. ^{13}C NMR (100.5 MHz, $CDCl_3$) spectrum of **3ma**.

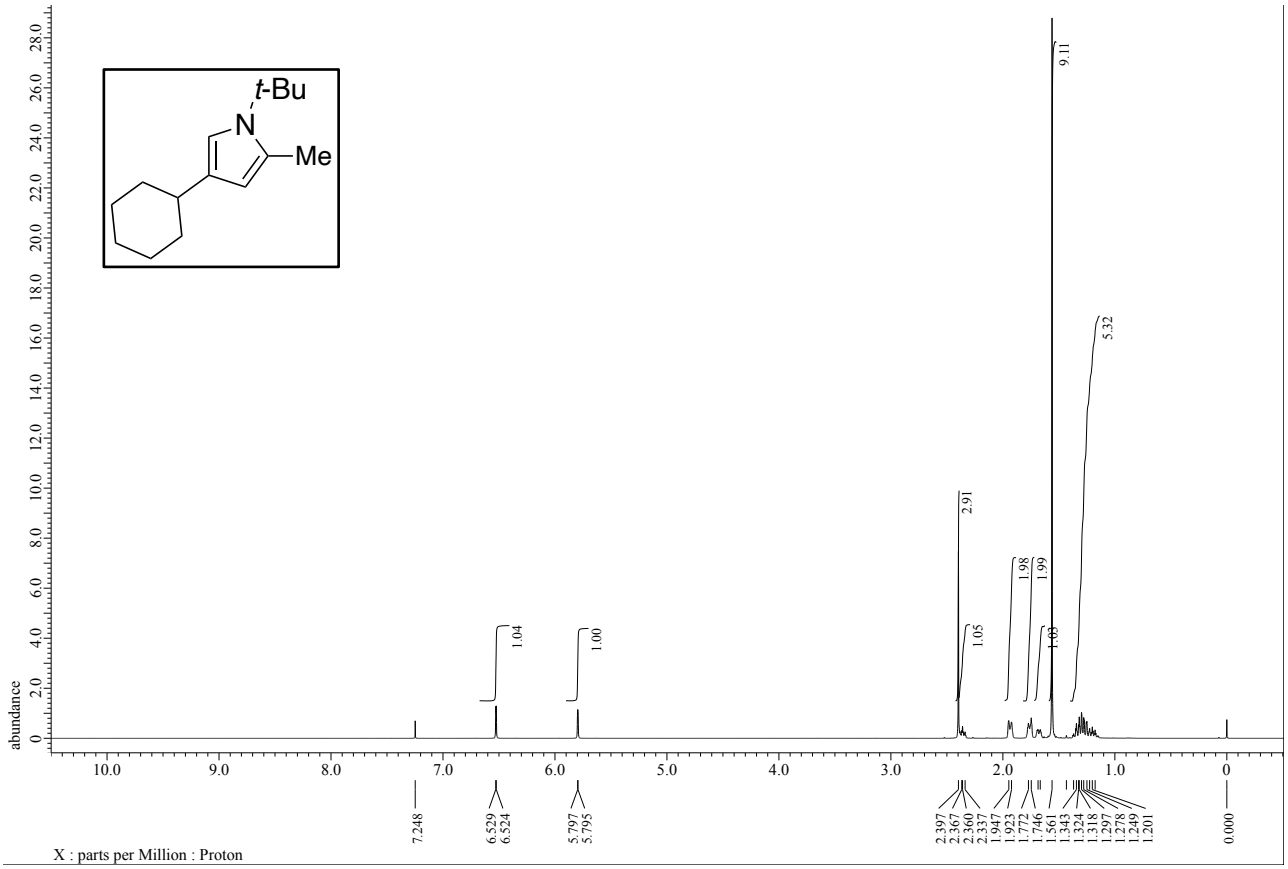


Figure S60. ^{1}H NMR (500 MHz, $CDCl_3$) spectrum of **3na**.

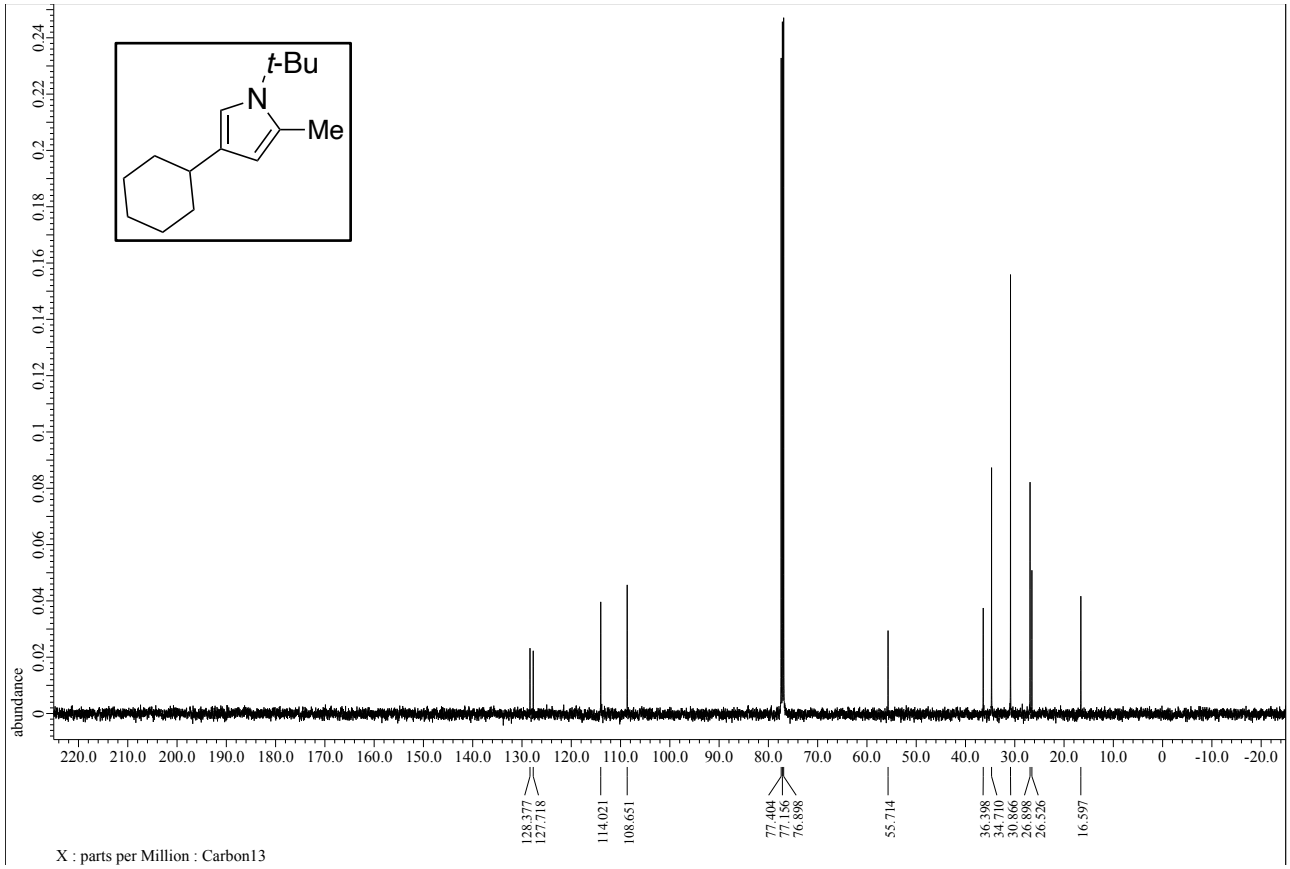


Figure S61. ^{13}C NMR (125.8 MHz, $CDCl_3$) spectrum of **3na**.

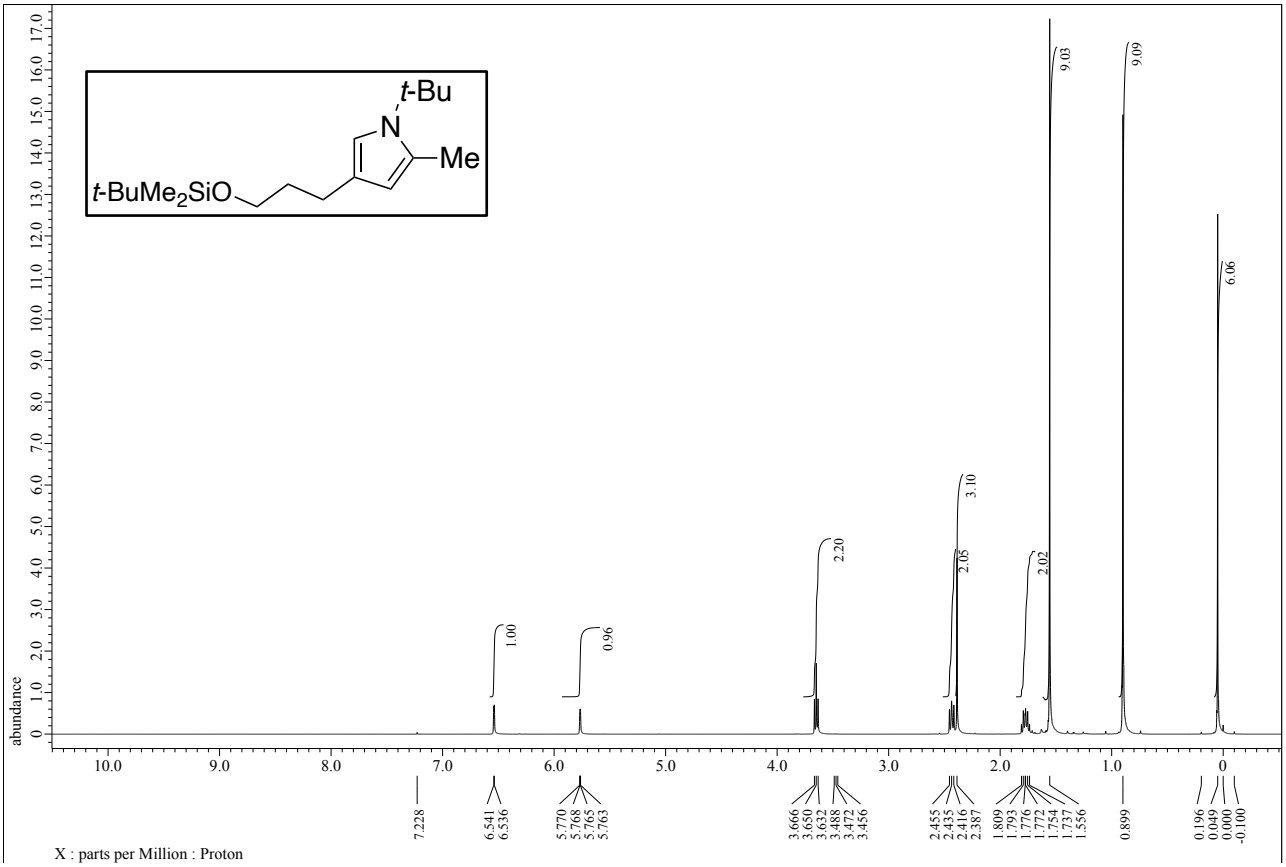


Figure S62. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **3oa**.

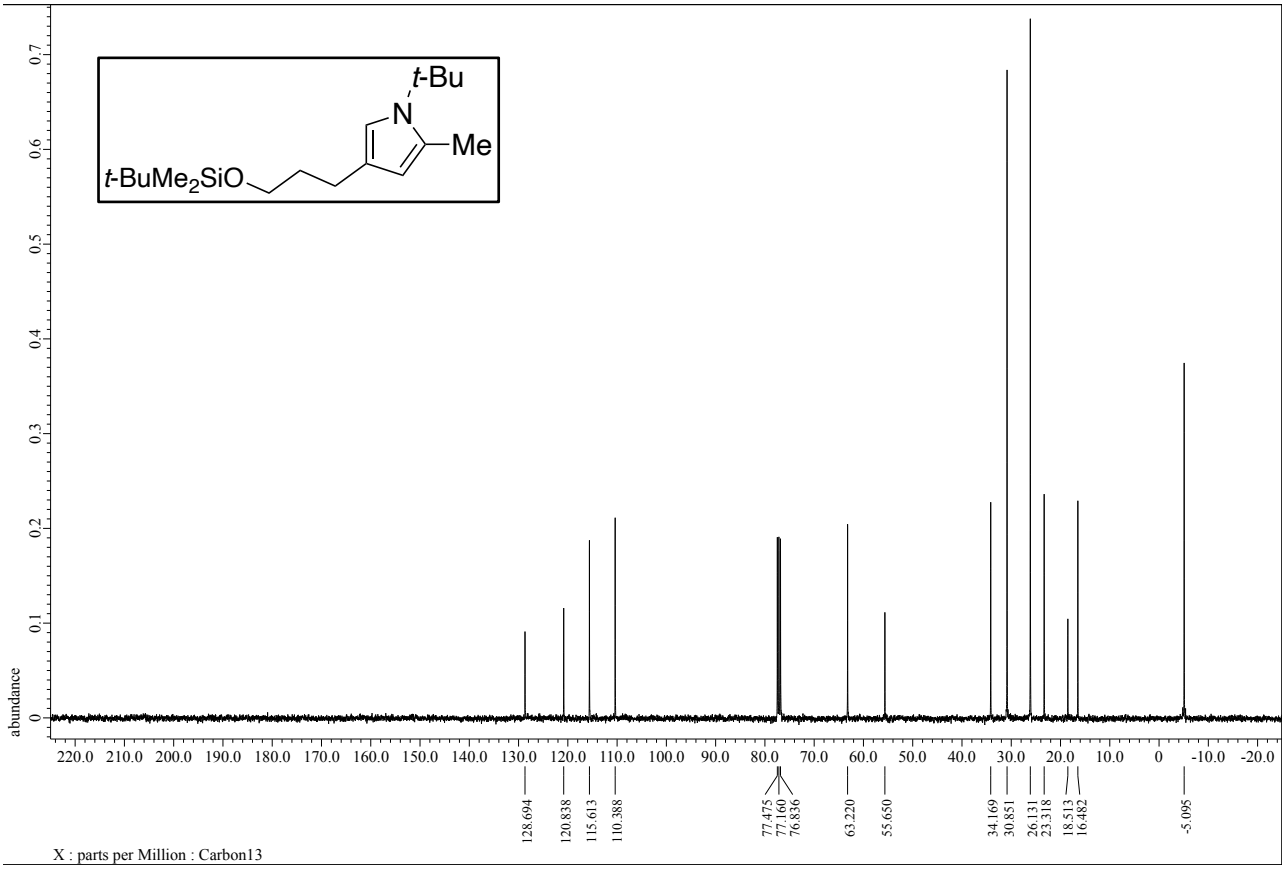


Figure S63. ^{13}C NMR (100.5 MHz, $CDCl_3$) spectrum of **3oa**.

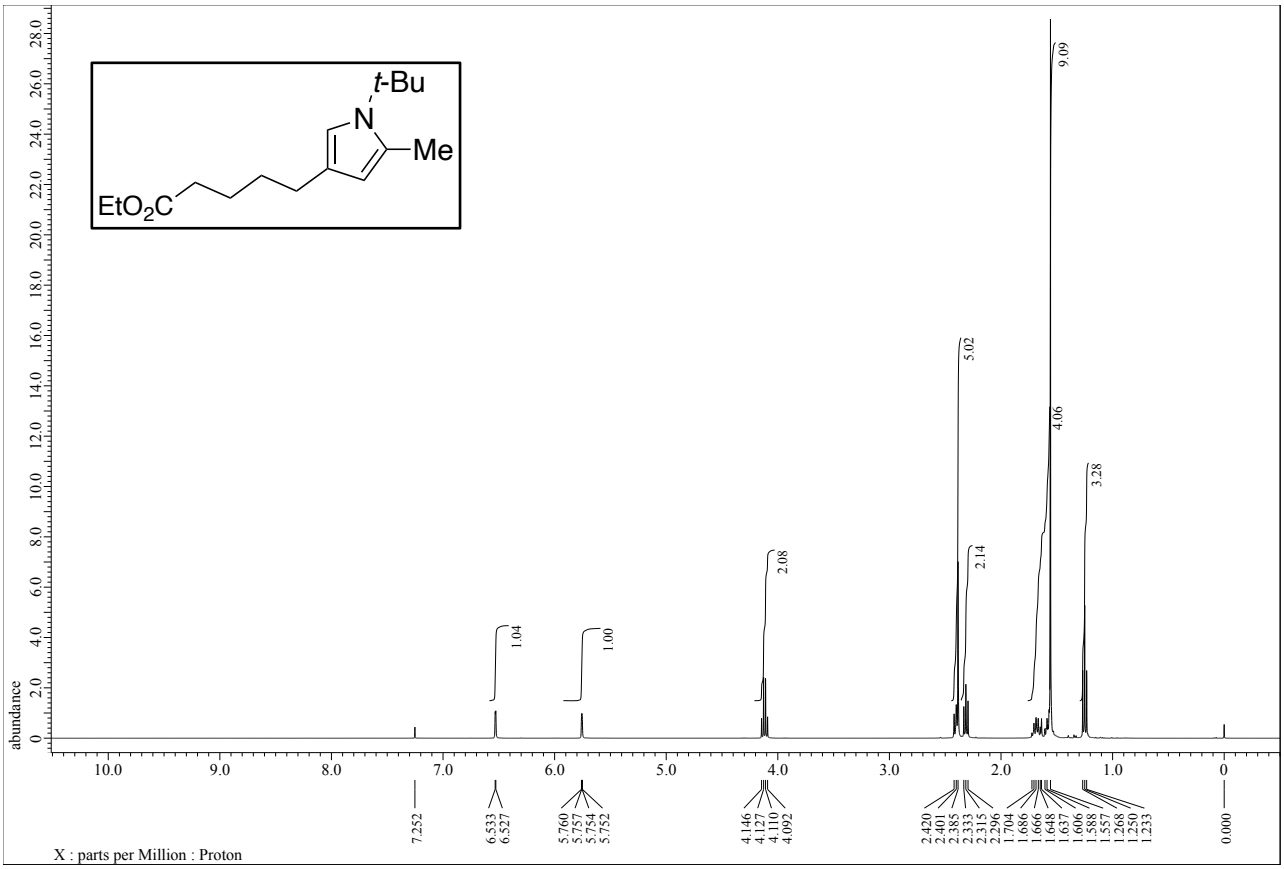


Figure S64. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **3pa**.

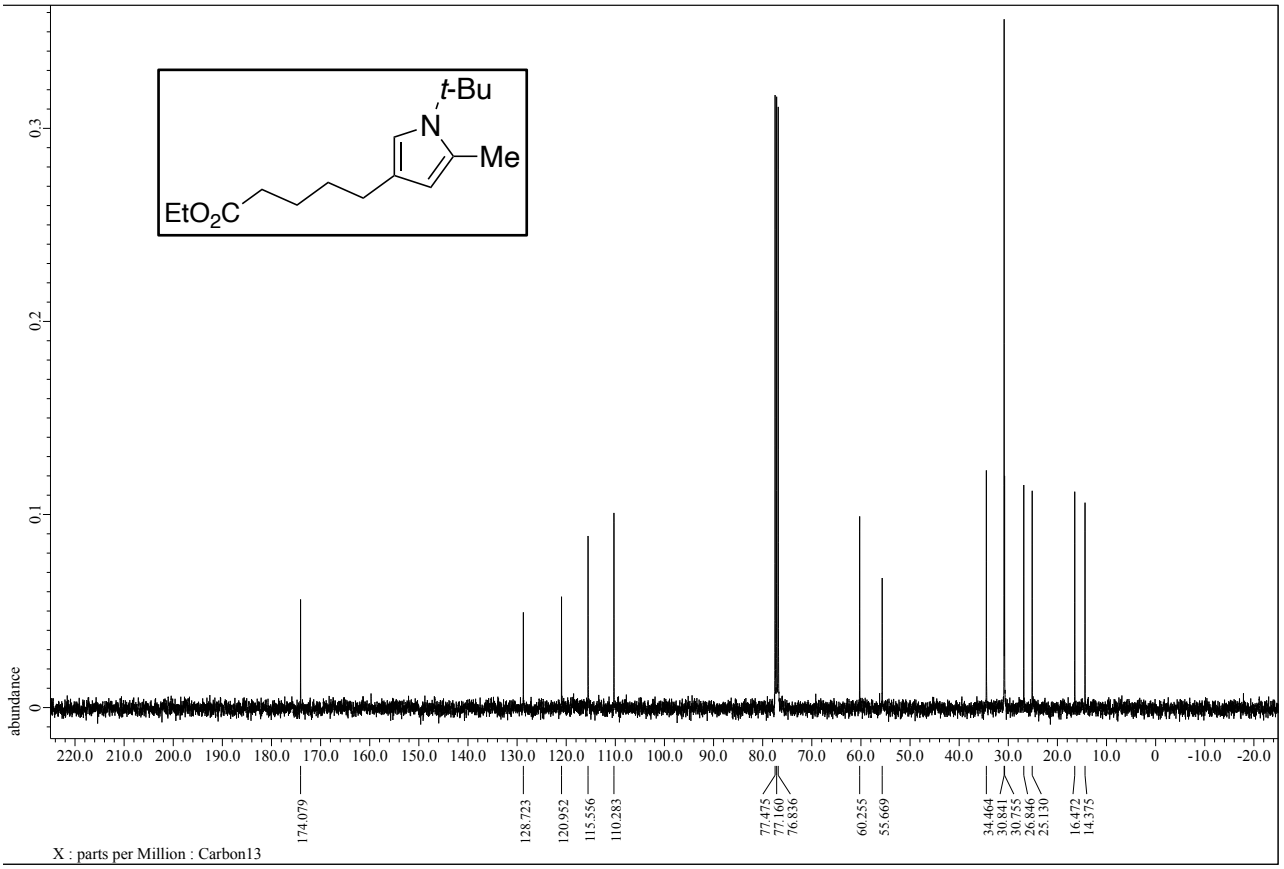


Figure S65. ^{13}C NMR (100.5 MHz, $CDCl_3$) spectrum of **3pa**.

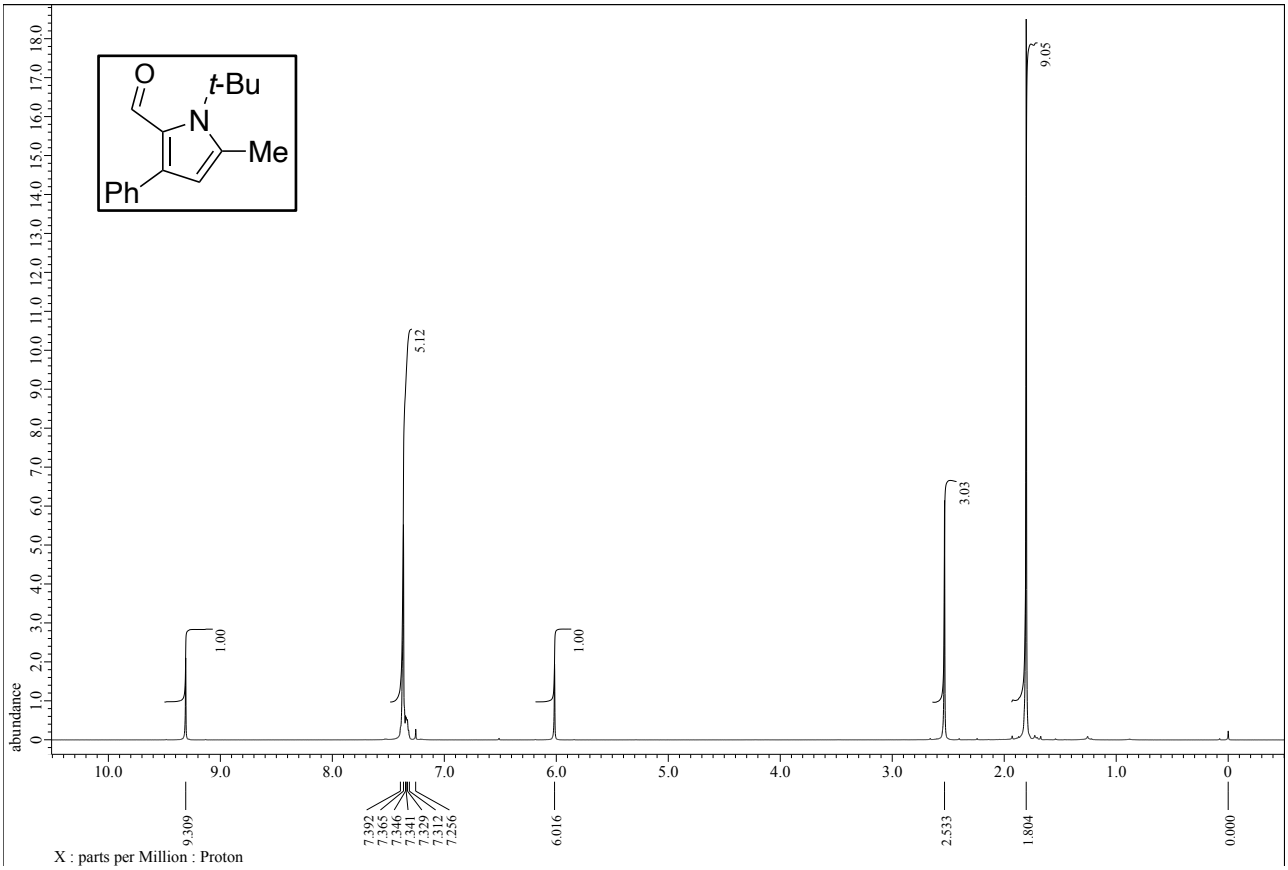


Figure S66. ^{1}H NMR (500 MHz, $CDCl_3$) spectrum of **5aa**.

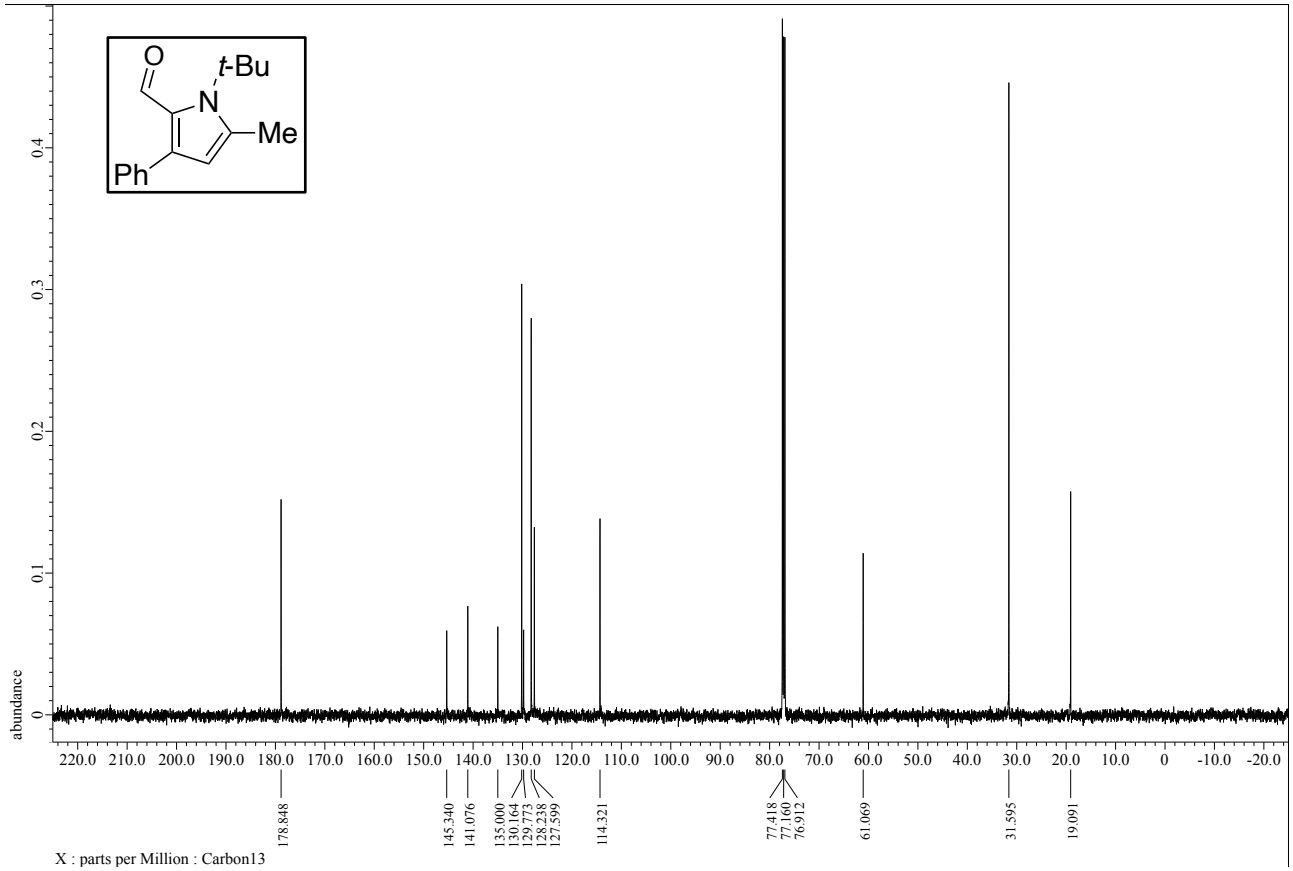


Figure S67. ^{13}C NMR (125.8 MHz, $CDCl_3$) spectrum of **5aa**.

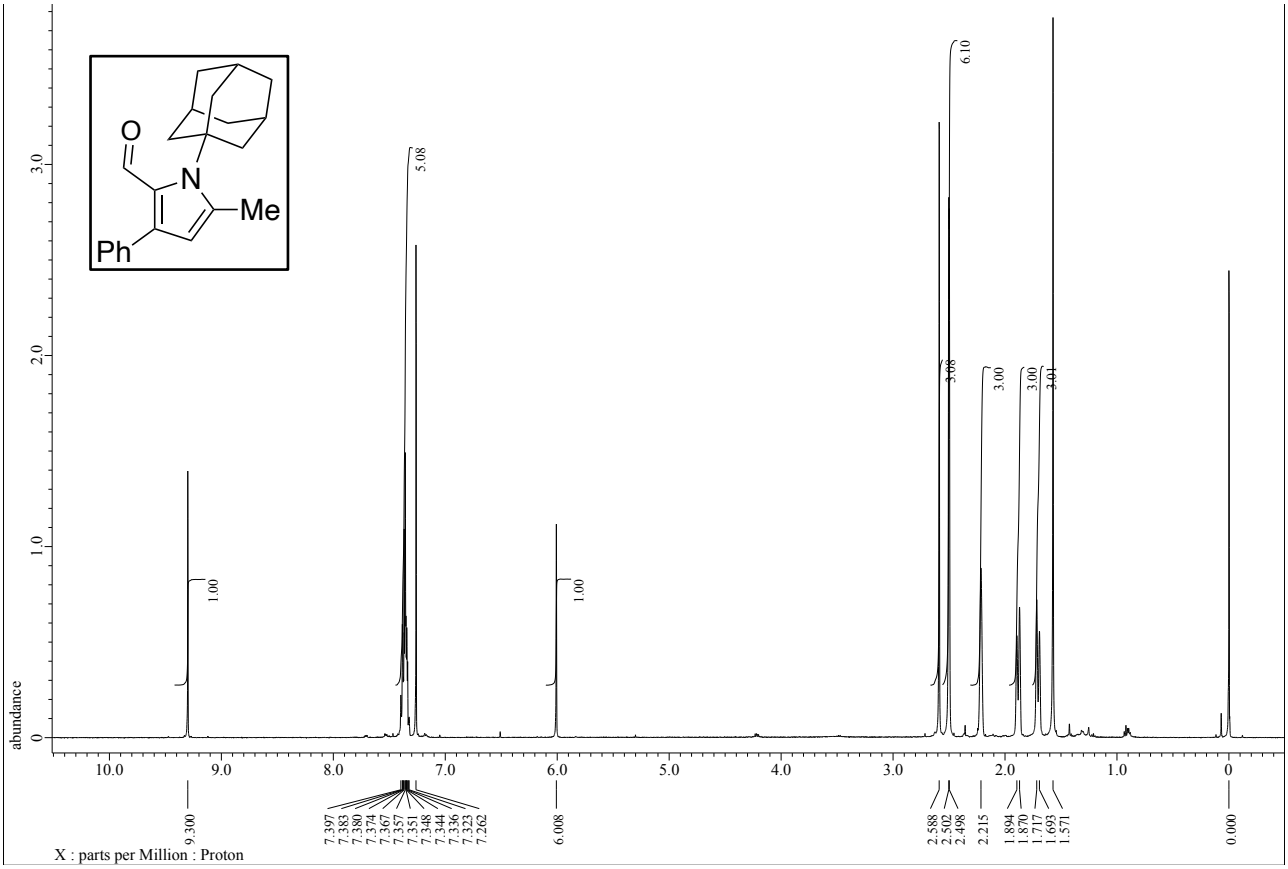


Figure S68. ^{1}H NMR (500 MHz, $CDCl_3$) spectrum of **5ab**.

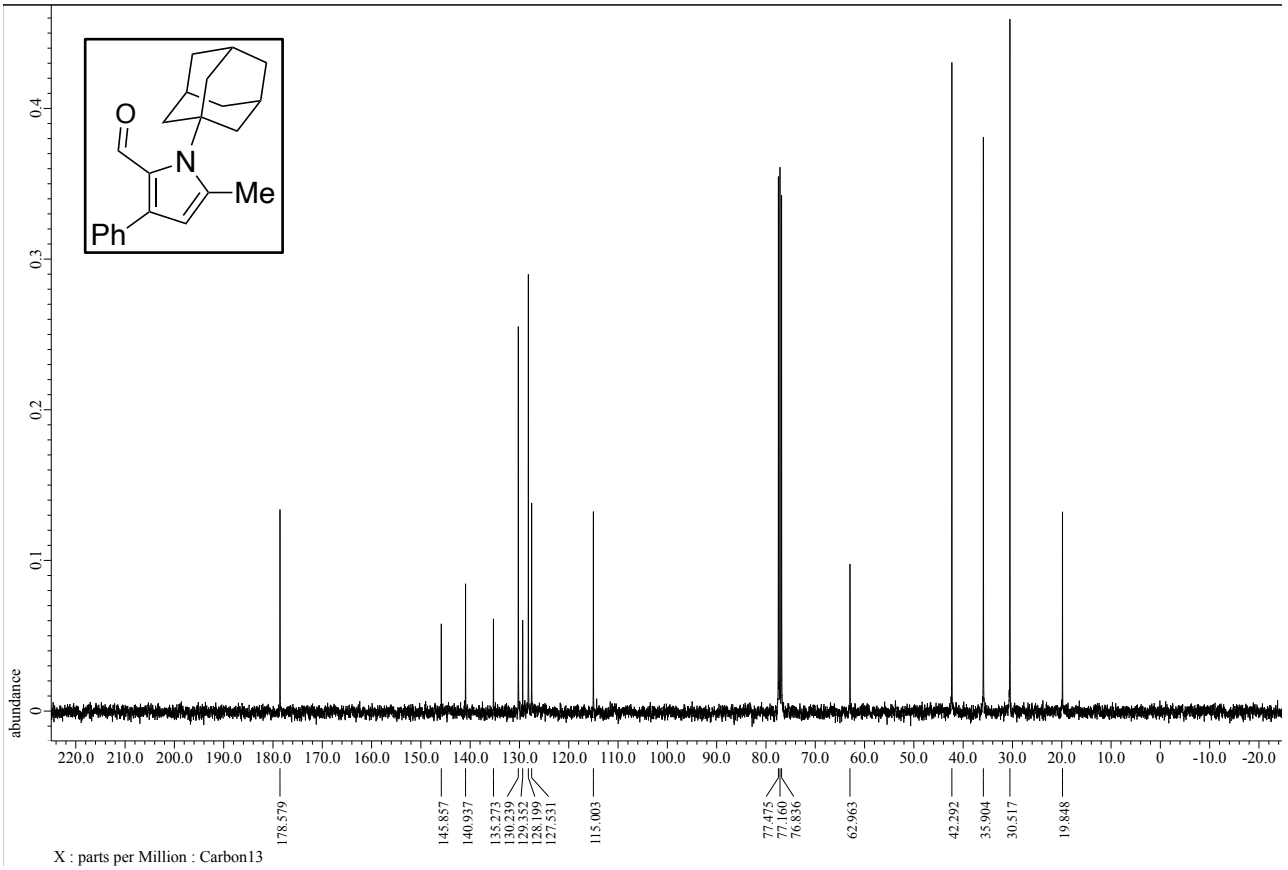


Figure S69. ^{13}C NMR (100.5 MHz, $CDCl_3$) spectrum of **5ab**.

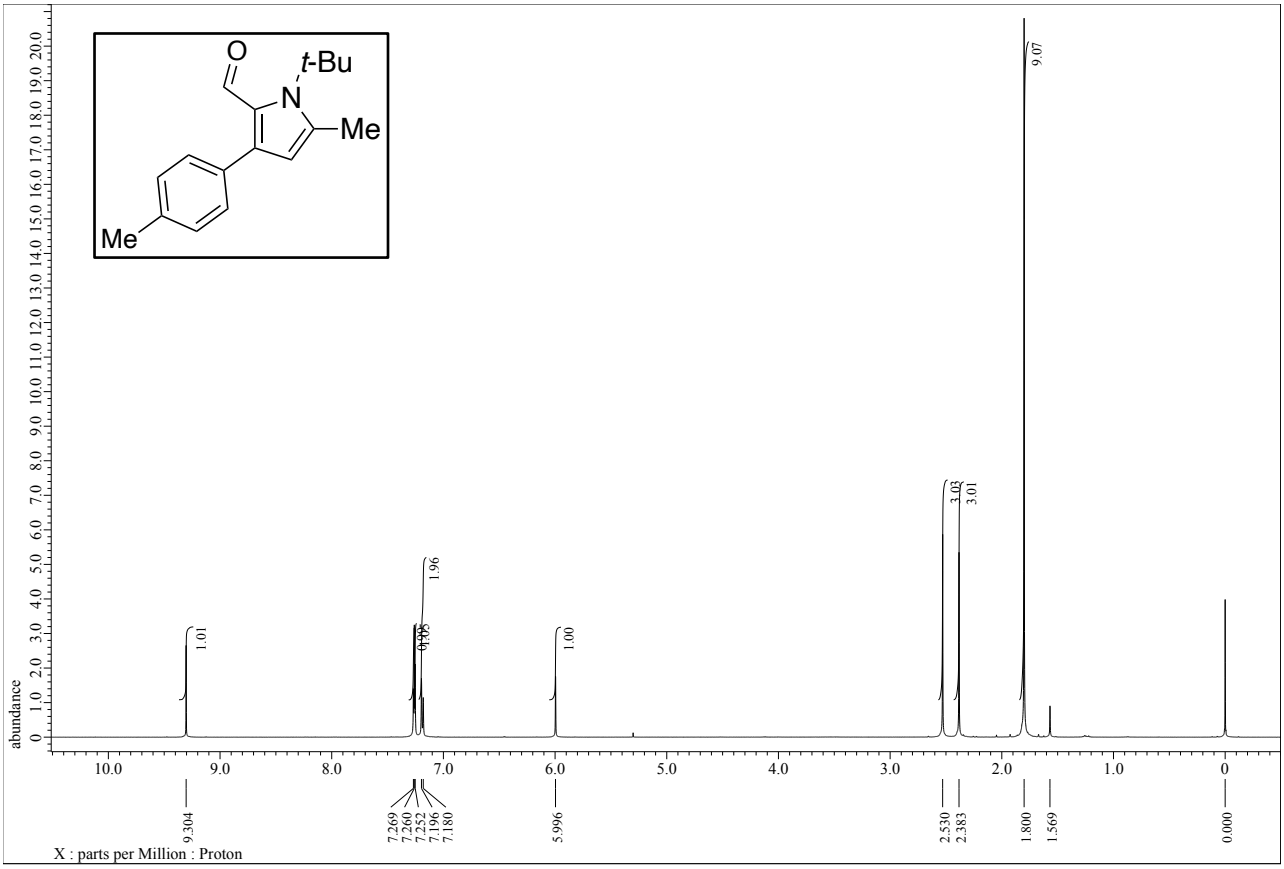


Figure S70. ^{1}H NMR (500 MHz, $CDCl_3$) spectrum of **5ba**.

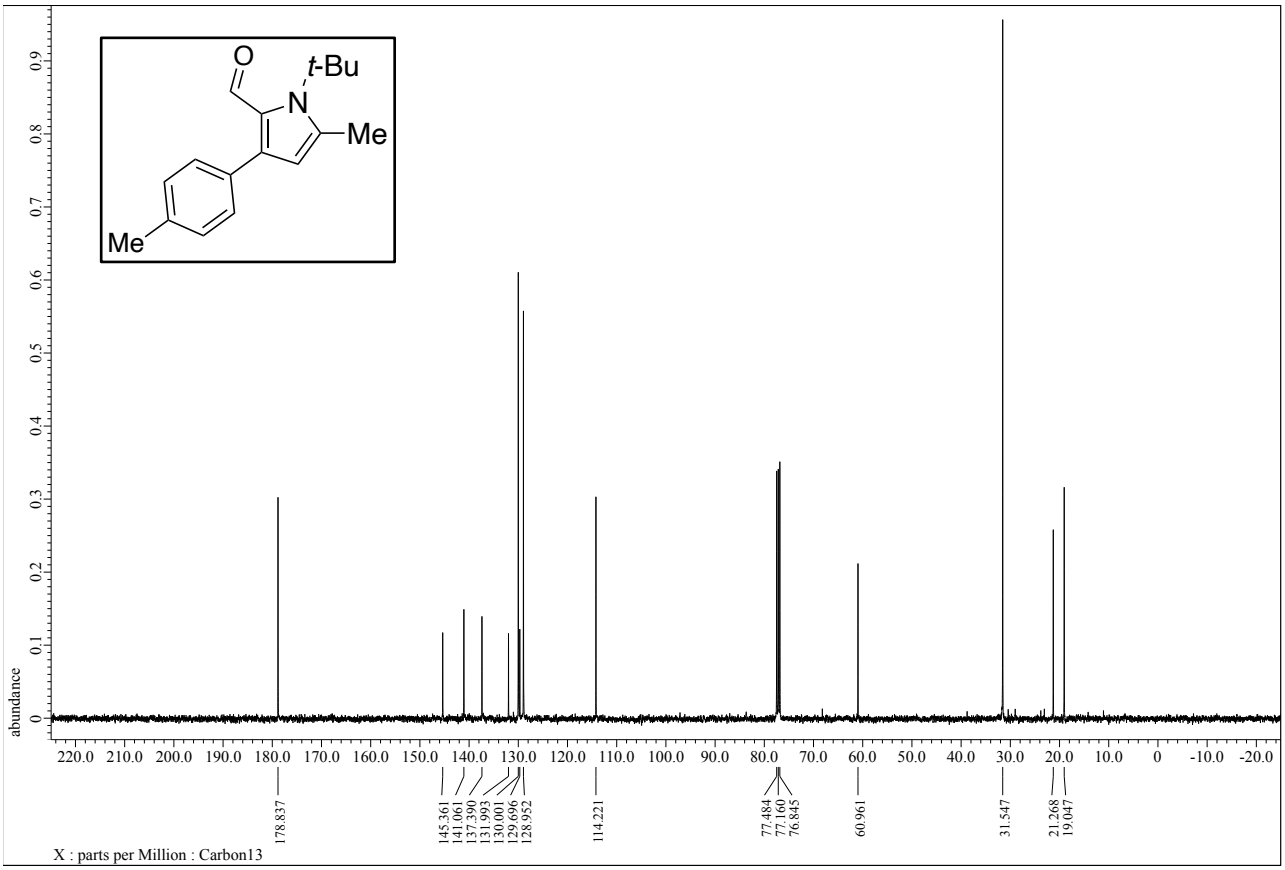


Figure S71. ^{13}C NMR (100.5 MHz, $CDCl_3$) spectrum of **5ba**.

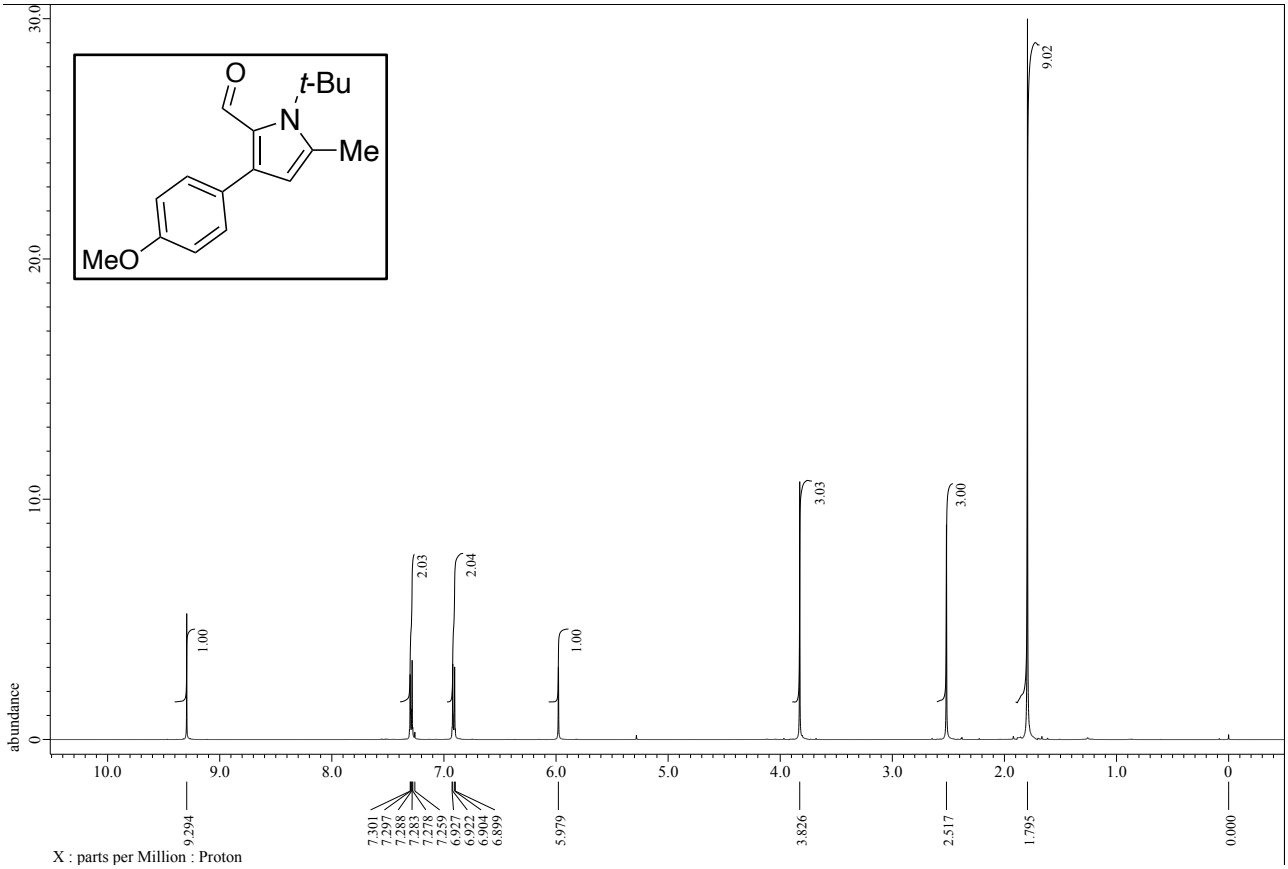


Figure S72. ^{1}H NMR (500 MHz, $CDCl_3$) spectrum of **5ca**.

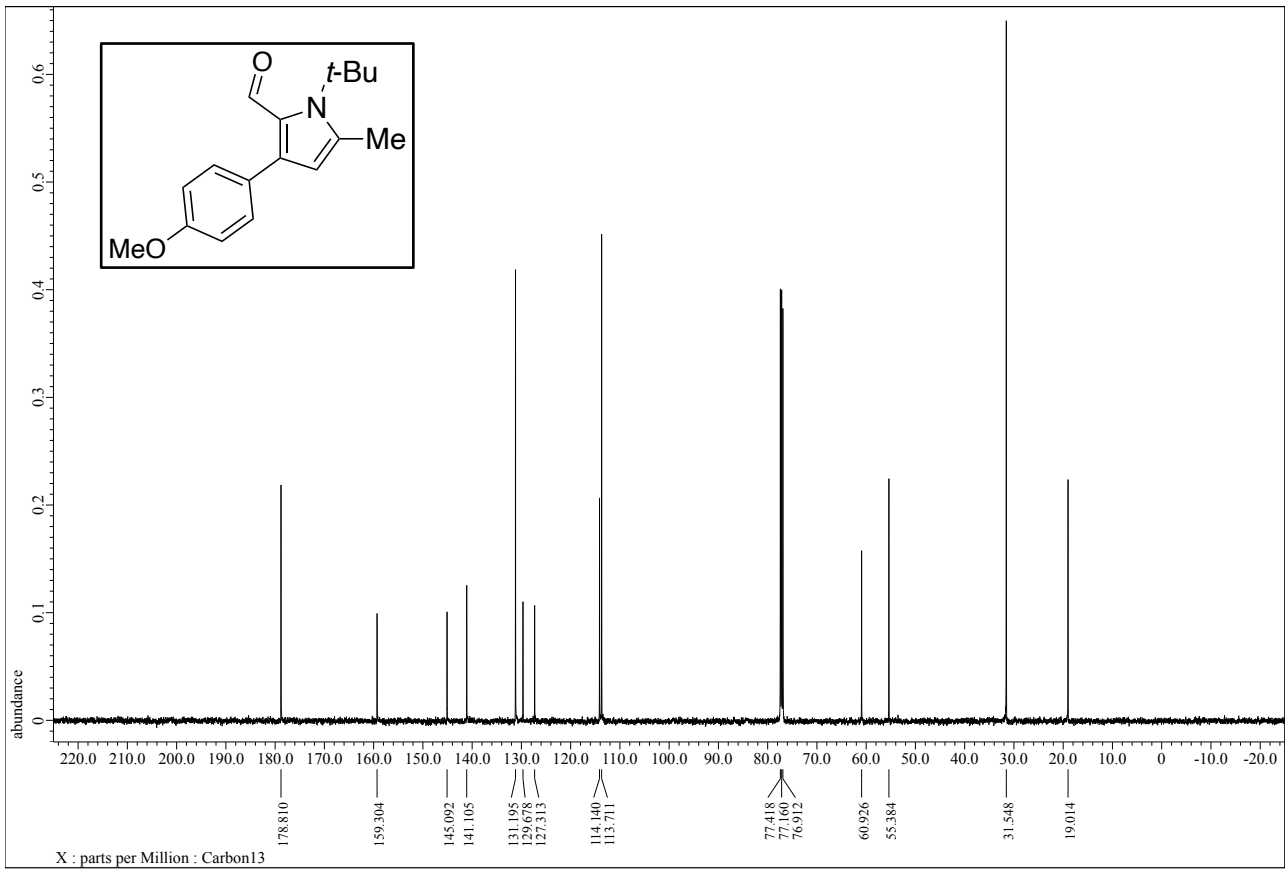


Figure S73. ^{13}C NMR (125.8 MHz, $CDCl_3$) spectrum of **5ca**.

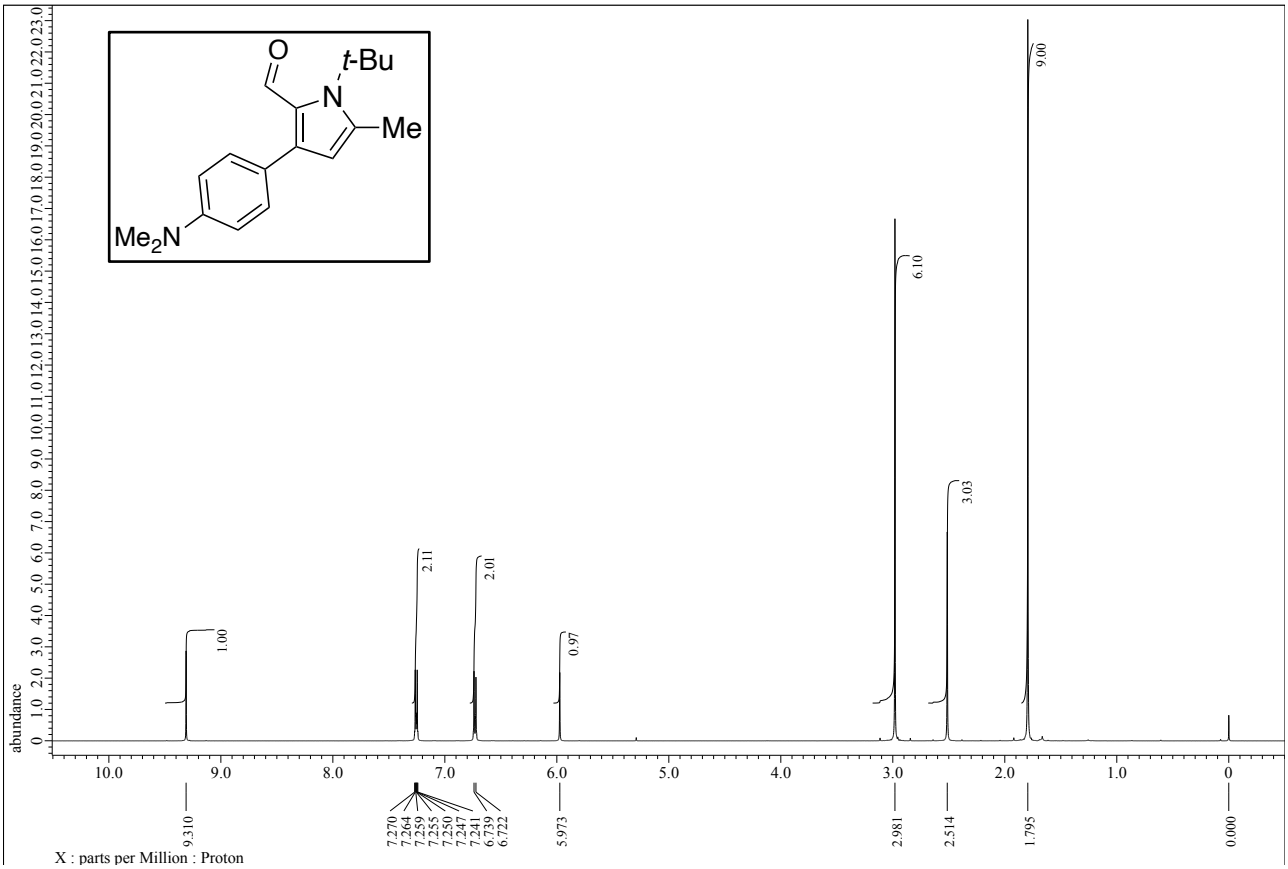


Figure S74. ^{1}H NMR (500 MHz, $CDCl_3$) spectrum of **5da**.

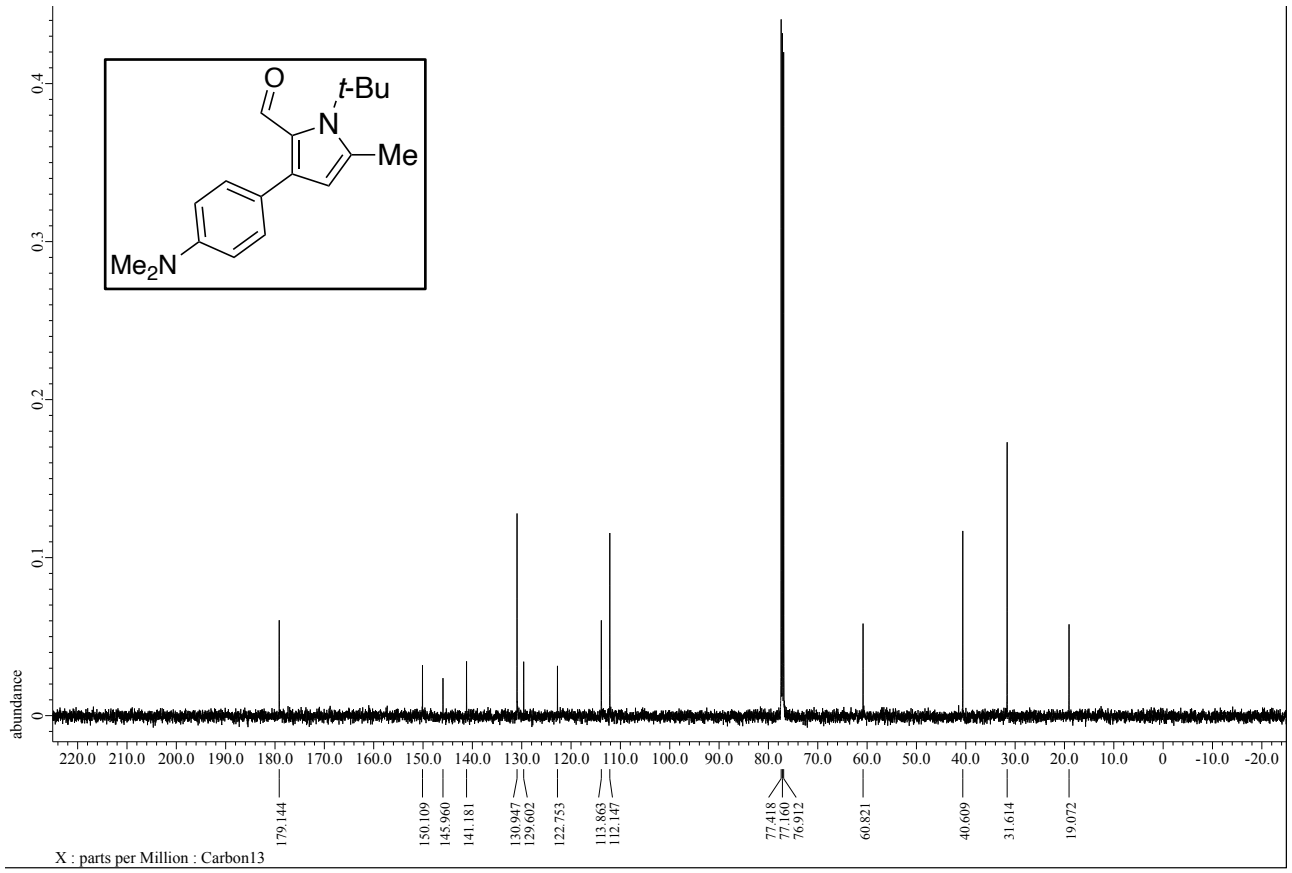


Figure S75. ^{13}C NMR (125.8 MHz, $CDCl_3$) spectrum of **5da**.

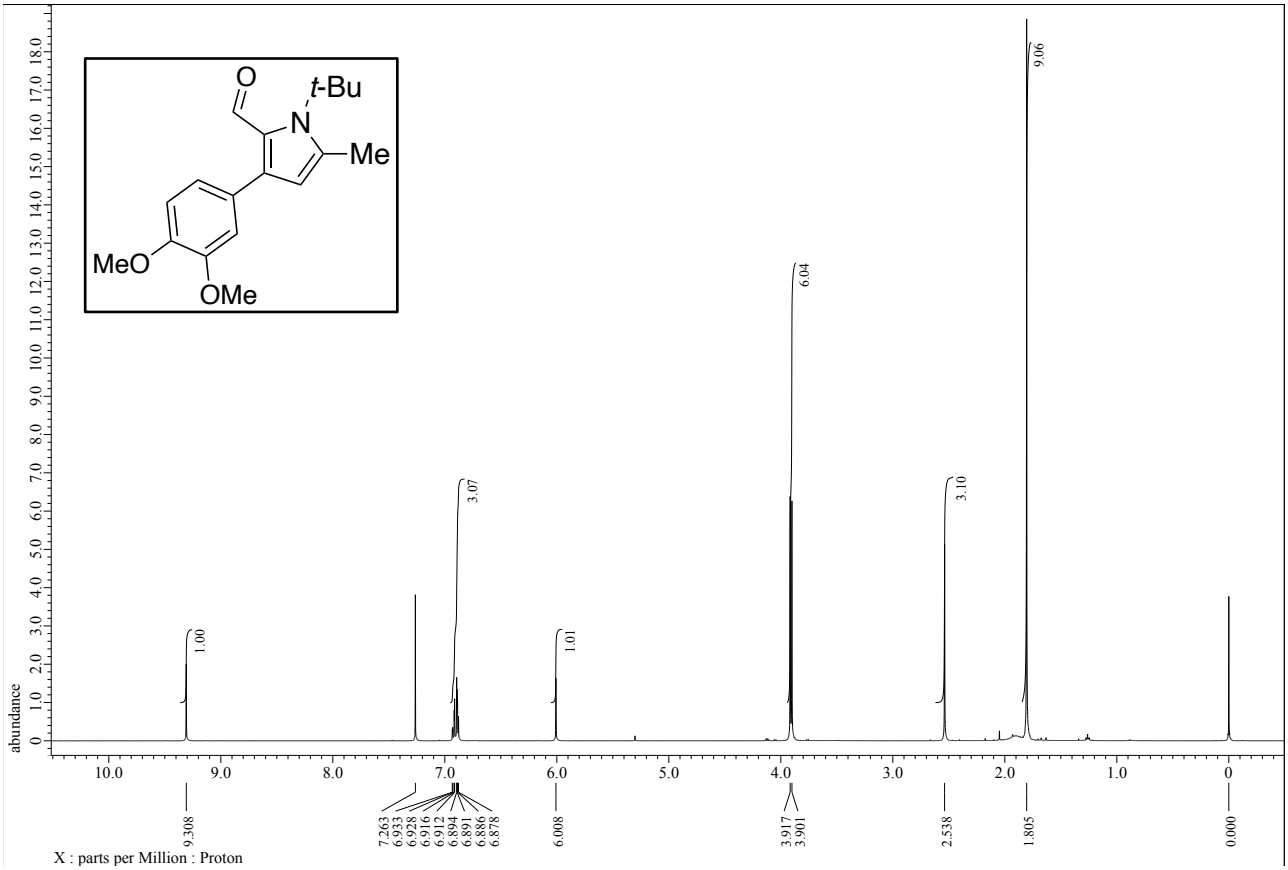


Figure S76. ^{1}H NMR (500 MHz, $CDCl_3$) spectrum of **5ea**.

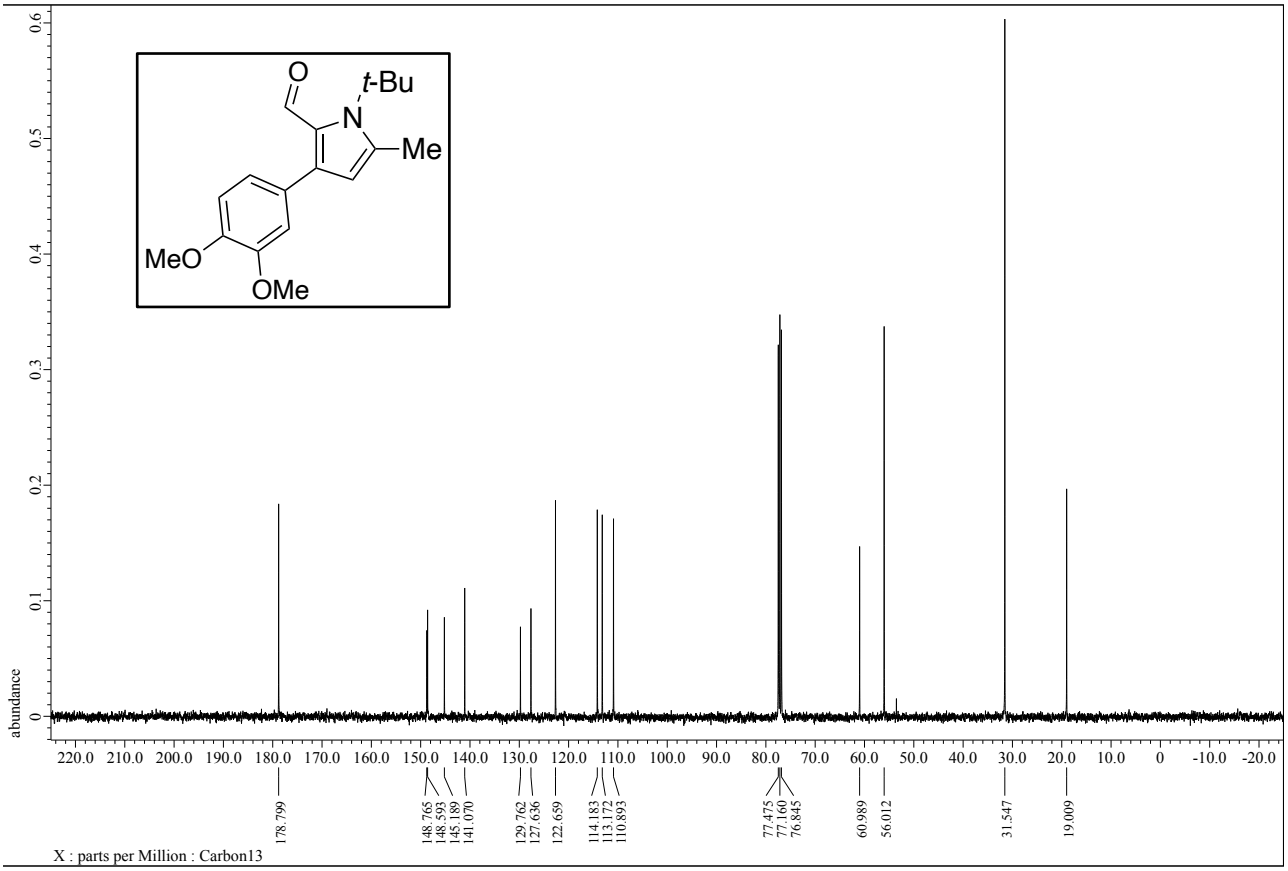


Figure S77. ^{13}C NMR (100.5 MHz, $CDCl_3$) spectrum of **5ea**.

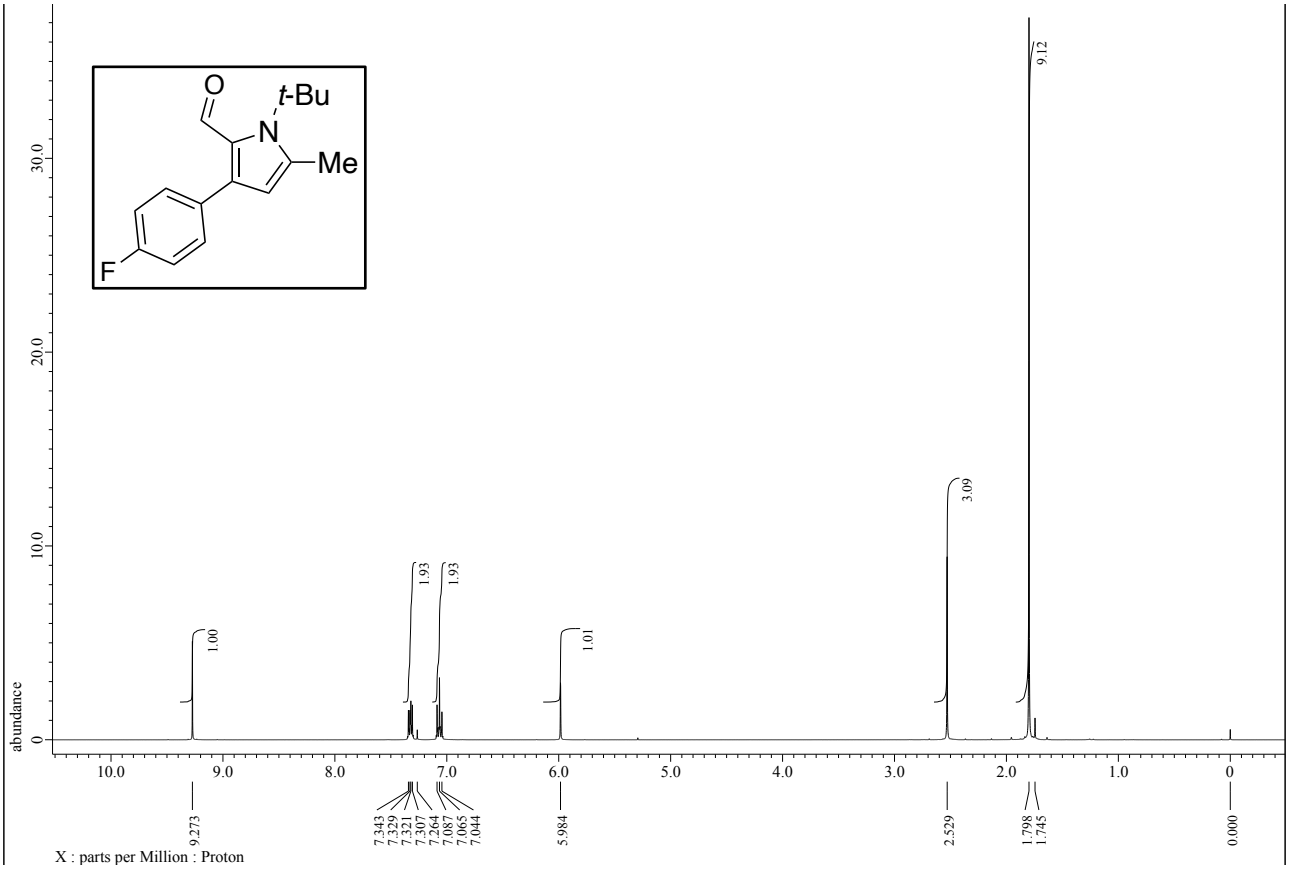


Figure S78. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **5fa**.

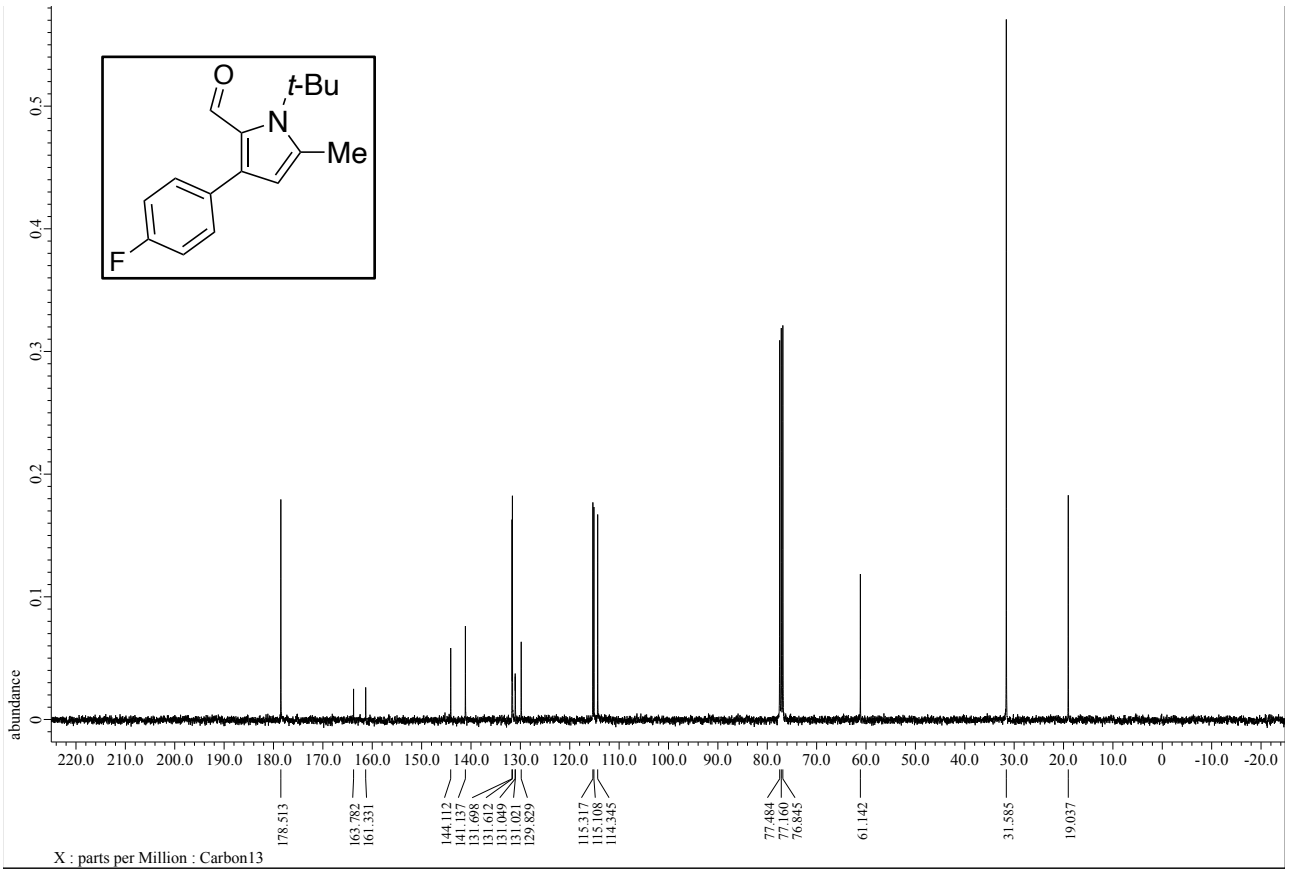


Figure S79. ^{13}C NMR (100.5 MHz, $CDCl_3$) spectrum of **5fa**.

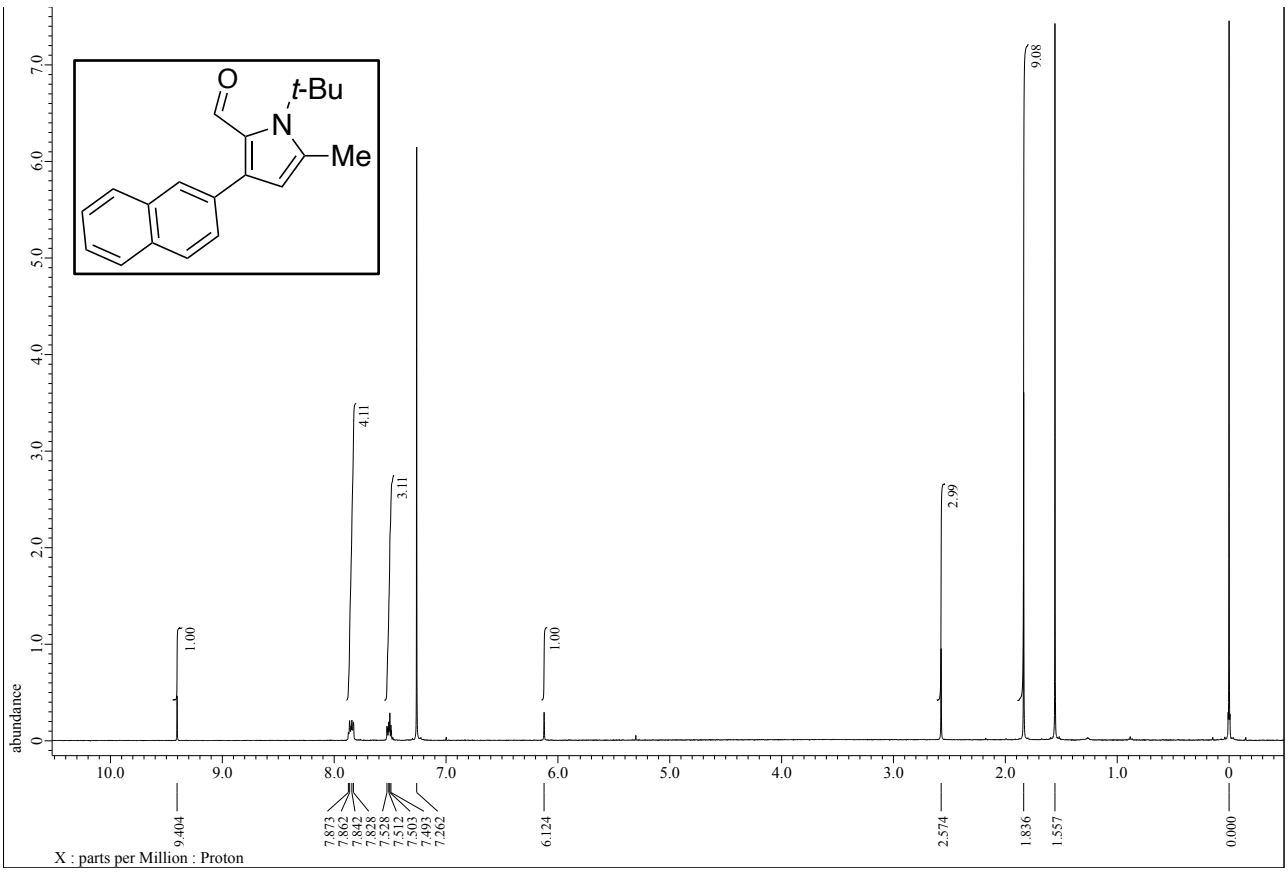


Figure S80. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **5ia**.

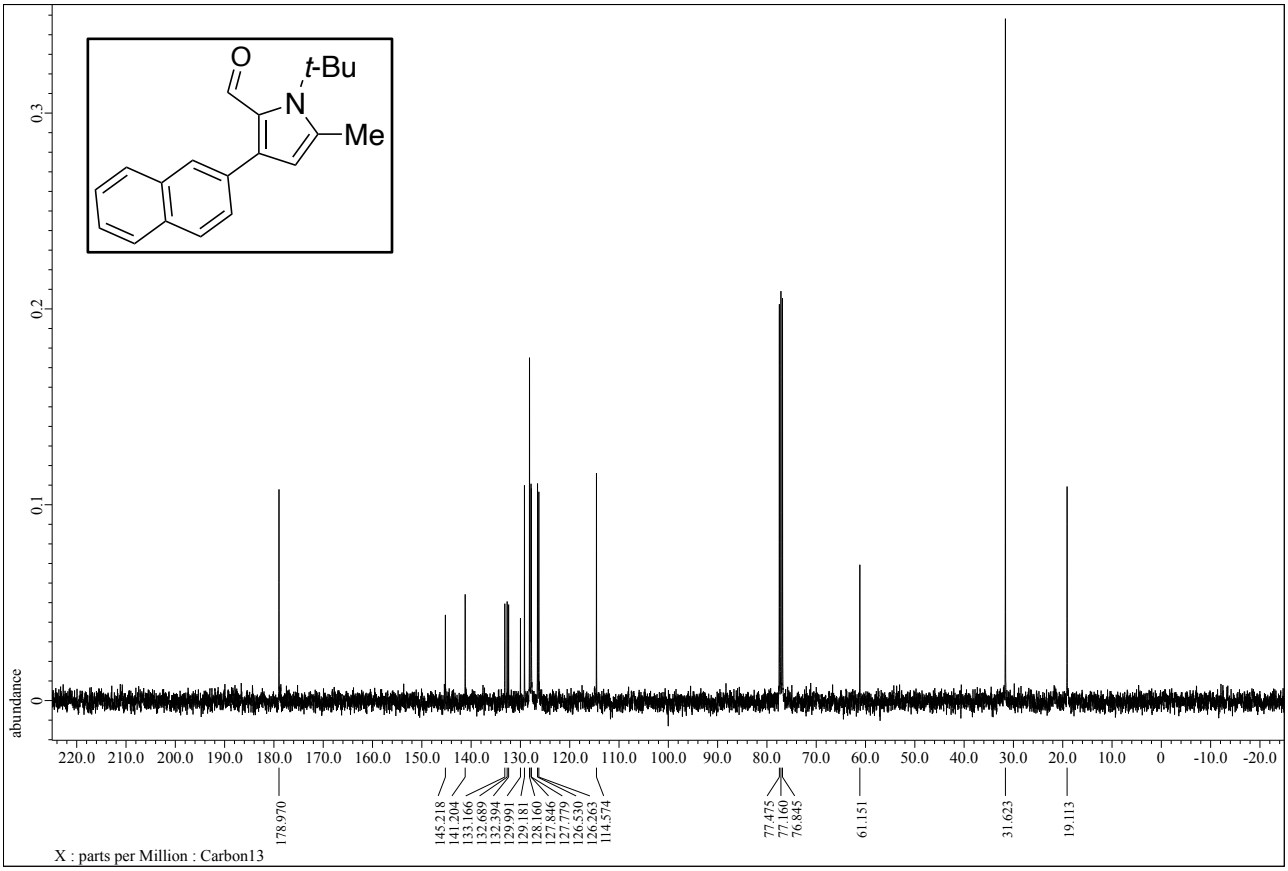


Figure S81. ^{13}C NMR (100.5 MHz, $CDCl_3$) spectrum of **5ia**.

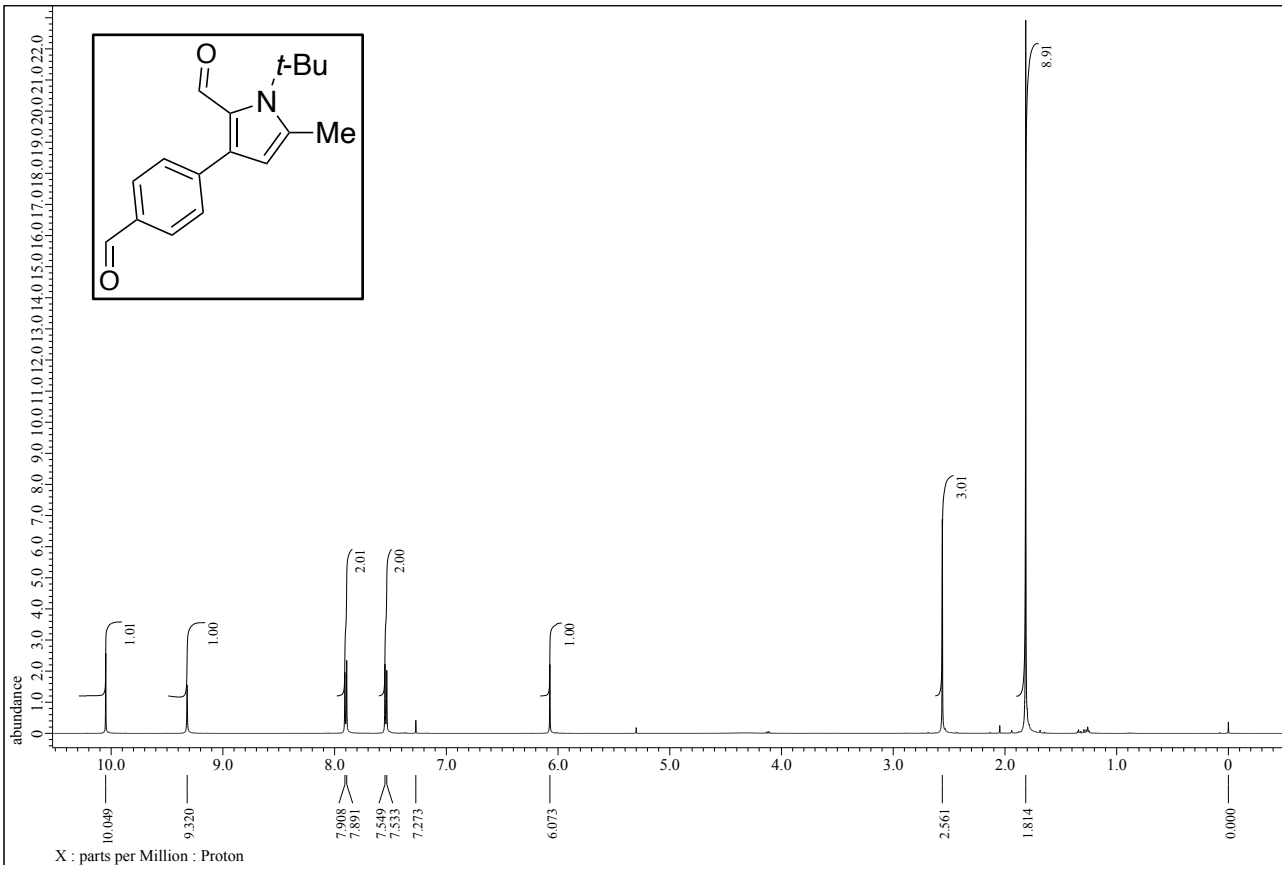


Figure S82. ^{1}H NMR (500 MHz, $CDCl_3$) spectrum of **7ja**.

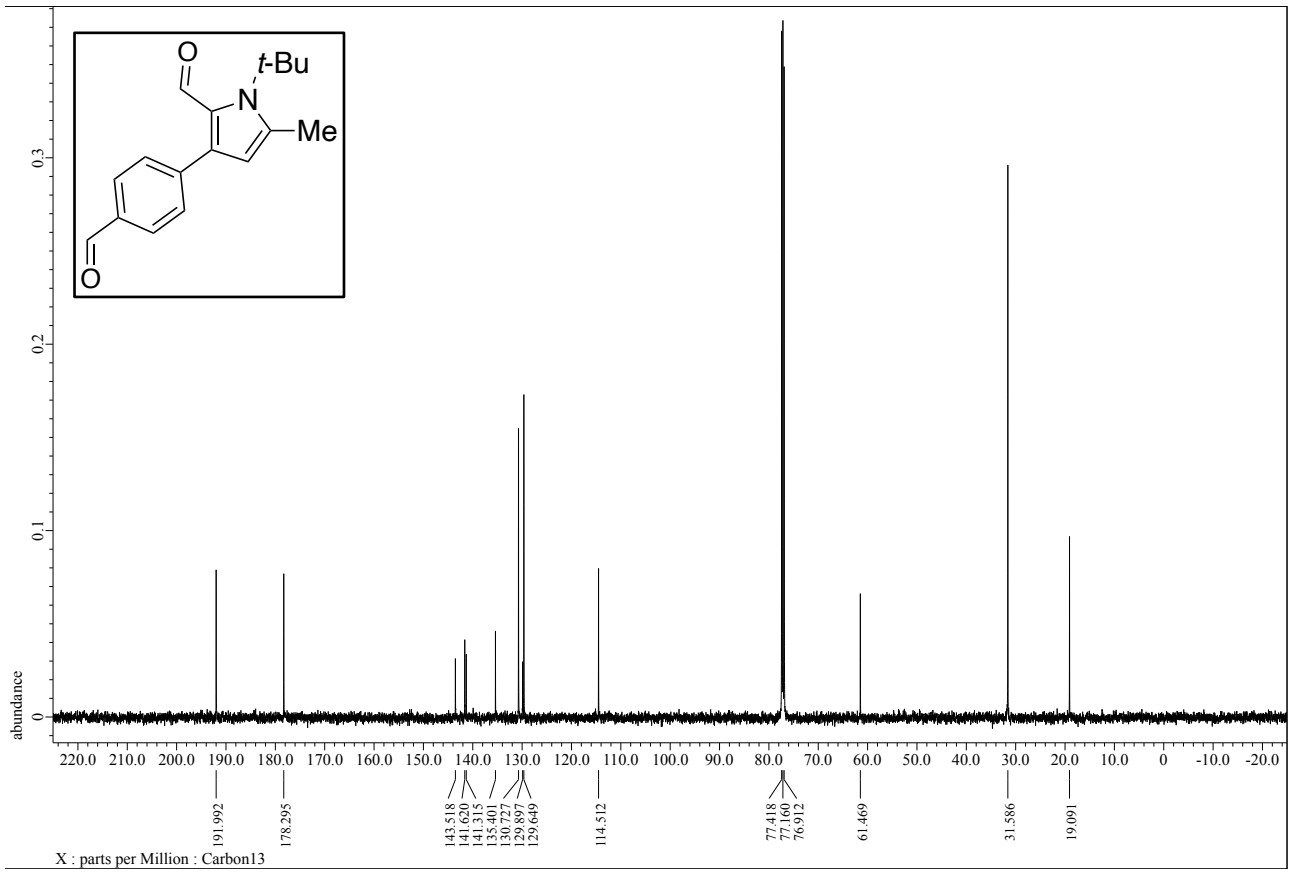


Figure S83. ^{13}C NMR (125.8 MHz, $CDCl_3$) spectrum of **7ja**.

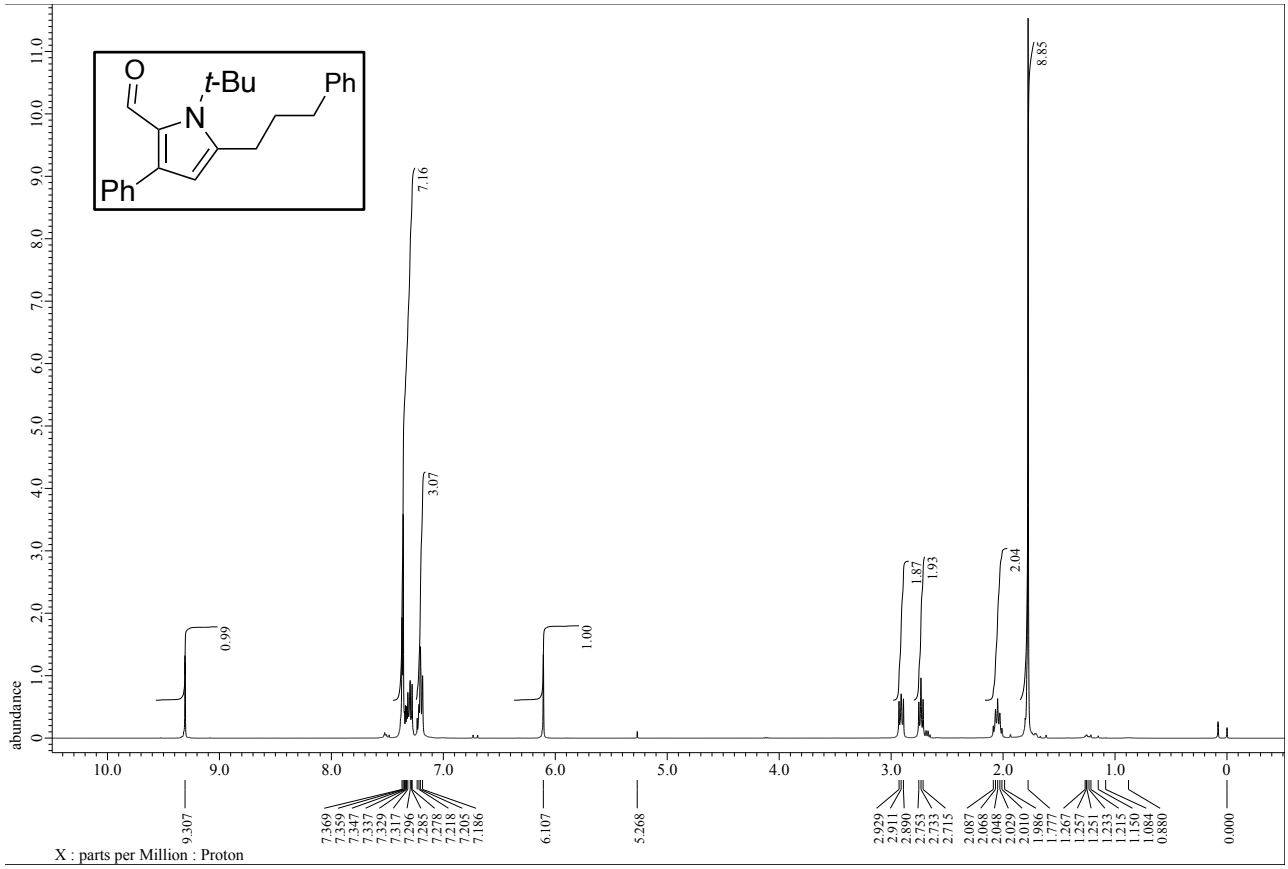


Figure S84. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **5ka**.

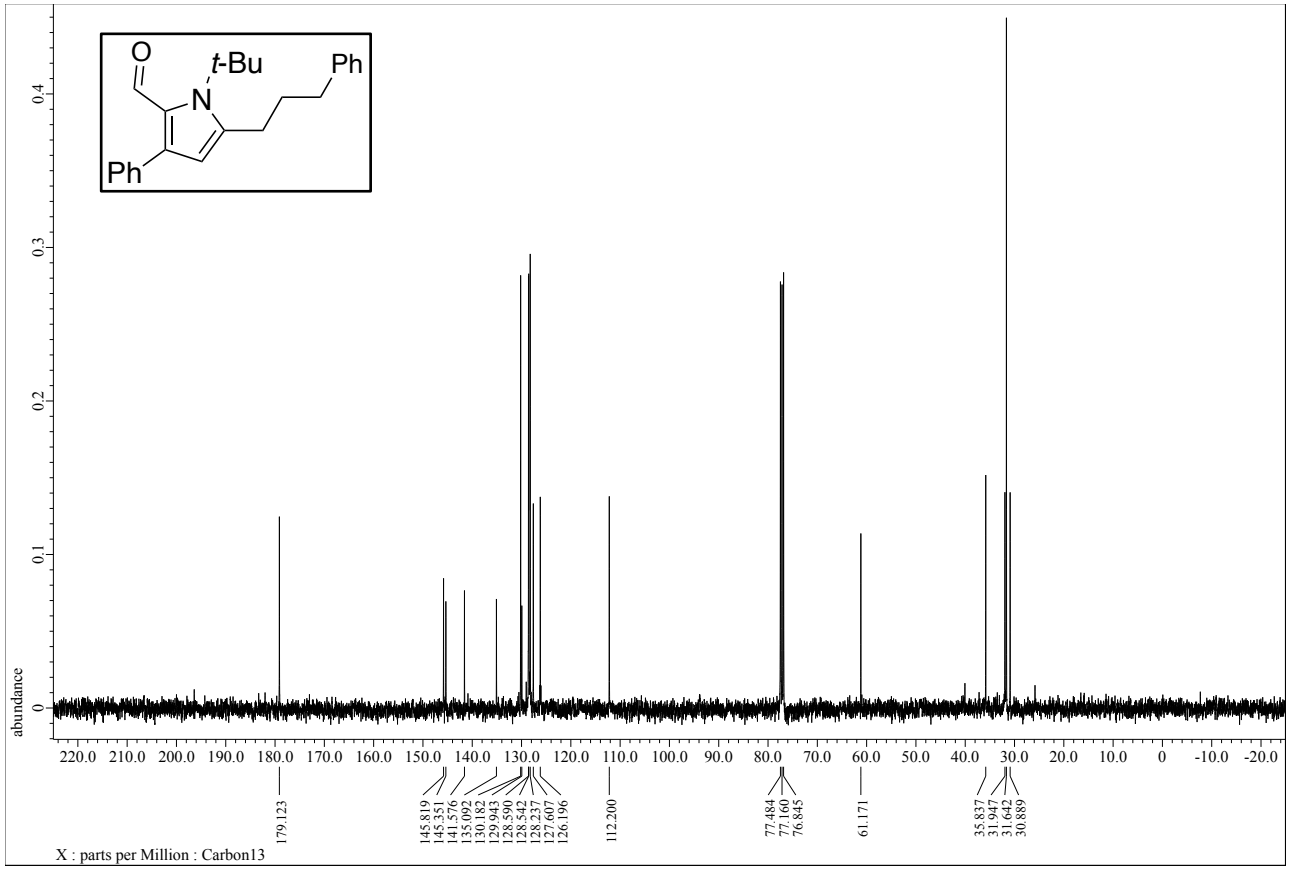


Figure S85. ^{13}C NMR (100.5 MHz, $CDCl_3$) spectrum of **5ka**.

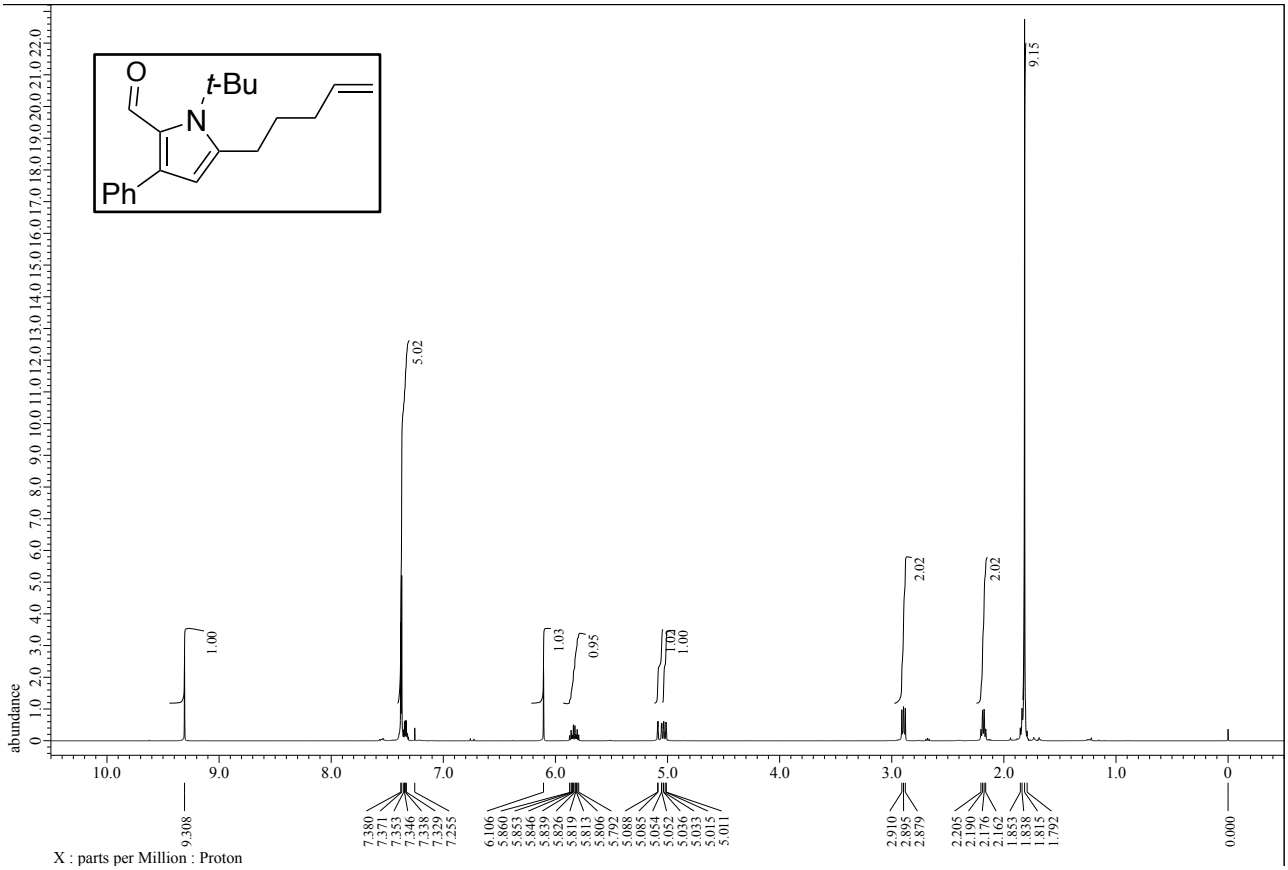


Figure S86. ^{1}H NMR (500 MHz, $CDCl_3$) spectrum of **5la**.

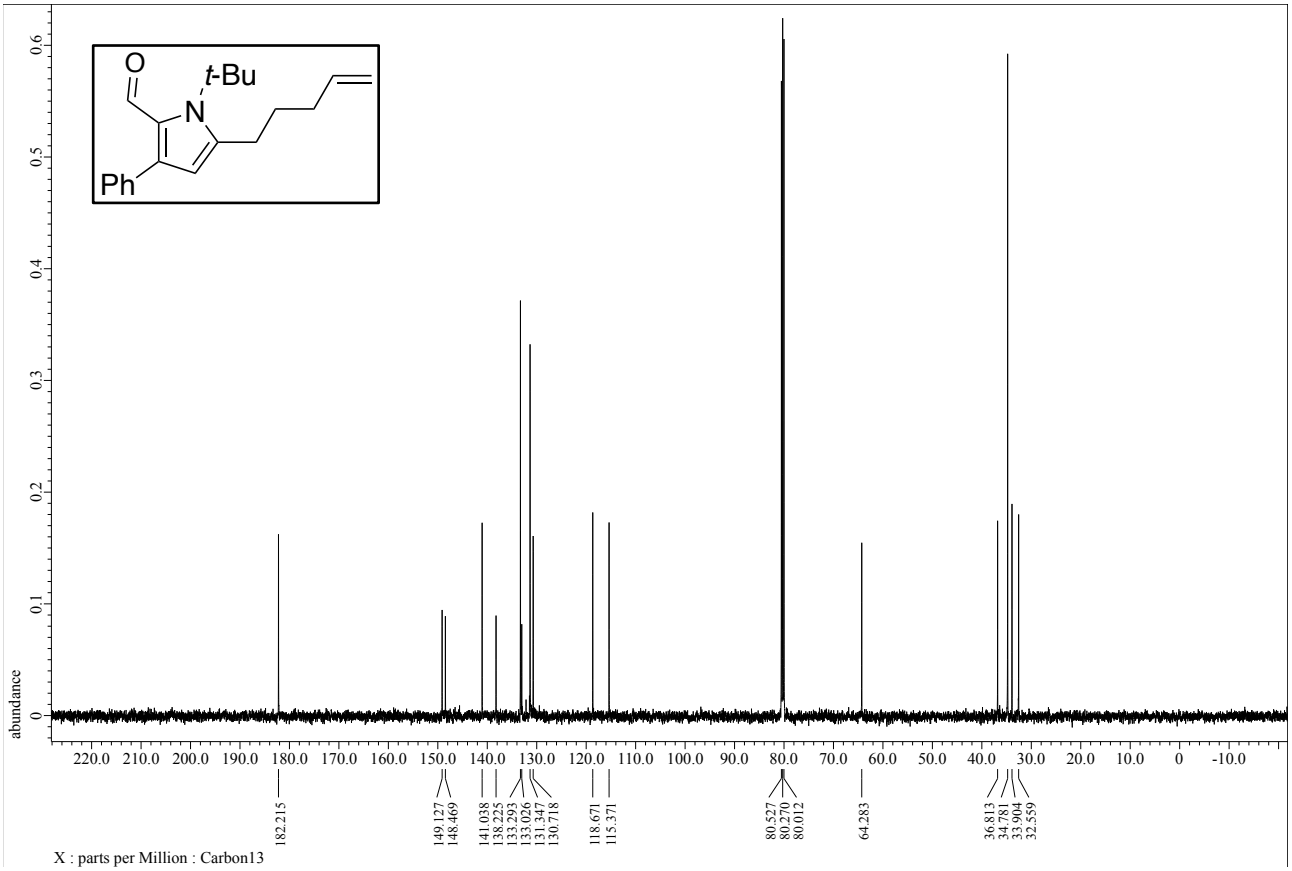


Figure S87. ^{13}C NMR (125.8 MHz, $CDCl_3$) spectrum of **5la**.

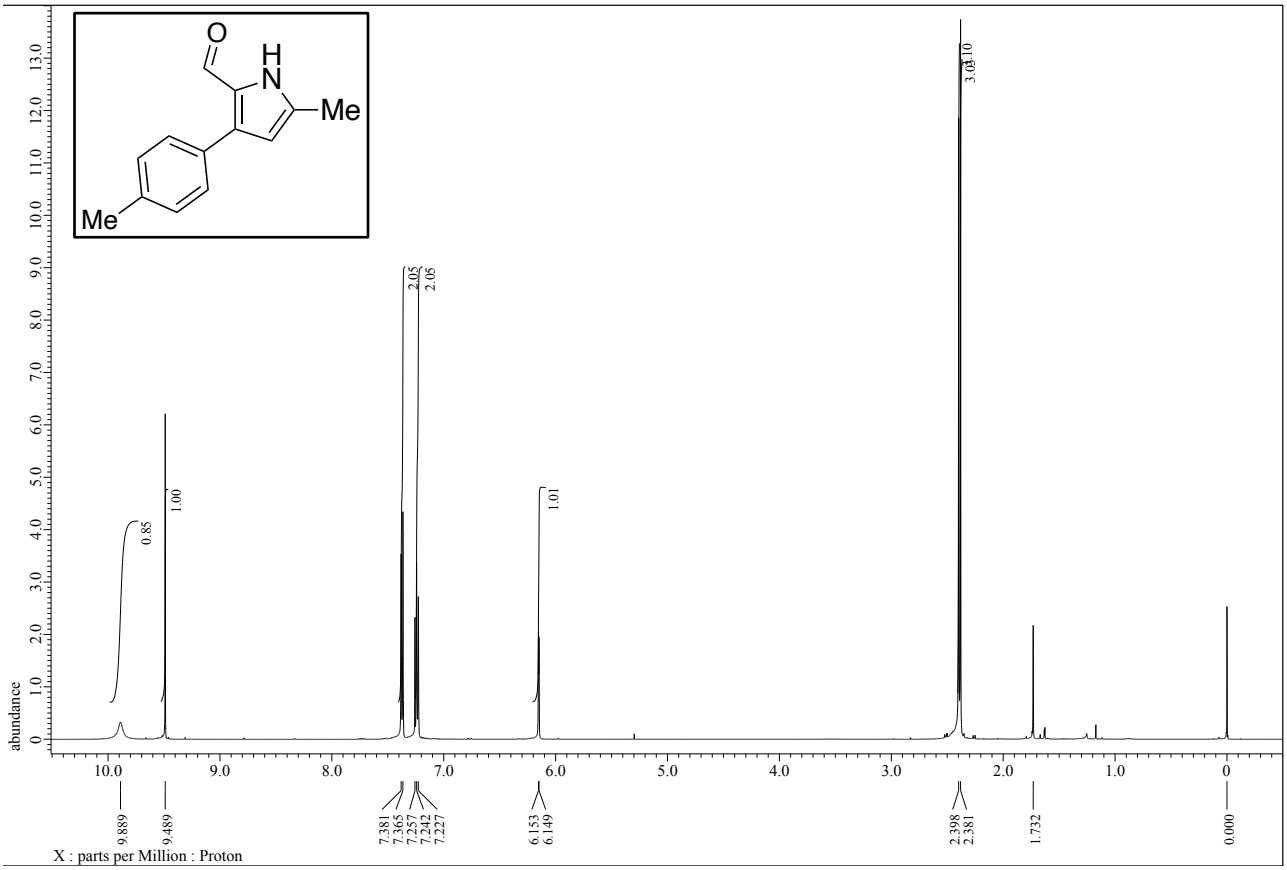


Figure S88. ^{1}H NMR (500 MHz, $CDCl_3$) spectrum of **8ba**.

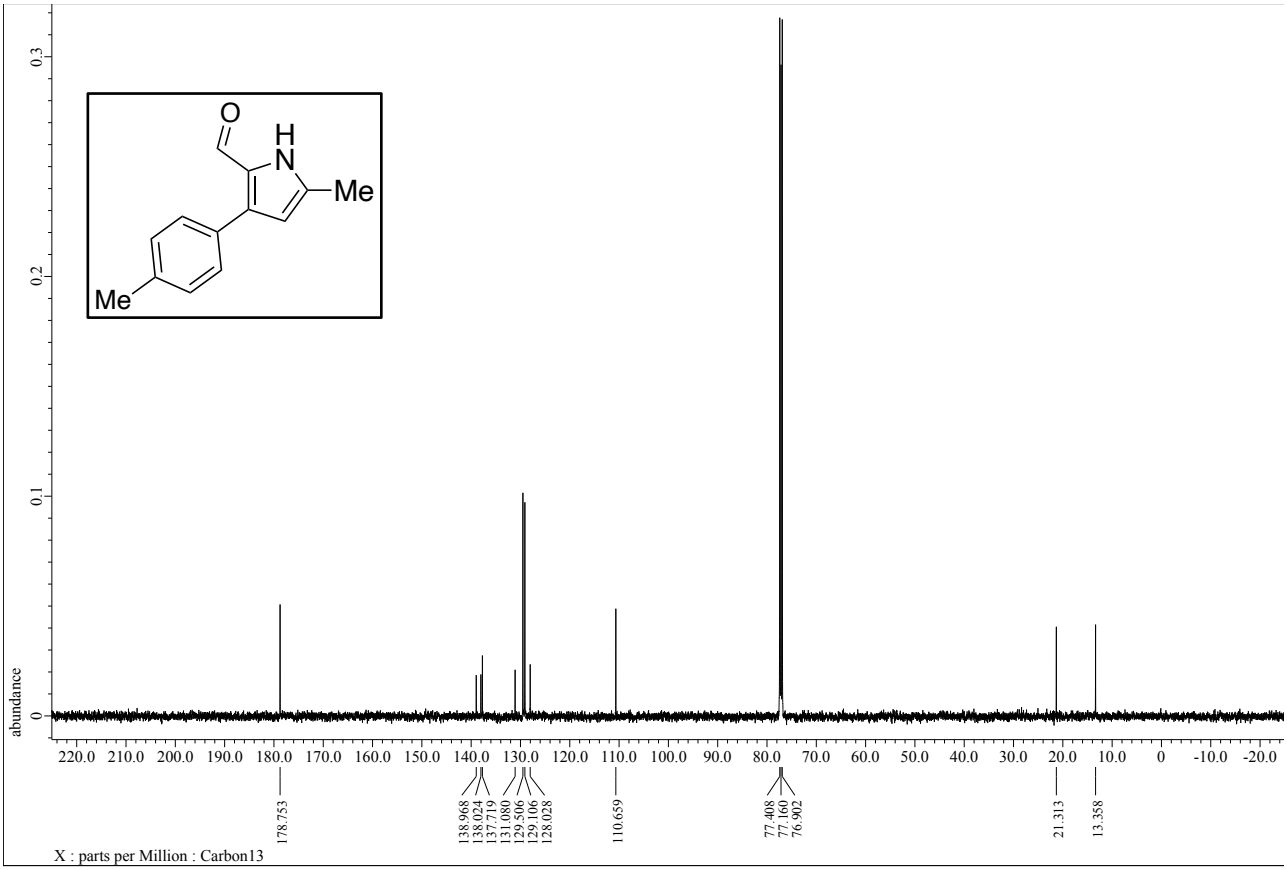


Figure S89. ^{13}C NMR (125.8 MHz, $CDCl_3$) spectrum of **8ba**.

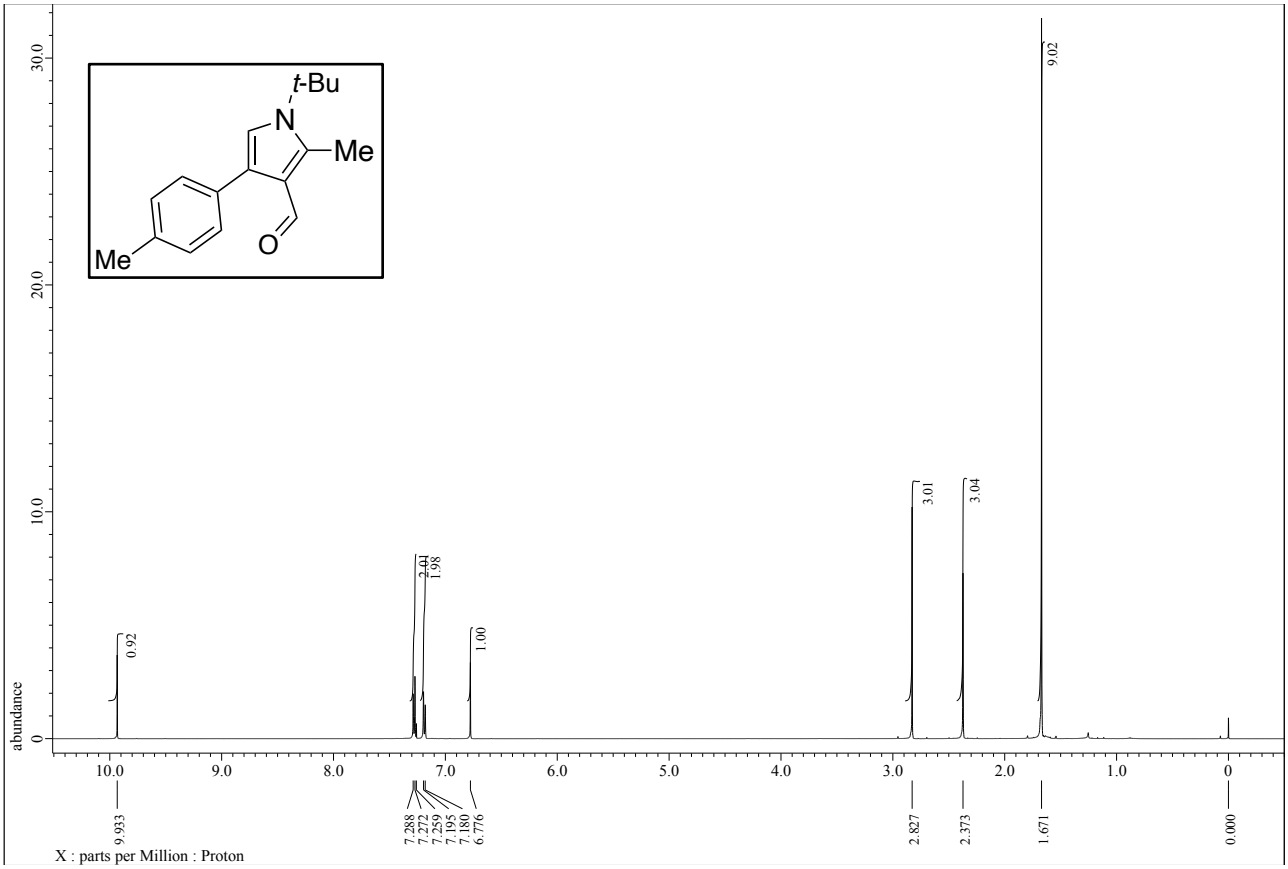


Figure S90. ^{1}H NMR (500 MHz, $CDCl_3$) spectrum of **9ba**.

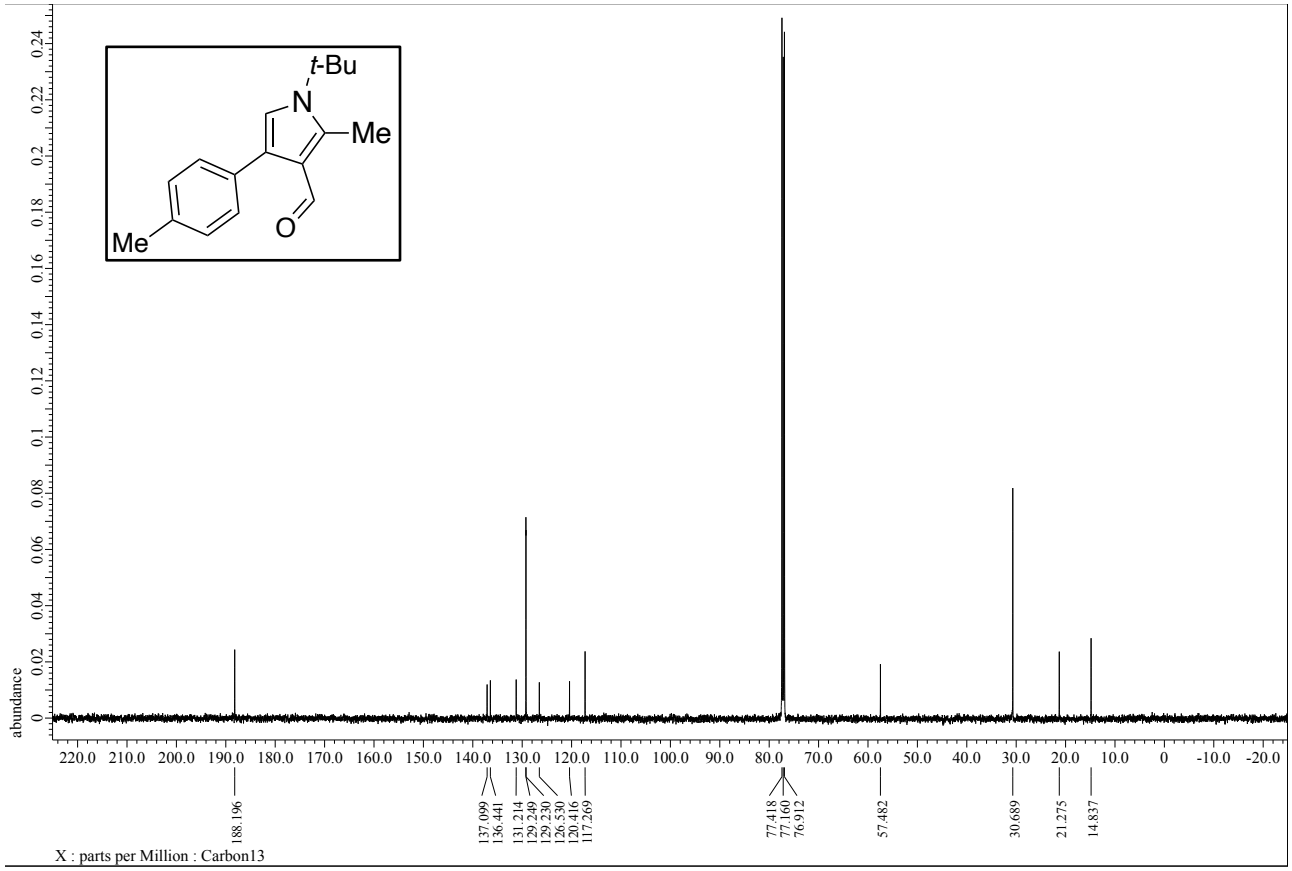


Figure S91. ^{13}C NMR (125.8 MHz, $CDCl_3$) spectrum of **9ba**.

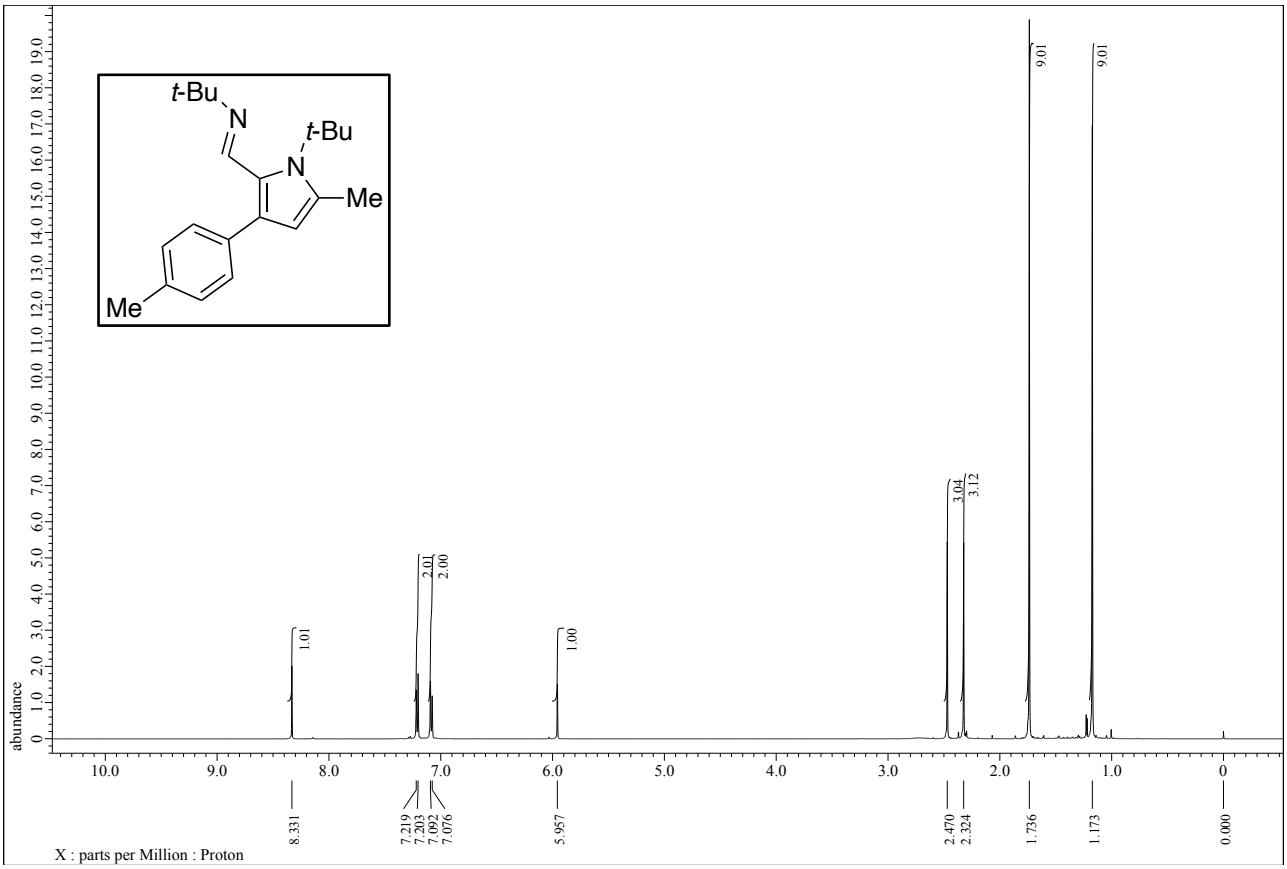


Figure S92. ^{1}H NMR (500 MHz, $CDCl_3$) spectrum of **4ba**.

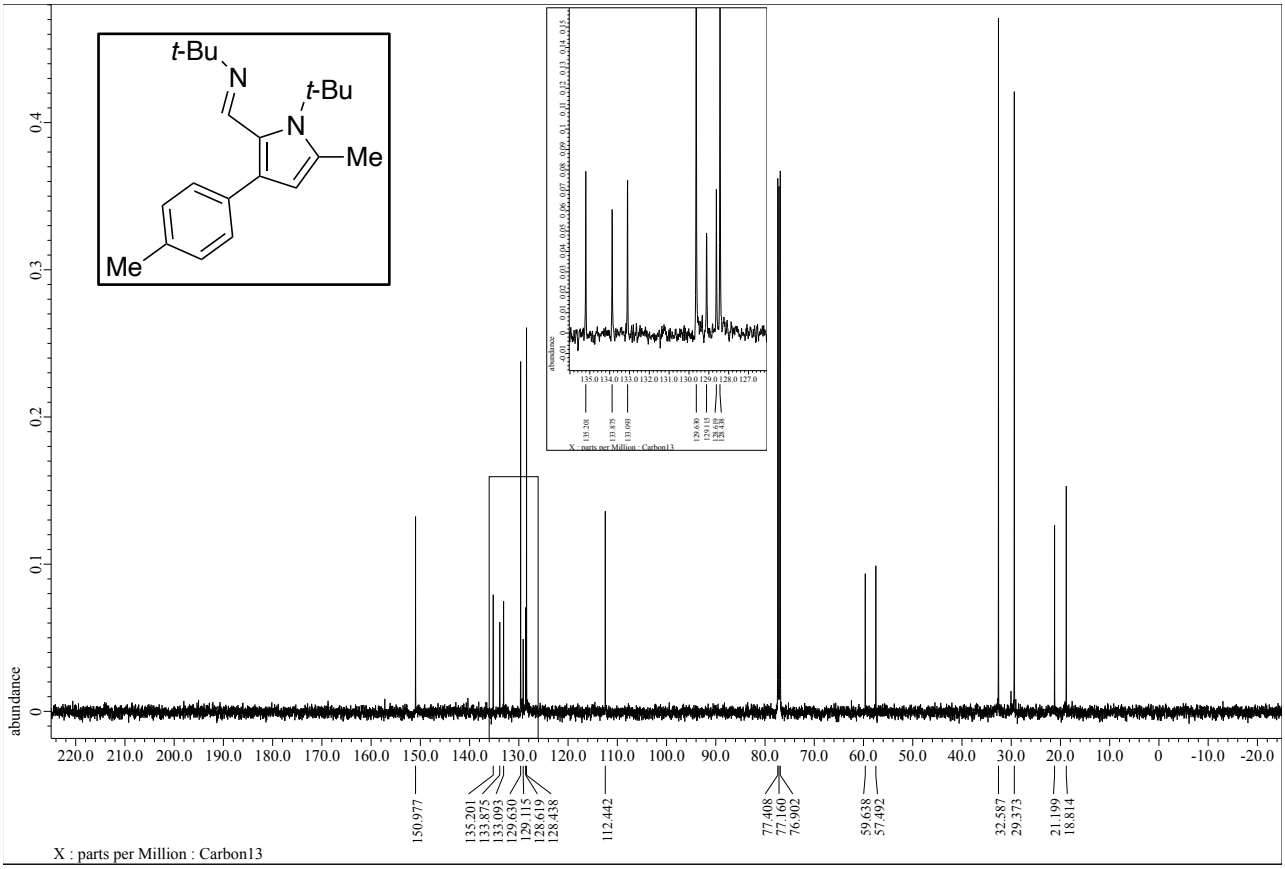


Figure S93. ^{13}C NMR (125.8 MHz, $CDCl_3$) spectrum of **4ba**.

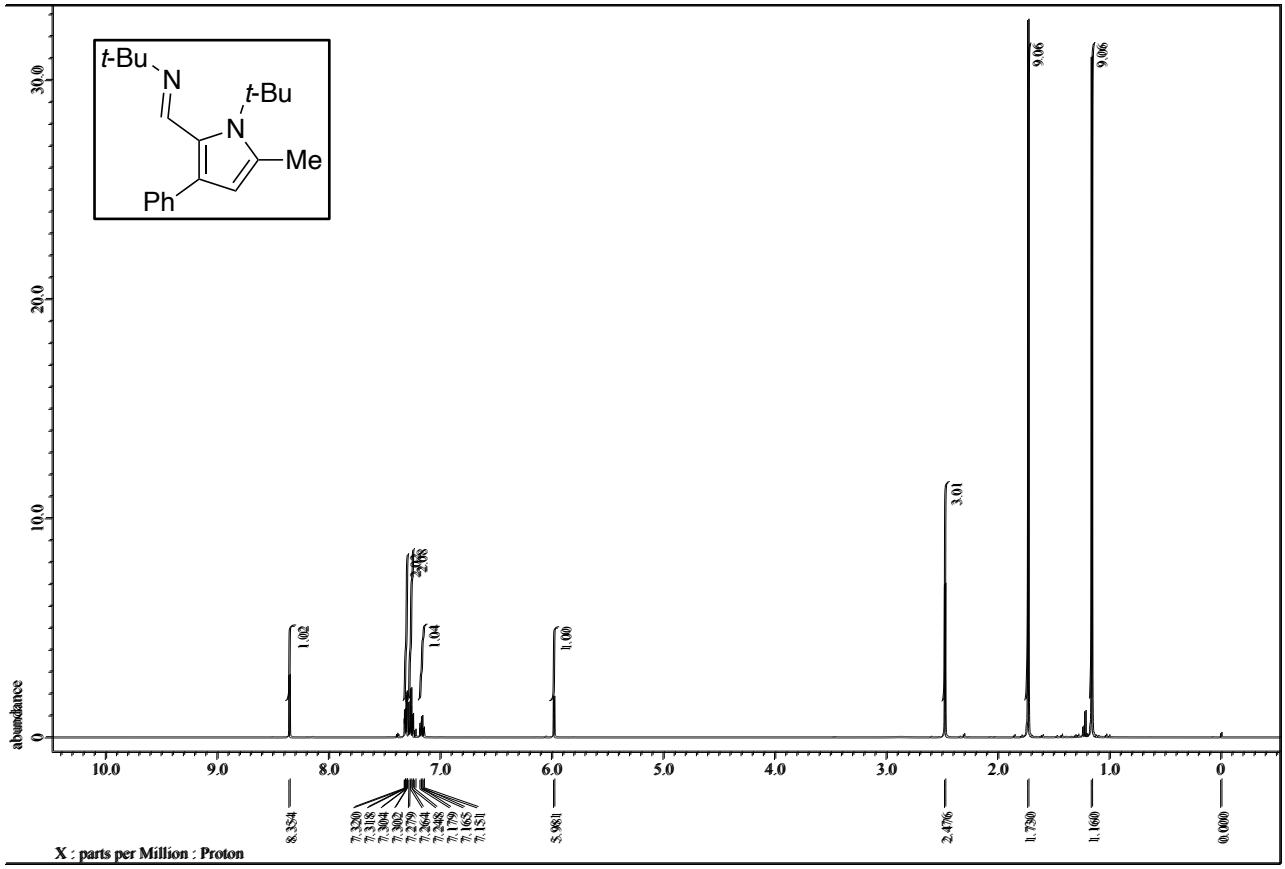


Figure S94. ^{1}H NMR (500 MHz, $CDCl_3$) spectrum of **4aa**.

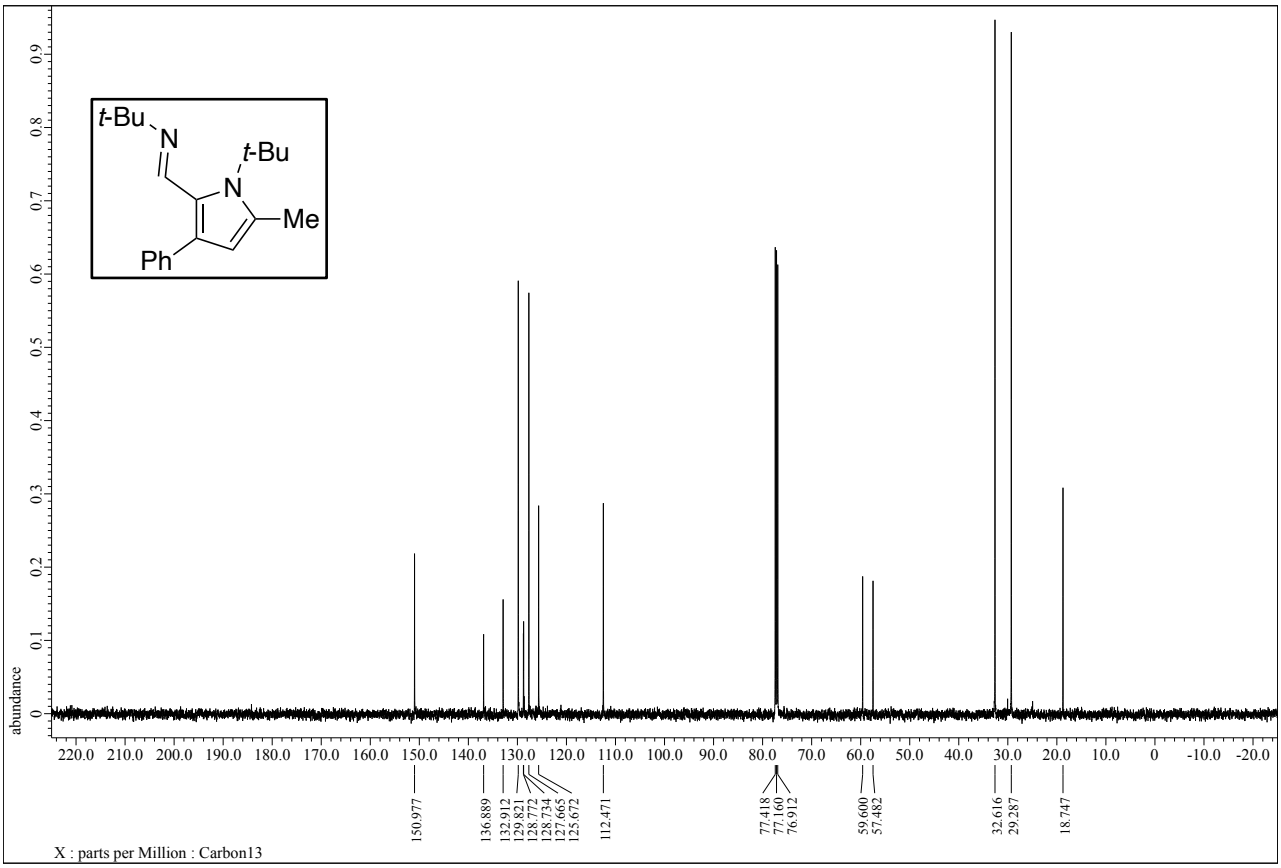


Figure S95. ^{13}C NMR (125.8 MHz, $CDCl_3$) spectrum of **4aa**.