Ti-Catalyzed Multicomponent Oxidative Carboamination of Alkynes with Alkenes and Diazenes

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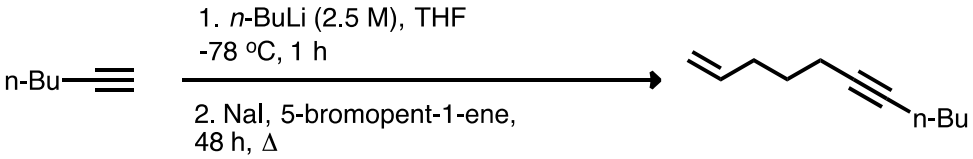
General Considerations

All air- and moisture-sensitive compounds were manipulated in a glovebox under a nitrogen atmosphere. Solvents for air- and moisture-sensitive reactions were vacuum transferred from sodium benzophenone ketyl (THF, Et_2O, pentane) or CaH_2 (DCM, $PhCF_3$, $CDCl_3$) or pre-dried on a Vacuum Atmospheres Solvent Purification System and filtered through activated basic alumina (hexanes, toluene, benzene, THF, Et_2O, or DCM). Solvents were stored over CaH_2 and filtered through dry basic alumina before use. HMPA was dried over CaH_2 and vacuum distilled before use. $[(py)_2TiCl_2(NPh)]_2$ was prepared according to literature procedure[S1] then purified by recrystallization from a DCM/pyridine mixture layered with hexanes at -35 °C then dried *in vacuo* at 80 °C overnight. Azobenzene was purified by sublimation (x2), crushed in a mortar and pestle, and then dried *in vacuo* overnight. All liquid alkynes or enynes were freeze-pump-thawed three times, brought into the glovebox and passed through activated basic alumina before being stored at -35 °C. Reagents were purchased from Sigma Aldrich, TCI America, Alfa Aesar, or Acros Organics and used without further purification. ^1H, ^{13}C, ^{15}N, HMBC, HSQC, NOE and no-D NMR spectra were recorded on Varian Inova 500 MHz, Bruker Avance III 500 MHz, Bruker Avance III HD 500 MHz, or Bruker Avance III HD 400 MHz spectrometers. Chemical shifts are reported with respect to residual protio-solvent impurities for ^1H (s, 7.16 ppm for C_6D_5H; s, 7.27 ppm for $CHCl_3$), solvent carbons for ^{13}C (t, 77.2 ppm for $CDCl_3$), and trifluoroacetic acid reference for ^{19}F (s, -76.6 ppm for trifluoroacetic acid in $CDCl_3$). All couplings are $J_{H\text{-}H}$ unless otherwise specified. All titanium-catalyzed reactions are highly air- and water-sensitive and all reagents and solvents should be thoroughly dried before use.

NMR Determination of Reaction Yields

For intramolecular reactions, to an NMR tube were added 7.0 mg $[(py)_2TiCl_2(NPh)]_2$ (0.1 equiv, 0.0191 mmol) and enyne (2.2 equiv, 0.423 mmol) and the mixture was diluted with a 0.5 mL stock solution of C_6D_5Br containing azobenzene (1 equiv, 0.192 mmol) and trimethoxybenzene (0.192 mmol as an internal standard), TMB. For intermolecular reactions, to an NMR tube were added 0.7 mg $[(py)_2TiCl_2(NPh)]_2$ (0.1 equiv, 0.0191 mmol), alkyne (5 equiv, 0.949 mmol), and alkene (10 equiv, 1.92 mmol) and then the mixture was diluted with a 0.5 mL stock solution of C_6D_5Br containing azobenzene (1 equiv, 0.192 mmol) and trimethoxybenzene (0.192 mmol as an internal standard). The NMR tube was then sealed and a Time = 0 h ^1H NMR spectrum was taken. The reaction was then heated in an oil bath for 16 h at 115 °C. Afterward, the reaction was cooled to room temperature and a Time = 16 h ^1H NMR spectra was taken. To the NMR tube was then added 0.2 mL 2 N HCl, the tube was inverted 3 times and sonicated for 15 minutes and a final Time = 16 h ^1H NMR spectrum was taken. ^1H NMR spectra were taken using d1 = 30, aq = 5, and ns = 8 on a Bruker Avance III HD 400 MHz NMR spectrometer. Yields were determined by comparison with trimethoxybenzene.

Synthesis of undec-1-en-6-yne (1a)



To a 100 mL Schlenk flask was added 40 mL THF and the flask was cooled to -78 °C. To this was added 1-hexyne (1.3 equiv, 3.18 g, 0.039 mol) and the solution was stirred for 5 min. Next, 16 mL *n*-BuLi (1.34 equiv, 2.5 M, 0.04 mol) over 15 mins was added and the mixture was left to stir for 30 min. To this were added 5-bromopent-1-ene (1 equiv, 4.4 g, 0.029 mol) and 300 mg NaI and the reaction was heated to 80 °C for 2 days. The reaction was quenched with NH_4Cl (5 mL) and poured into 50 mL H_2O. The reaction was extracted with 3x 50 mL hexanes. The organics were combined, dried over $MgSO_4$, filtered and concentrated to a crude yellow oil, which was passed through a plug of silica using hexanes to give a clear colorless oil of **1a** (4.178 g, 92% yield). Spectral data were consistent with literature values.[S2]

^{1}H NMR (400 MHz, $CDCl_3$; δ, ppm): 0.92 (t, J = 7.2 Hz, 3H, -CH_2CH_3), 1.51-1.36 (m, 4H, -$CH_2CH_2CH_2CH_3$), 1.58 (quint, J = 6.6 Hz, 2H, -$CH_2CH_2CH_2$), 2.16 (m, 6H, H_2C=CHCH_2- and -$CH_2CH_2CCCH_2CH_2$-), 4.98 (ddt, J = 10.2, 2.2, 1.1 Hz, 1H, H*H*C=CHCH_2-), 5.04 (dq, J = 17.1, 1.8 Hz, 1H, H*H*C=CHCH_2-), 5.81 (ddt, J = 17.0, 10.3, 6.7 Hz, 1H, H_2C=C*H*CH_2-).

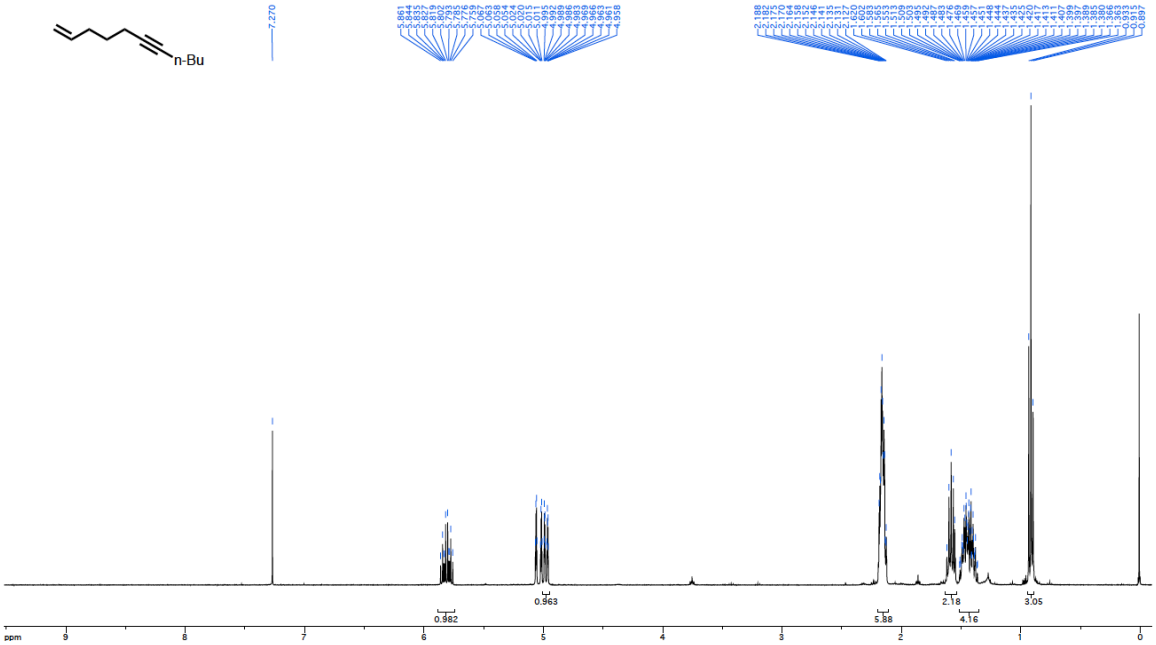
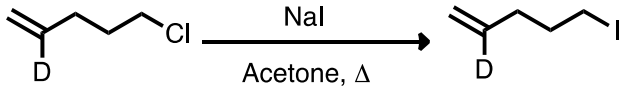
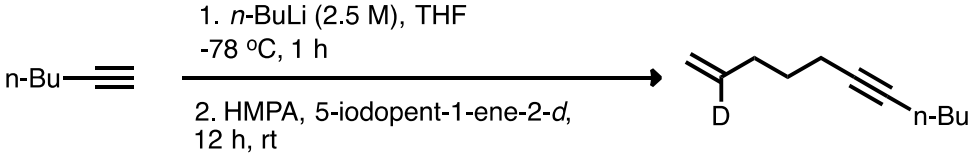


Figure S1: ^{1}H NMR spectrum of **1a** in $CDCl_3$.

Synthesis of undec-1-en-6-yne-2-*d* (1b)



On a N_2 Schlenk line, a 50 mL round bottom flask with a stir bar was charged with 5-chloropent-1-ene-2-*d*[S3] (2.26 g, 0.0214 mol) and 20 mL acetone. NaI (2 equiv, 6.41 g, 0.0428 mol) was added with stirring. The reaction mixture was then heated to 60 °C for 12 h. An additional portion of NaI (1 equiv, 3.20 g, 0.0214 mol) was then added. After heating for an additional 12 h, the ^{1}H NMR spectrum of the crude mixture showed complete conversion to the product. The reaction mixture was then poured into 200 mL DI H_2O and the aqueous layer was extracted with 3x 50 mL pentane. The organic layers were combined and washed with 50 mL brine, dried over $MgSO_4$, filtered and concentrated on a rotovap to give the crude iodo product as a yellow liquid (3.56 g, 84% yield) which was carried on to the next step with no further purification.



In a glovebox, a 100 mL Schlenk flask with a small stir bar was charged with 10 mL dry THF. The flask was removed from the glovebox and 10 mL dry HPMA was added then the flask was cooled to -78 °C. 1.62 g of 1-hexyne (1.1 equiv, 2.27 mL, 0.020 mol) was then added and the solution was stirred for 5 minutes. To this was added 8.0 mL n-BuLi (1.1 equiv, 2.5 M in hexanes, 0.020 mol) dropwise over 15 minutes. The reaction mixture was then left to stir for 1 h. The crude 3.56 g of 5-iodopent-1-ene-2-*d* (1.0 equiv, 0.018 mol) was added and the reaction was stirred overnight while slowly warming to room temperature. The reaction was quenched with 2 mL 2 M HCl, stirred for 5 minutes, then 20 mL 2 M HCl was added and the mixture was poured into a separatory funnel containing 50 mL pentane and 100 mL 2 M HCl. The aqueous layer was then extracted 3x with pentane, the organic layers were collected, washed with 50 mL H_2O, 50 mL $NaHCO_3$, and 50 mL brine, dried over $MgSO_4$, filtered and concentrated on a rotovap to give a yellow oil. The crude yellow oil was passed through a short plug of 20 g of silica gel using pentanes to give **1b** as a clear, colorless oil (1.976 g, 72.3% yield, 95% *d*-labeling).

^{1}H NMR (400 MHz, $CDCl_3$; δ, ppm): 0.92 (t, J = 7.2 Hz, 3H, -CH_2CH_3), 1.50-1.36 (m, 4H, -$CH_2CH_2CH_2CH_3$), 1.58 (quint, J = 7.2 Hz, 2H, -$CH_2CH_2CH_2$-), 2.19-2.13 (m, 6H, H2C=CDCH_2- and -CH_2CCCH_2-), 4.97 (m, 1H, H*H*C=CDCH_2-), 5.03 (m, 1H, H*H*C=CDCH_2-).

^{13}C NMR (101 MHz, $CDCl_3$; δ, ppm): 13.8, 18.3, 18.6, 22.1, 28.5, 31.4, 32.9, 79.7, 80.5, 114.8, 137.8 (t, $^1J_{C\text{-}D}$ = 23.2 Hz).

GC-HRMS: Calc for $C_{11}H_{17}D$ [M^+] 151.1471; found 151.1460.

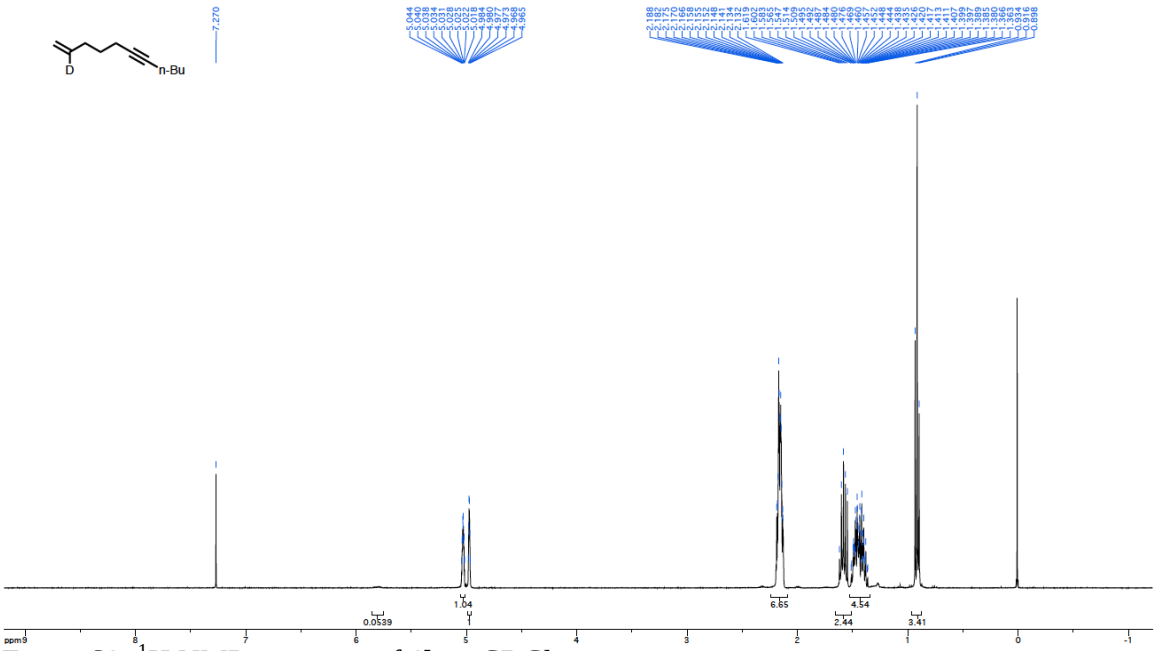


Figure S2: ^{1}H NMR spectrum of **1b** in $CDCl_3$.

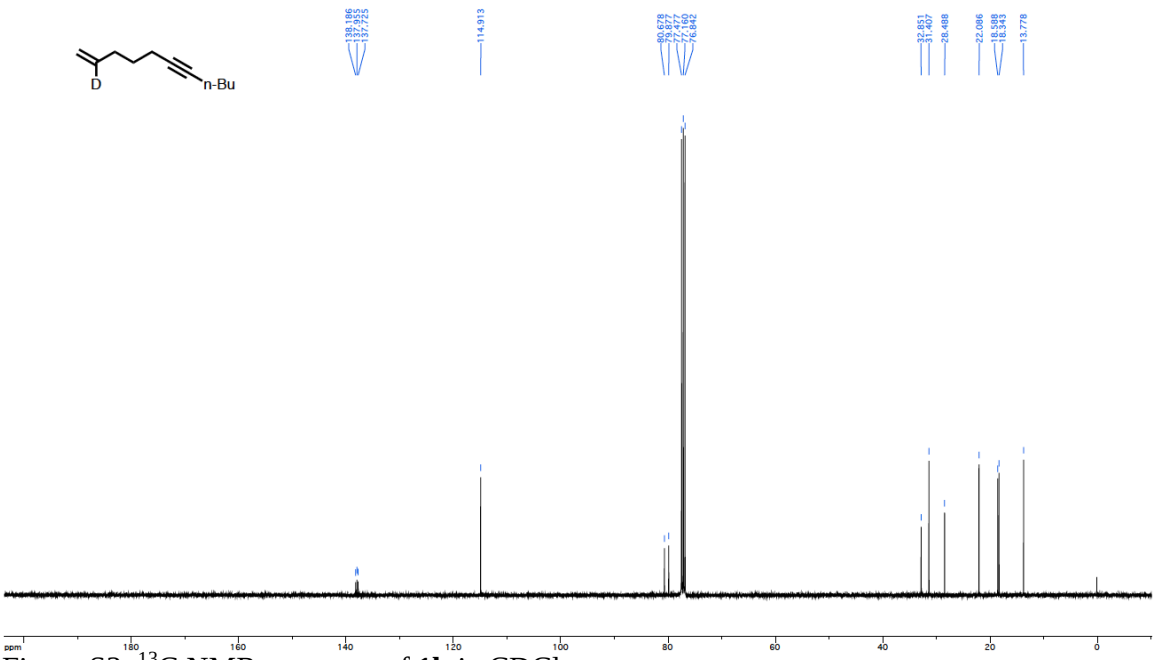
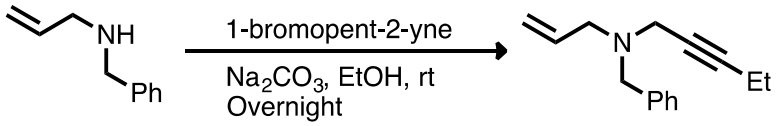


Figure S3: ^{13}C NMR spectrum of **1b** in $CDCl_3$.

Synthesis of *N*-allyl-*N*-benzylpent-2-yn-1-amine (1c)



To a 100 mL round bottom flask were added 3.00 g *N*-allylbenzylamine[S4] (1 equiv, 0.0204 mol) and 50 mL EtOH. To this was added 4.37 g Na_2CO_3 (2 equiv, 0.0407 mol) and then 3.15 g 1-bromo-2-pentyne (1.05 equiv, 0.0214 mol) was added dropwise over 5 minutes. The reaction was left to stir overnight at room temperature, then was quenched with H_2O and 5 mL 2 M HCl. The aqueous layer was then extracted with 3x 50 mL Et_2O. The organics were collected, washed with H_2O, dried over $MgSO_4$, and concentrated on a rotovap. The crude oil was purified by column chromography on silica gel using 5% EtOAc/hexanes to give product **1c** as a clear, colorless oil (2.4 g, 55.2% yield).

^{1}H NMR (400 MHz, $CDCl_3$; δ, ppm): 1.20 (t, *J* = 7.5 Hz, 3H, -CH_2CH_3), 2.26 (qt, *J* = 7.5, 2.2 Hz, 2H, -CCH_2CH_3), 3.17 (dt, *J* = 6.5, 1.3 Hz, 2H, -$CHCH_2$N-), 3.28 (t, *J* = 2.2 Hz, 2H, -NCH_2C-), 3.64 (s, 2H, $C_6H_5CH_2$N-), 5.17 (ddt, *J* = 10.1, 2.1, 1.1 Hz, 1H, *H*HCCHCH_2-), 5.27 (dq, *J* = 17.2, 1.7 Hz, 1H, *H*HCCHCH_2-), 5.90 (ddt, *J* = 17.0, 10.3, 6.6 Hz, 1H, H_2CCHCH_2-), 7.27-7.23 (m, 1H,), 7.38-7.30 (m, 4H).

^{13}C NMR (101 MHz, $CDCl_3$; δ, ppm): 12.6, 14.5, 42.0, 56.8, 57.4, 74.0, 87.2, 117.9, 127.1, 128.4, 129.3, 136.0, 139.0.

GC-HRMS: Calc for $C_{15}H_{19}N$ [M^+] 213.1517; found 213.1507.

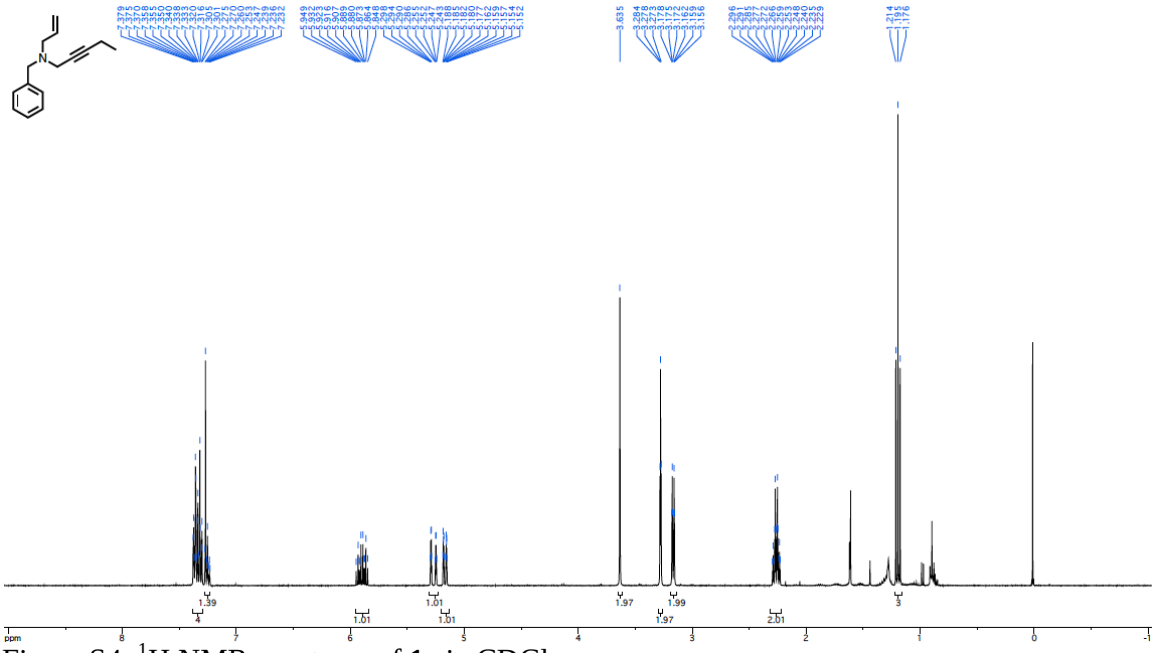


Figure S4: ^{1}H NMR spectrum of **1c** in $CDCl_3$.

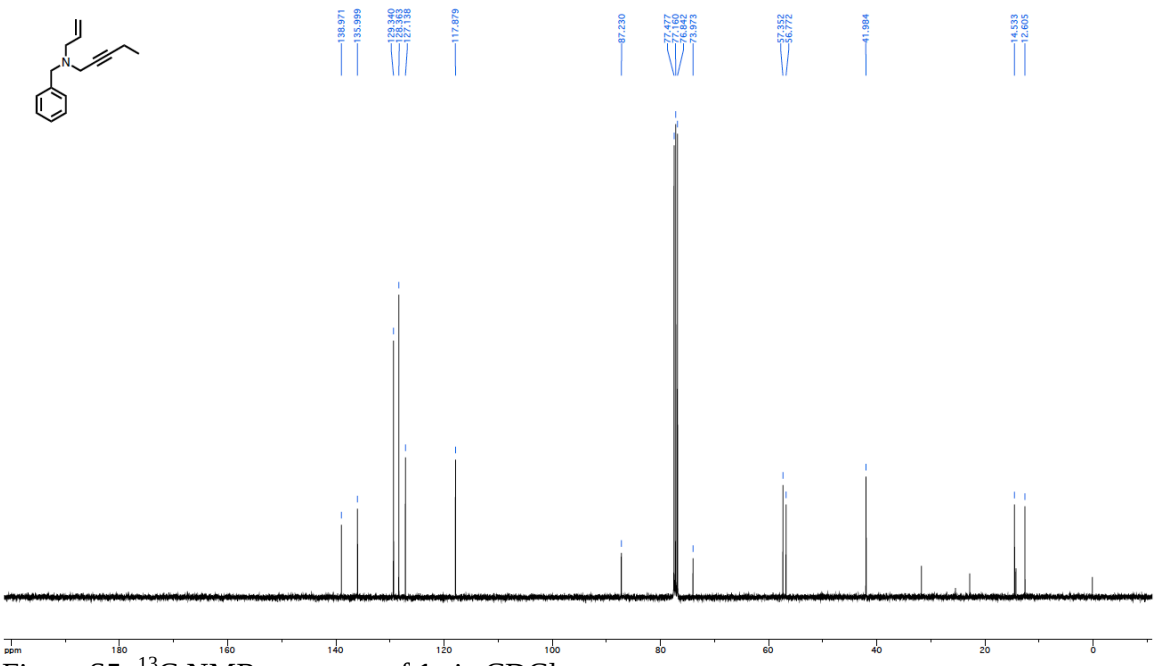
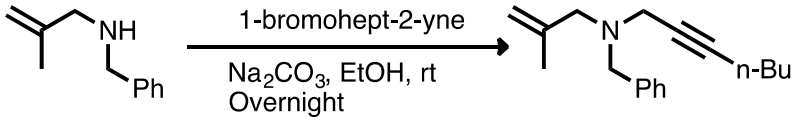


Figure S5: ^{13}C NMR spectrum of **1c** in $CDCl_3$.

Synthesis of *N*-benzyl-*N*-(2-methylallyl)hept-2-yn-1-amine (1d)



To a 100 mL round bottom flask with a stir bar were added 2.63 g *N*-benzyl(2-methylallyl)amine[S5] (0.0155 mol) and 50 mL EtOH. To this was added 3.287 g Na_2CO_3 (2 equiv, 0.0310 mol) and then 2.986 g 1-bromo-2-heptyne[S6] (1.05 equiv, 0.0171 mol) was added dropwise over 5 minutes. The reaction mixture was left to stir overnight at room temperature and then poured into a separatory funnel containing 100 mL 4 N HCl. The aqueous layer was washed once with hexanes. The aqueous layer was then basified to pH 14 using a saturated NaOH solution. The aqueous layer was extracted with 3x 20 mL and 1x 40 mL hexanes. The organics were collected and washed with brine, dried over $MgSO_4$, and concentrated on a rotovap. The crude oil was purified by column chromatography on silica gel using 5% EtOAc/hexanes to give **1d** as a clear, colorless oil (2.915 g, 74% yield).

^{1}H NMR (400 MHz, $CDCl_3$; δ, ppm): 0.96 (t, *J* = 7.2 Hz, 4H, -CH_2CH_3), 1.56-1.49 (m, 4H, -$CH_2CH_2CH_2CH_3$), 1.79 (s, 3H, $H_3CC(CH_2$-)=CH_2), 2.26 (tt, *J* = 6.9, 2.2 Hz, 2H, $CH_2CCCH_2CH_2$-), 3.05 (s, 2H, $H_3CC(CH_2N$-)=CH_2), 3.25 (t, *J* = 2.2 Hz, 2H, -NCH_2CCCH_2-), 3.60 (s, 2H, -NCH_2Ph), 4.89 (td, *J* = 1.5, 0.8 Hz, 1H, H*H*C=C(CH_3)CH_2-), 4.99 (dq, *J* = 2.3, 1.1 Hz, 1H, H*H*C=C(CH_3)CH_2-), 7.27-7.23 (m, 1H, -NCH_2(*p*-*H*C_6H_4)), 7.34-7.29 (m, 2H, -NCH_2(*o*-*H*$_2C_6H_3$)), 7.39-7.36 (m, 2H-NCH_2(*m*-*H*$_2C_6H_3$)).

^{13}C NMR (101 MHz, $CDCl_3$; δ, ppm): 13.8, 18.6, 20.9, 22.1, 31.4, 41.9, 57.2, 60.4, 74.7, 85.7, 113.2, 127.0, 128.3, 129.1, 139.5, 143.5.

GC-HRMS: Calc for $C_{18}H_{25}N$ [M^+] 255.1987; found 255.1963.

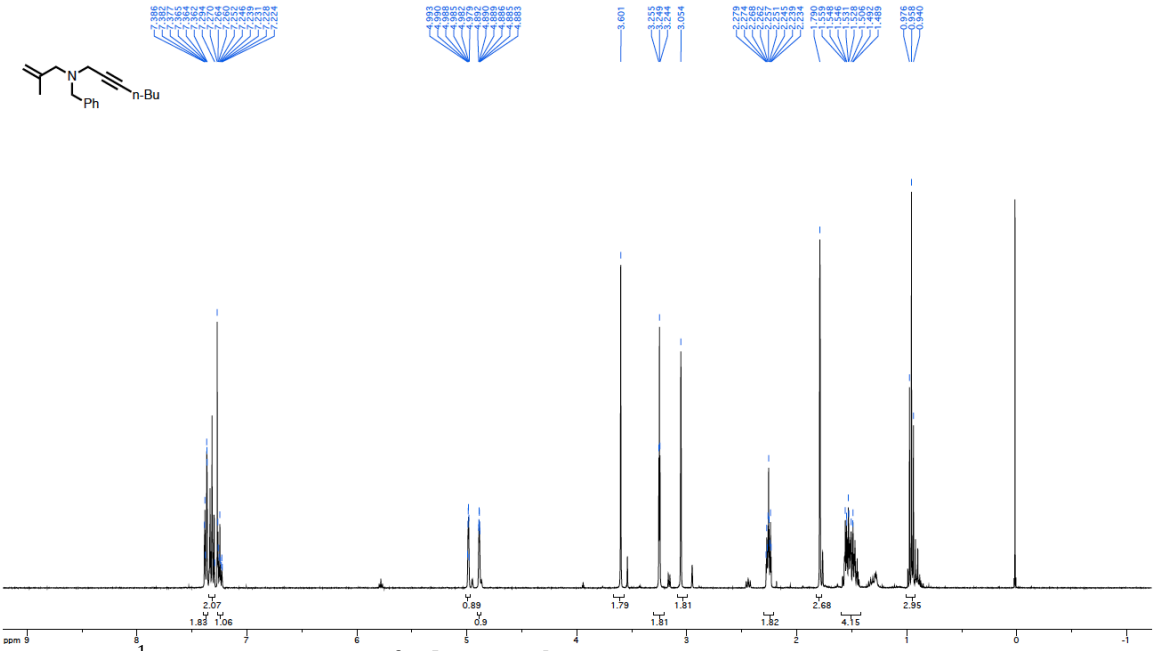


Figure S6: ^{1}H NMR spectrum of **1d** in $CDCl_3$.

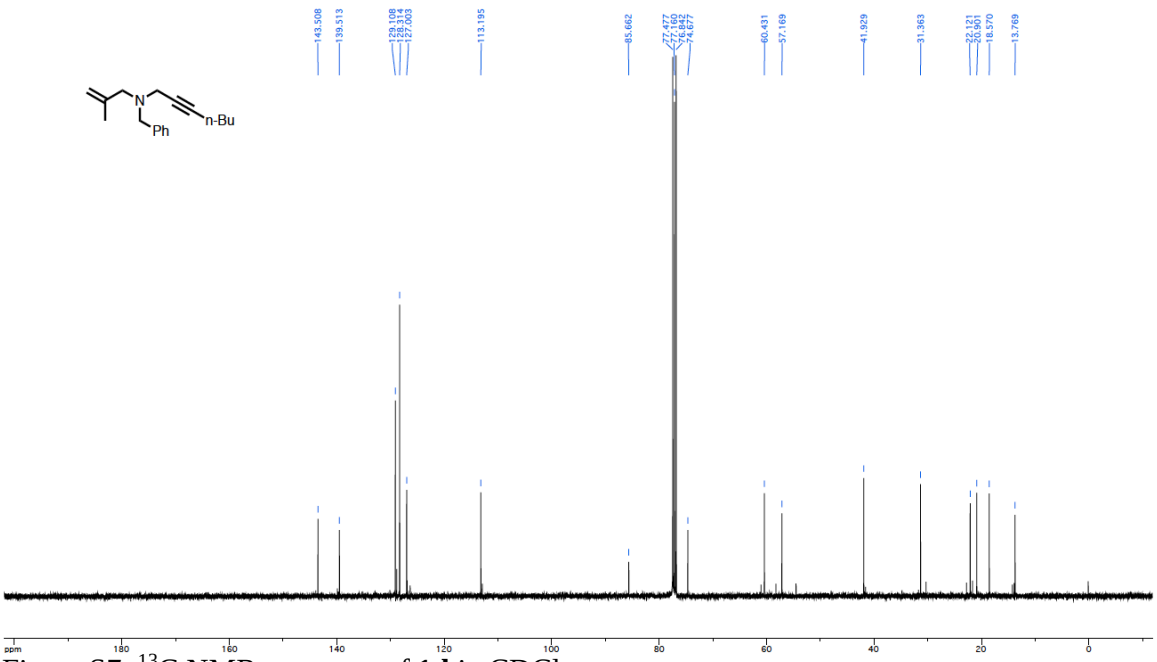
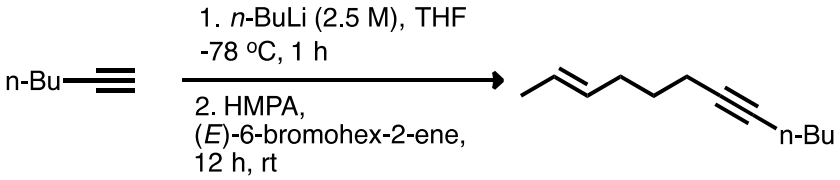


Figure S7: ^{13}C NMR spectrum of **1d** in $CDCl_3$.

Synthesis of (*E*)-dodec-2-en-7-yne (1e)



In a glovebox, a 100 mL Schlenk flask with a small stir bar was charged with 20 mL dry THF. The flask was removed from the glovebox, attached to a N_2 Schlenk line, and then cooled to -78 °C. 1.83 g of 1-hexyne (1.2 equiv, 2.559 mL, 0.022 mol) was then added and the solution was stirred for 5 minutes. To this was added 8.83 mL n-BuLi (1.2 equiv, 2.5 M in hexanes, 0.022 mol) dropwise over 15 minutes. The reaction mixture was then left to stir for 1 h. To this was added 3 g of (*E*)-6-bromohex-2-ene[S8] followed by 10 mL HMPA. The reaction mixture was allowed to warm to room temperature and stirred for 12 h. The reaction was quenched with 5 mL saturated NH_4Cl and then poured into a separatory funnel containing 50 mL 2 N HCl. The aqueous layer was then extracted 3x with pentanes, the organic layers were collected, washed with 25 mL 2 N HCl, 50 mL H_2O, and 50 mL brine, dried over $MgSO_4$, filtered and concentrated on a rotovap to give a yellow oil. The crude yellow oil was passed through a silica plug with hexanes to give **1e** as a clear, colorless oil (2.11 g, 69.6% yield).

^{1}H NMR (400 MHz, $CDCl_3$; δ, ppm): 0.90 (t, *J* = 7.2 Hz, 3H, -CH_2CH_3), 1.53-1.38 (m, 6H, -$CH_2CH_2CH_2$- and -$CH_2CH_2CH_2CH_3$), 1.64-1.62 (m, 3H, CH_3CH=CH-), 2.06-2.03 (m, 2H, -CH=CHCH_2-), 2.15-2.10 (m, 4H, -CH_2CCCH_2-), 5.48-5.35 (m, 2H, -CH=CH-).

^{13}C NMR (101 MHz, $CDCl_3$; δ, ppm): 13.5, 17.8, 18.1, 18.4, 21.9, 29.0, 31.3, 31.6, 79.8, 80.2, 125.3, 130.5.

GC-HRMS: Calc for $C_{12}H_{20}$ [M^+] 164.1565; found 164.1565.

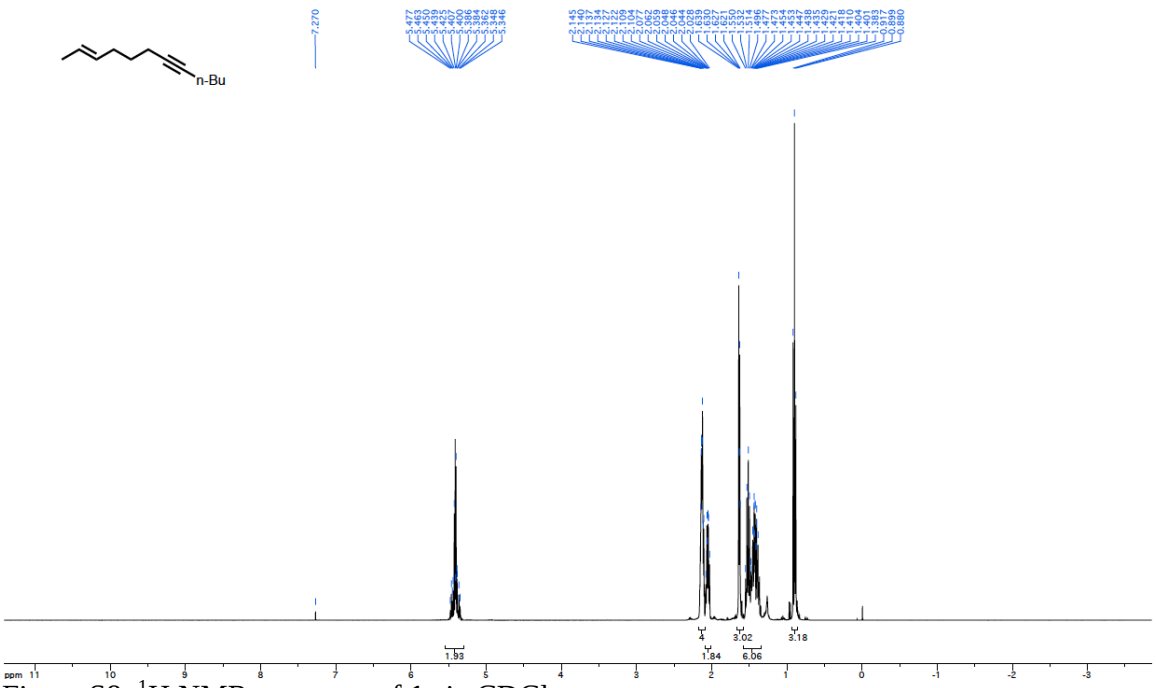


Figure S8: ^{1}H NMR spectrum of **1e** in $CDCl_3$.

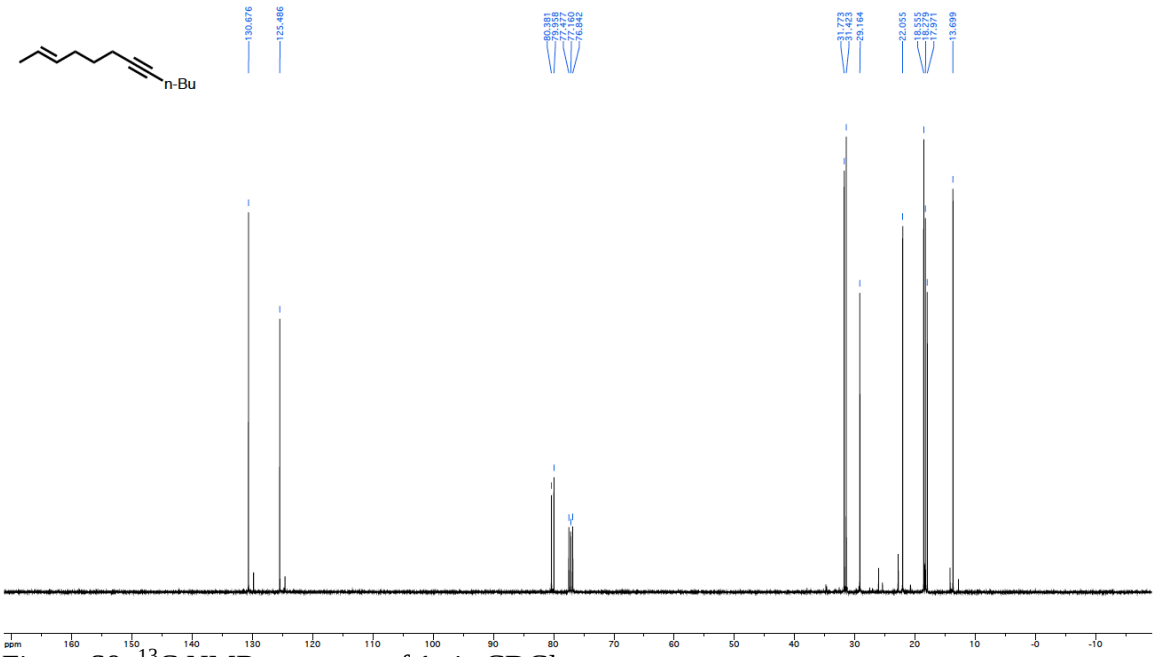
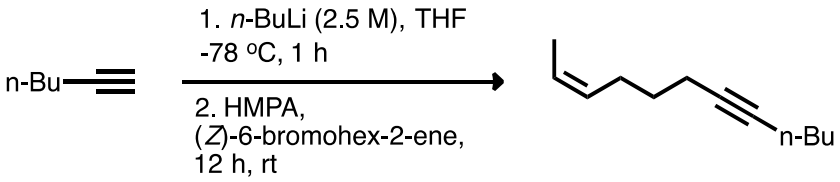


Figure S9: ^{13}C NMR spectrum of **1e** in $CDCl_3$.

Synthesis of (*Z*)-dodec-2-en-7-yne (1f)



In a glovebox, a 100 mL Schlenk flask with a small stir bar was charged with 20 mL dry THF. The flask was removed from the glovebox, placed on a N_2 Schlenk line, and then cooled to -78 °C. 1.83 g of 1-hexyne (1.2 equiv, 2.56 mL, 0.022 mol) was then added and the solution was stirred for 5 minutes. To this was added 8.83 mL n-BuLi (1.2 equiv, 2.5 M in hexanes, 0.022 mol) dropwise over 15 minutes. The reaction mixture was then left to stir for 1 h. To this was added 3.00 g of (*Z*)-6-bromohex-2-ene[S7] (1.0 equiv, 0.018 mol) followed by 10 mL HMPA. The reaction mixture was allowed to warm to room temperature and stirred for 12 h. The reaction mixture was quenched with 5 mL saturated NH_4Cl and poured into a separatory funnel containing 50 mL 2 N HCl. The aqueous layer was then extracted 3x with pentanes, the organic layers were collected, washed with 25 mL 2 N HCl, 50 mL H_2O, and 50 mL brine, dried over $MgSO_4$, filtered and concentrated on a rotovap to give a yellow oil. The crude yellow oil was passed through a silica plug of hexanes to give **1f** as a clear, colorless oil (2.28 g, 75% yield).

^{1}H NMR (400 MHz, $CDCl_3$; δ, ppm): 0.90 (t, *J* = 7.2 Hz, 3H, -CH_2CH_3), 1.46-1.39 (m, 4H, -CH_2CH_2-), 1.53 (quint, *J* = 7.3 Hz, 2H, -$CH_2CH_2CH_2$-), 1.61 (ddt, *J* = 6.7, 1.7, 0.8 Hz, 3H, CH_3CH=CH-), 2.16-2.11 (m, 6H, -CH=CHCH_2- and -CH_2CCCH_2-), 5.36 (dtq, *J* = 10.7, 7.2, 1.7 Hz, 1H, -C*H*=CH-), 5.51-5.43 (m, 1H, -C*H*=CH-).

^{13}C NMR (101 MHz, $CDCl_3$; δ, ppm): 12.8, 13.7, 18.4, 18.6, 22.1, 26.1, 29.1, 31.4, 80.0, 80.4, 124.6, 129.8.

GC-HRMS: Calc for $C_{12}H_{20}$ [M^+] 164.1565; found 164.1566.

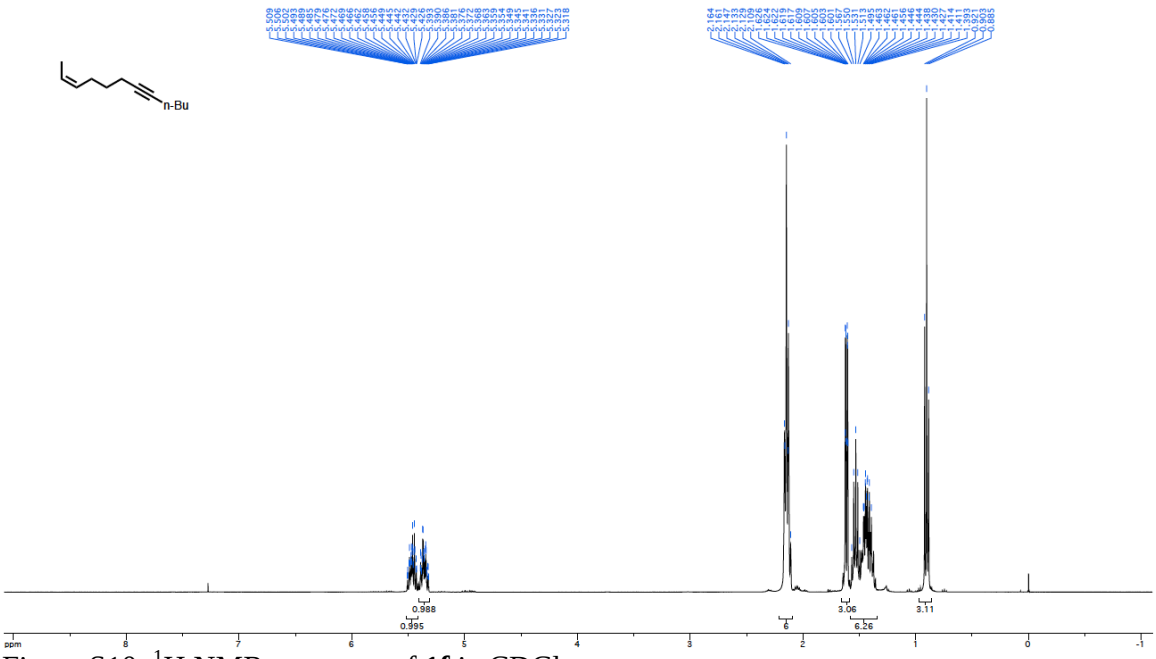


Figure S10: ^{1}H NMR spectrum of **1f** in $CDCl_3$.

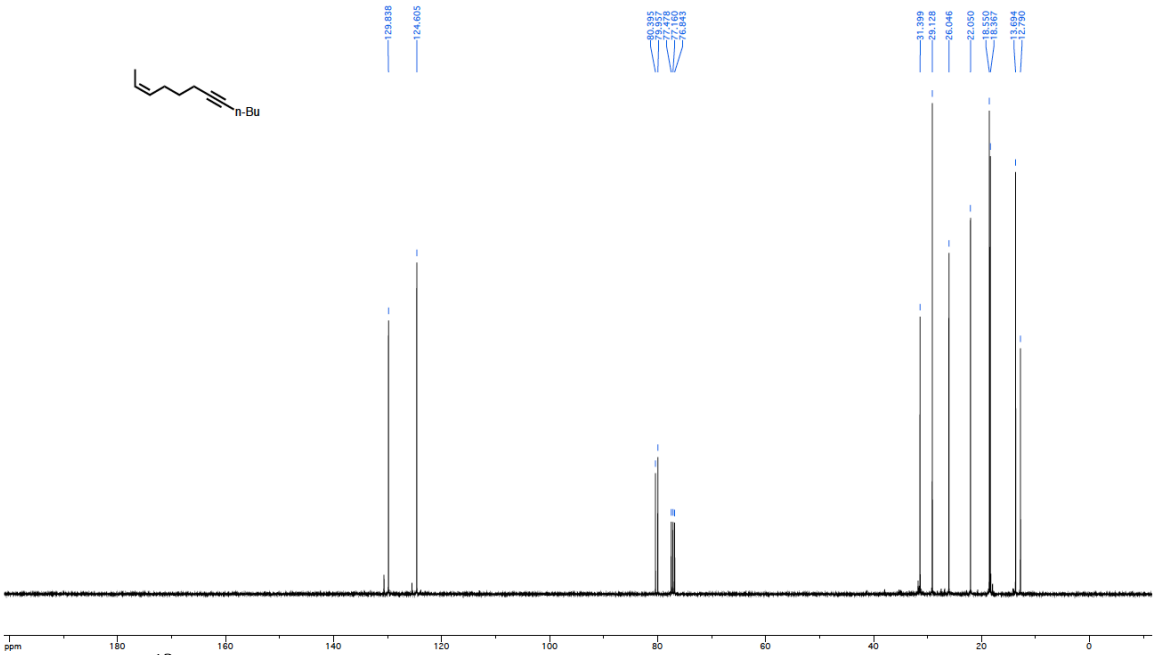
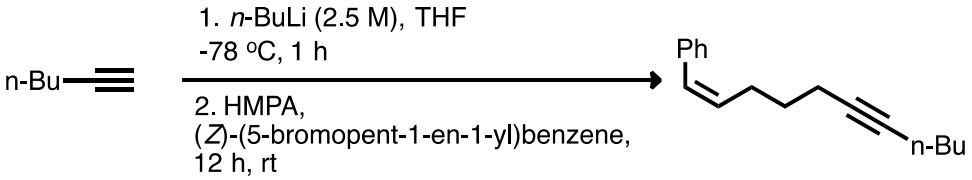


Figure S11: ^{13}C NMR spectrum of **1f** in $CDCl_3$.

Synthesis of (*Z*)-undec-1-en-6-yn-1-ylbenzene (1g)



In a glovebox, a 100 mL Schlenk flask with a small stir bar was charged with 20 mL dry THF. The flask was removed from the glovebox, attached to a N_2 Schlenk line, and then cooled to -78 °C. 1.2 g of 1-hexyne (1.2 equiv, 1.68 mL, 0.0146 mol) was then added and the solution was stirred for 5 minutes. To this was added 5.86 mL n-BuLi (1.1 equiv, 2.5 M in hexanes, 0.022 mol) dropwise over 15 minutes. The reaction mixture was then left to stir for 1 h. To this was added 3.00 g of (*Z*)-(5-bromo-pent-1-en-1-yl)benzene at 0 °C,[S9] followed by 10 mL HMPA. The reaction mixture was then allowed to warm to room temperature whereupon the reaction turned a deep red color and was left to stir for 12 h. The reaction was quenched with 5 mL saturated NH_4Cl and then poured into a separatory funnel containing 50 mL 2 N HCl and 50 mL hexanes. The aqueous layer was extracted 3x with hexanes, the organic layers were collected and washed with 50 mL $NaHCO_3$, 50 mL H_2O, and 50 mL brine, dried over $MgSO_4$, filtered and concentrated on a rotovap to give a colorless oil. The crude oil was passed through a silica plug of pentane to give **1g** as a clear, colorless oil (1.26 g, 41.7% yield).

^{1}H NMR (400 MHz, $CDCl_3$; δ, ppm): 0.91 (t, *J* = 7.2 Hz, 3H, -CH_2CH_3), 1.46-1.40 (m, 4H, -$CH_2CH_2CH_2CH_3$), 1.66 (quint, *J* = 7.4 Hz, 2H, -$CH_2CH_2CH_2$-), 2.23-2.13 (m, 4H, CH_2CCCH_2-), 2.46 (qd, *J* = 7.4, 2.0 Hz, 2H, -CH=CHCH_2-), 5.67 (dt, *J* = 11.7, 7.3 Hz, 1H, -CH=C*H*CH_2-), 6.46 (d, *J* = 11.6 Hz, 1H, PhC*H*=CH-), 7.26-7.21 (m, 1H, -*p*-C_6H_4-*H*), 7.37-7.30 (m, 4H, -*o*,*m*-C_6H-H_4).

^{13}C NMR (101 MHz, $CDCl_3$; δ, ppm): 13.8, 18.6, 18.6, 22.1, 27.9, 29.5, 31.4, 79.7, 80.9, 126.6, 128.3, 128.9, 129.5, 132.2, 137.8.

GC-HRMS: Calc for $C_{17}H_{22}$ [M^+] 226.1722; found 226.1698.

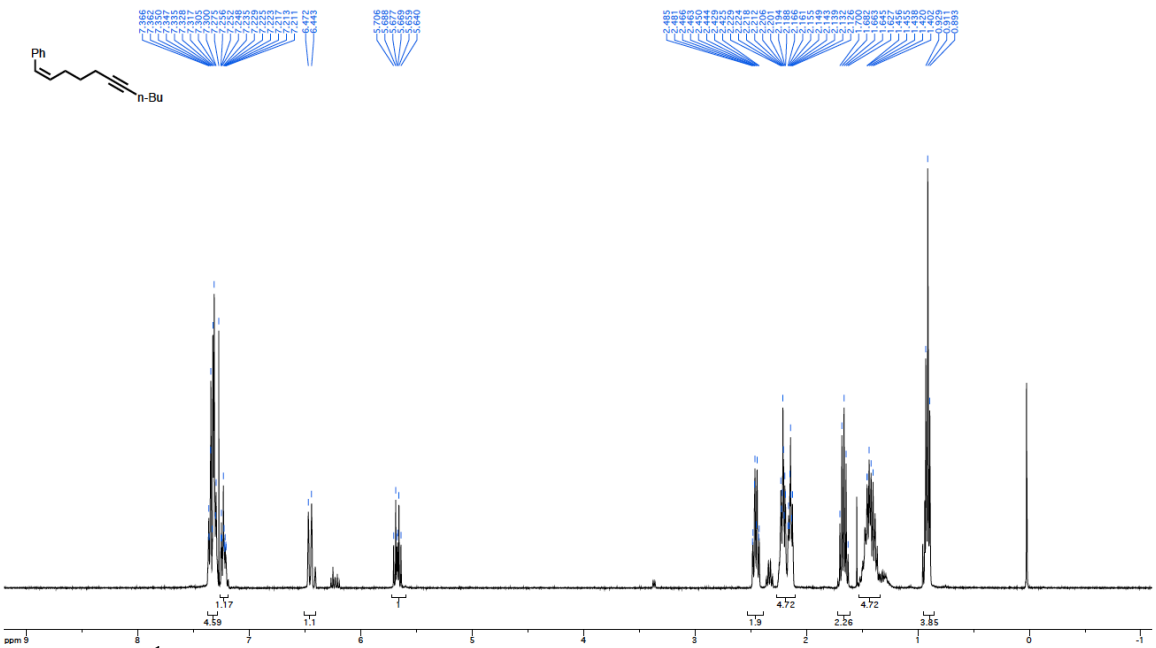


Figure S12: ^{1}H NMR spectrum of **1g** in $CDCl_3$.

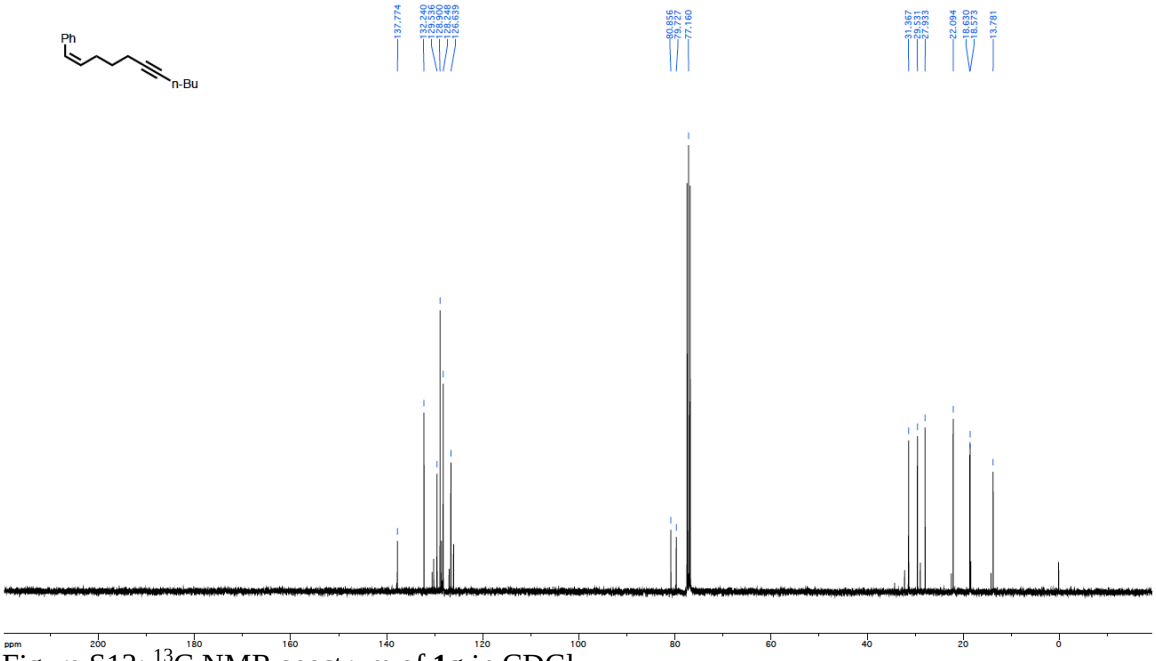
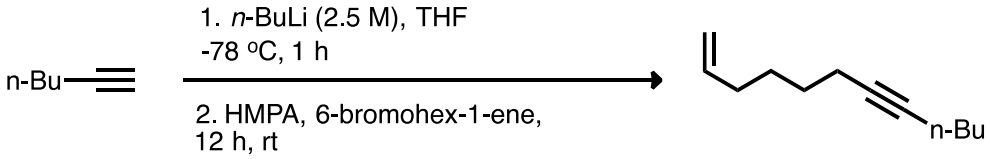


Figure S13: ^{13}C NMR spectrum of **1g** in $CDCl_3$.

Synthesis of dodec-1-en-7-yne (1h)



In a glovebox, a 100 mL Schlenk flask with a small stir bar was charged with 40 mL dry THF. The flask was removed from the glovebox, attached to a N_2 Schlenk line, and then cooled to -78 °C. 2.11 g of 1-hexyne (1.4 equiv, 2.95 mL, 0.0257 mol) was then added and the solution was stirred for 5 minutes. To this was added 10.3 mL n-BuLi (1.01 equiv, 2.5 M in hexanes, 0.0258 mol) dropwise over 15 minutes. The reaction mixture was then left to stir for 1 h. To this were added 3.00 g of 6-bromo-1-hexene (1.0 equiv, 0.0183 mol) and 150 mg NaI (0.05 equiv, 0.001 mol). The reaction mixture was then heated to 80 °C for 2 days. The reaction was quenched with 5 mL saturated NH_4Cl and then poured into a separatory funnel containing 100 mL H_2O. The aqueous layer was extracted 3x with hexanes, the organic layers were collected, washed with 50 mL brine, dried over $MgSO_4$, filtered and concentrated on a rotovap to give a yellow oil. The crude yellow oil was passed through a plug of silica using hexanes to give **1h** as a clear, colorless oil (2.22 g, 74% yield). Spectral data were consistent with literature values.[S10]

^{1}H NMR (400 MHz, $CDCl_3$; δ, ppm): 0.91 (d, J = 14.4 Hz, 3H, -CH_2CH_3), 1.53-1.26 (m, 10H), 2.18-2.04 (m, 6H), 4.95 (ddt, J = 10.2, 2.2, 1.1 Hz, 1H, HHC=$CHCH_2$-), 5.02 (dq, J = 17.1, 1.8 Hz, 1H, HHC=$CHCH_2$-), 5.82 (ddt, J = 17.0, 10.3, 6.7 Hz, 1H, H_2C=CHCH_2-).

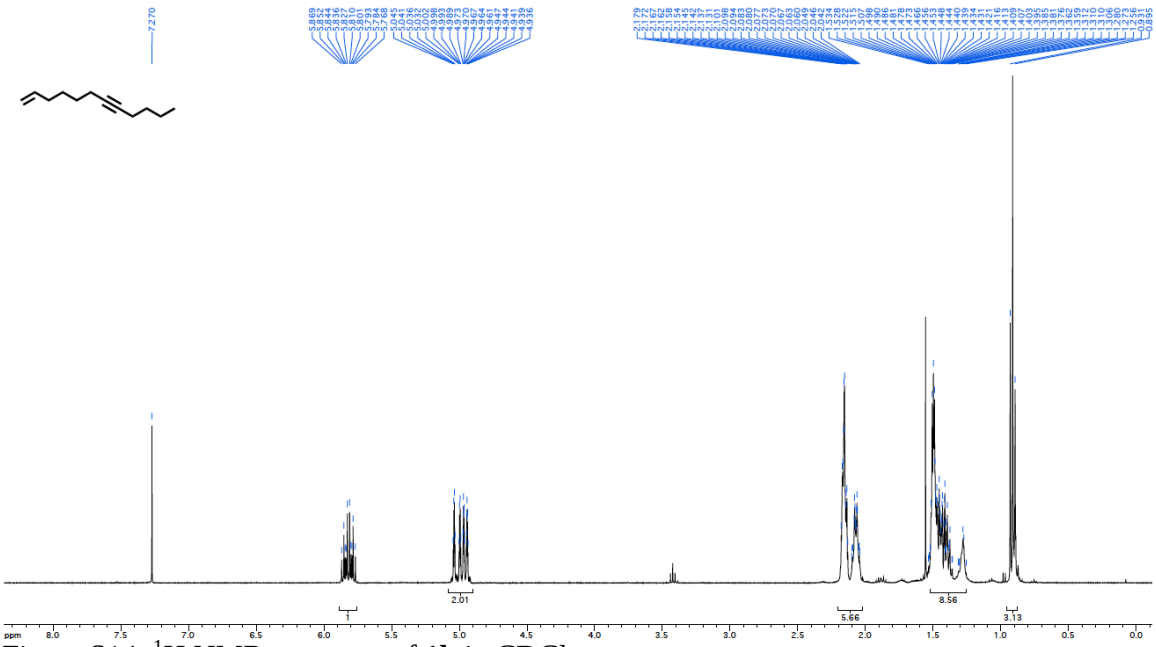
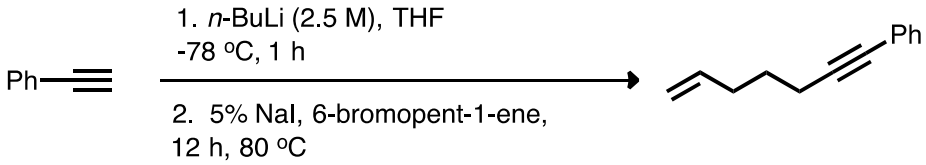


Figure S14: ^{1}H NMR spectrum of **1h** in $CDCl_3$.

Synthesis of hept-6-en-1-yn-1-ylbenzene (1i)



In a glovebox, a 100 mL Schlenk flask with a small stir bar was charged with 40 mL dry THF. The flask was removed from the glovebox, attached to a N_2 Schlenk line, and then cooled to -78 °C. 2.87 g of phenylacetylene (1.4 equiv, 0.0281 mol) was then added and the solution was stirred for 5 minutes. To this was added 11.3 mL n-BuLi (1.01 equiv, 2.5 M in hexanes, 0.0283 mol) dropwise over 15 minutes. The reaction mixture was then left to stir for 1 h. To this were added 3.00 g of 5-bromo-1-pentene (1.00 equiv, 2.04 mL, 0.0201 mol) and 160 mg NaI (0.05 equiv, 0.001 mol). The reaction mixture was then heated to 80 °C for 2 days. The reaction was quenched with 5 mL saturated NH_4Cl and then poured into a separatory funnel containing 100 mL H_2O. The aqueous layer was extracted 3x with pentanes, the organic layers were collected, washed with 25 mL 2 N HCl, 50 mL H_2O, and 50 mL brine, dried over $MgSO_4$, filtered and concentrated on a rotovap to give a yellow oil. The crude yellow oil was passed through a plug of silica using pentanes and then concentrated at 50 °C at 3 torr on a rotovap to remove any residual phenylacetylene, leaving **1i** as a clear off-yellow oil (2.918 g, 85.4% yield). Spectral data were consistent with literature values.[S11]

^{1}H NMR (400 MHz, $CDCl_3$; δ, ppm): 1.72 (quint, J = 7.3 Hz, 2H, -$CH_2CH_2CH_2$-), 2.27-2.22 (m, 2H, H_2C=CHCH_2CH_2-), 2.44 (t, J = 7.1 Hz, 2H, -CH_2CH_2CC-), 5.02 (ddt, J = 10.2, 2.1, 1.1 Hz, 1H, H*H*C=CHCH_2-), 5.09 (dq, J = 17.1, 1.8 Hz, 1H, H*H*C=CHCH_2-), 5.85 (ddt, J = 17.1, 10.3, 6.7 Hz, 1H, H_2C=C*H*CH_2-), 7.30-7.28 (m, 3H, -CC-*o/p*-$H_3C_6H_2$), 7.42-7.40 (m, 2H, -CC-*m*-$H_2C_6H_3$).

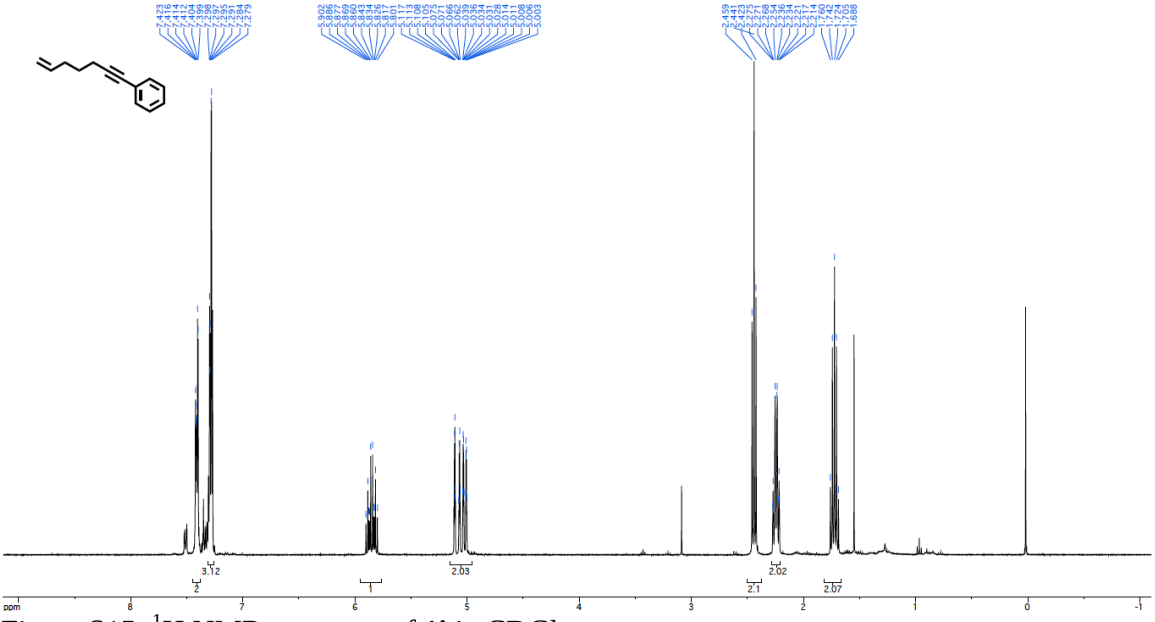
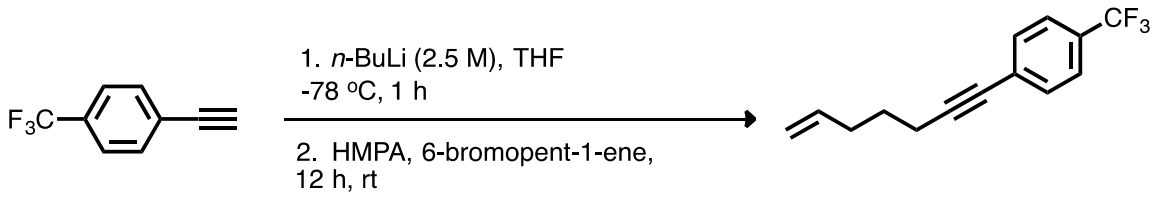


Figure S15: ^{1}H NMR spectrum of **1i** in $CDCl_3$.

Synthesis of 1-(hept-6-en-1-yn-1-yl)-4-(trifluoromethyl)benzene (1j)



In a glovebox, a 100 mL Schlenk flask with a small stir bar was charged with 40 mL dry THF. The flask was removed from the glovebox, attached to a N_2 Schlenk line, and then cooled to -78 °C. 2.8 g of 4-ethynyl-α,α,α-trifluorotoluene (1 equiv, 0.0164 mol) was then added and the solution was stirred for 5 minutes. To this was added 7.0 mL n-BuLi (1.13 equiv, 2.5 M in hexanes, 0.0175 mol) dropwise over 15 minutes. The reaction mixture was then left to stir for 1 h. To this were added 2.57 g of 5-bromopentene (1.05 equiv, 2.04 mL, 0.01724 mol) and HMPA (10 mL) and the mixture was warmed to room temperature and stirred overnight then heated to 50 °C for 1 h. The reaction was quenched with 5 mL saturated NH_4Cl and then poured into a separatory funnel containing 100 mL H_2O. The aqueous layer was extracted 3x with pentanes, the organic layers were collected, washed with 25 mL 2 N HCl, 50 mL H_2O, and 50 mL brine, dried over $MgSO_4$, filtered and concentrated on a rotovap to give a yellow oil. The crude yellow oil was vacuum distilled to give **1j** as a clear, colorless oil (2.06 g, 52.7% yield).

^{1}H NMR (400 MHz, $CDCl_3$; δ, ppm): 1.73 (quint, J = 7.3 Hz, 2H, -$CH_2C\mathit{H}_2CH_2$-), 2.26-2.20 (m, 2H, H_2C=CHCH_2CH_2-), 2.45 (t, J = 7.1 Hz, 2H, -$CH_2C\mathit{H}_2$CC-), 5.02 (ddt, J = 10.2, 1.9, 1.0 Hz, 1H, HHC=CHCH_2-), 5.08 (dq, J = 17.1, 1.7 Hz, 1H, HHC=CHCH_2-), 5.84 (ddt, J = 17.0, 10.3, 6.7 Hz, 1H, H_2C=C$\mathit{H}$$CH_2$-), 7.49 (d, J = 8.4 Hz, 2H, CH_2-(*m*-$\mathit{H}_2C_6H_2$-CF_3)), 7.54 (d, J = 8.4 Hz, 2H, CH_2-(*o*-$\mathit{H}_2C_6H_2$-CF_3)).

^{13}C NMR (101 MHz, $CDCl_3$; δ, ppm): 19.0, 27.9, 33.0, 80.0, 93.0, 115.5, 124.2 (q, $^1J_{C\text{-}F}$ = 272.1 Hz), 125.3 (q, $^3J_{C\text{-}F}$ = 3.8 Hz), 128.1 (q, $^4J_{C\text{-}F}$ = 1.5 Hz), 129.5 (q, $^2J_{C\text{-}F}$ = 32.6 Hz), 131.9, 137.8.

^{19}F NMR (470 MHz MHz, $CDCl_3$; δ, ppm): -61.6 (s, -CF_3).

GC-HRMS: Calc for $C_{14}H_{13}F_3$ [M^+] 238.0969; found 238.0960.

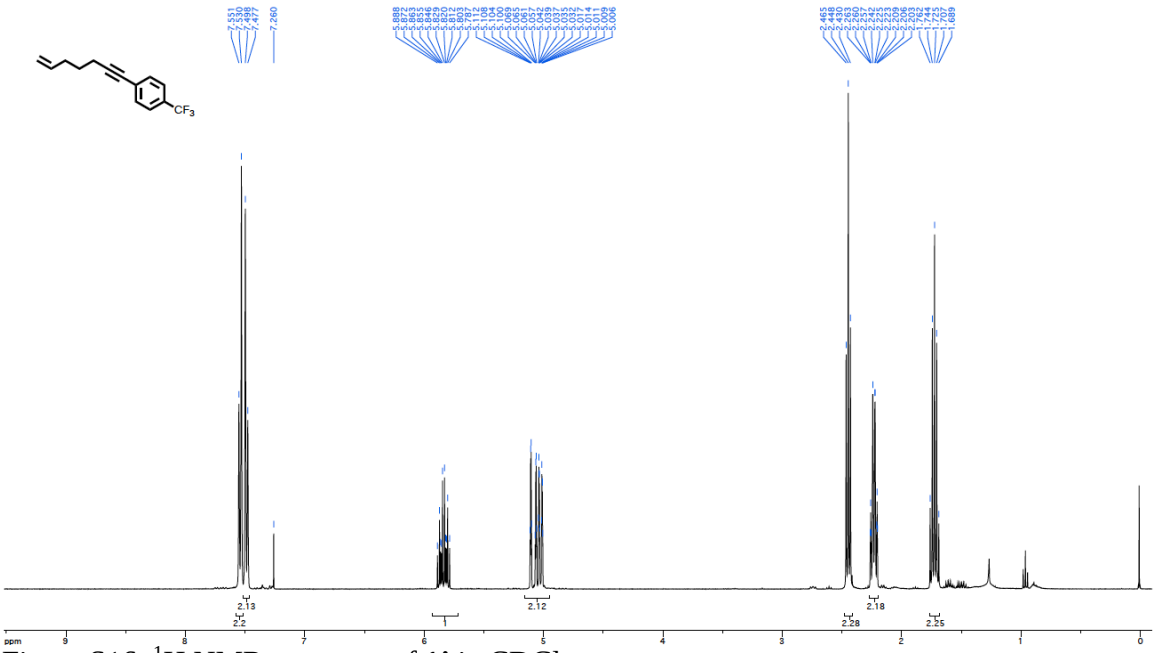


Figure S16: ^{1}H NMR spectrum of **1j** in $CDCl_3$.

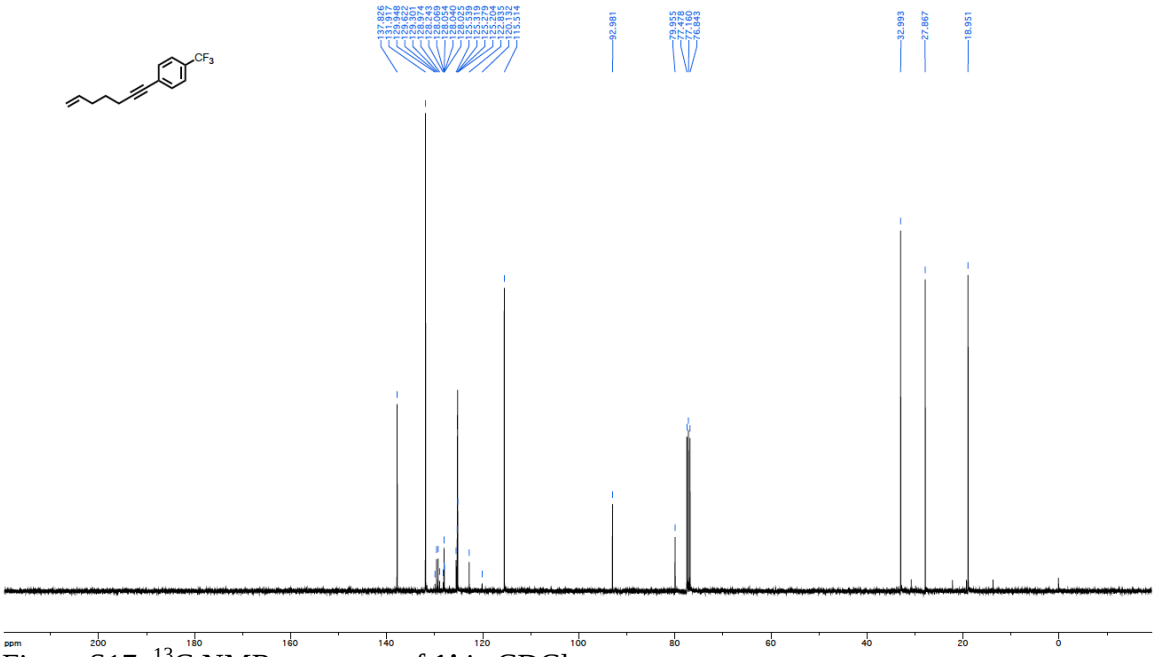


Figure S17: ^{13}C NMR spectrum of **1j** in $CDCl_3$.

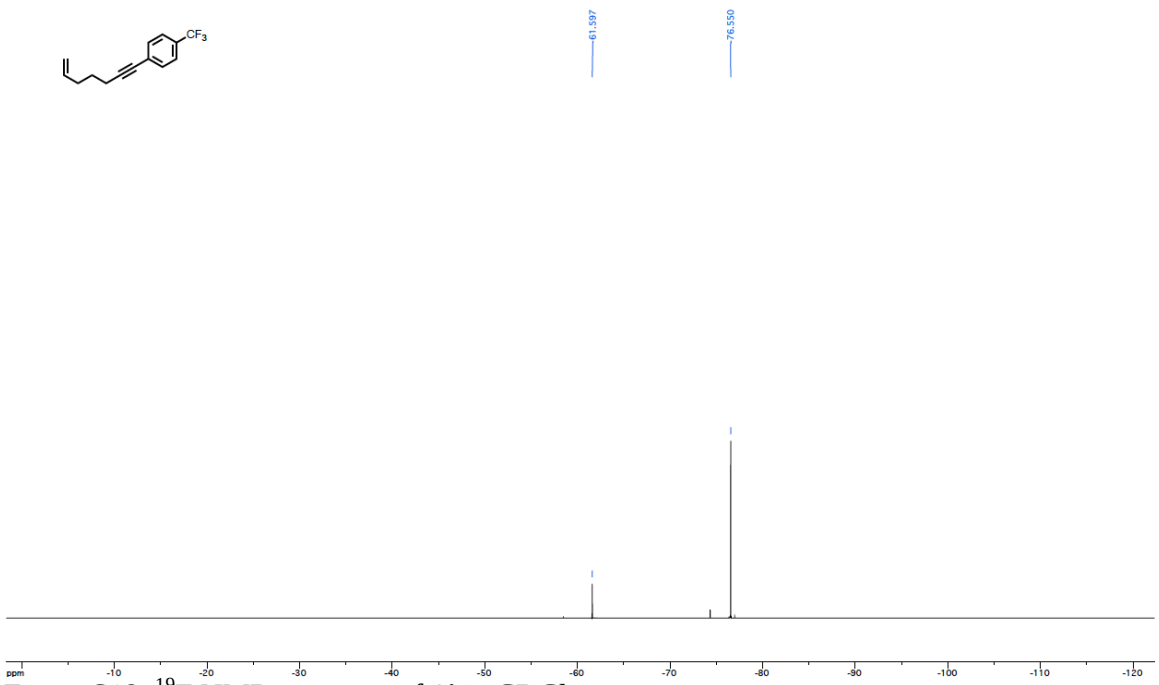
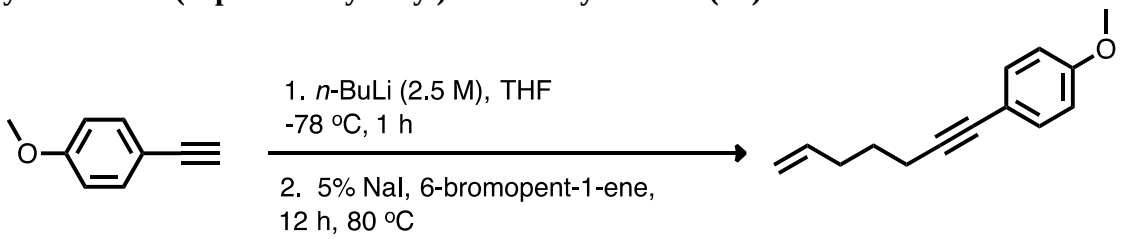


Figure S18: ^{19}F NMR spectrum of **1j** in $CDCl_3$.

Synthesis of 1-(hept-6-en-1-yn-1-yl)-4-methoxybenzene (1k)



In a glovebox, a 100 mL Schlenk flask with a small stir bar was charged with 40 mL dry THF. The flask was removed from the glovebox, attached to a N_2 Schlenk line, and then cooled to -78 °C. 3.00 g of 4-ethynylanisole (1.05 equiv, 0.022 mol) was then added and the solution was stirred for 5 minutes. To this was added 10.0 mL n-BuLi (1.13 equiv, 2.5 M in hexanes, 0.025 mol) dropwise over 15 minutes. The reaction mixture was then left to stir for 1 h. To this were added 3.2 g of 5-bromopentene (1 equiv, 2.53 mL, 0.0214 mol) and 160 mg NaI (0.05 equiv, 0.001 mol). The reaction mixture was then heated to 80 °C for 2 days. The reaction was quenched with 5 mL saturated NH_4Cl and poured into a separatory funnel containing 100 mL H_2O. The aqueous layer was extracted 3x with pentanes, the organic layers were collected, washed with 25 mL 2 N HCl, 50 mL H_2O, and 50 mL brine, dried over $MgSO_4$, filtered and concentrated on a rotovap to give a yellow oil. The crude yellow oil was vacuum distilled at 110 °C to give **1k** as a clear, colorless oil (2.74 g, 63.9% yield).

^{1}H NMR (400 MHz, $CDCl_3$; δ, ppm): 1.71 (quint, J = 7.3 Hz, 2H, -$CH_2CH_2CH_2$-), 2.26-2.20 (m, 2H, H_2C=CHCH_2CH_2-), 2.42 (t, J = 7.1 Hz, 2H, -CH_2CH_2CC-), 3.81 (s, 3H, -OCH_3), 5.01 (ddt, J = 10.2, 2.1, 1.1 Hz, 1H, H*H*C=CHCH_2-), 5.08 (dq, J = 17.1, 1.8 Hz, 1H, H*H*C=CHCH_2-), 5.85 (ddt, J = 17.1, 10.3, 6.7 Hz, 1H, H_2C=C*H*CH_2-), 6.84-6.81 (m, 2H, -CH_2-(*o*-H_2-C_6H_2-OCH_3)), 7.36-7.32 (m, 2H, -CH_2-(*m*-H_2-C_6H_2-OCH_3)).

^{13}C NMR (101 MHz, $CDCl_3$; δ, ppm): 19.0, 28.2, 33.0, 55.4, 80.7, 88.4, 113.9, 115.3, 116.3, 133.0, 138.1, 159.2.

GC-HRMS: Calc for $C_{14}H_{16}O_1$ [M^+] 200.1201; found 200.1191.

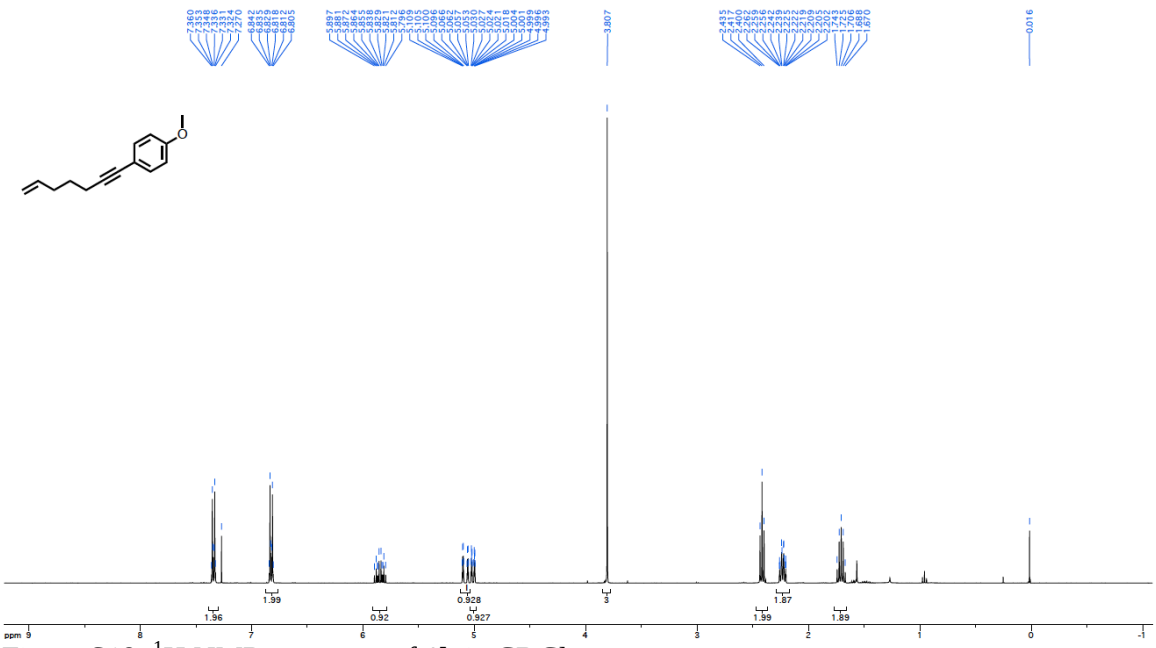


Figure S19: ^{1}H NMR spectrum of **1k** in $CDCl_3$.

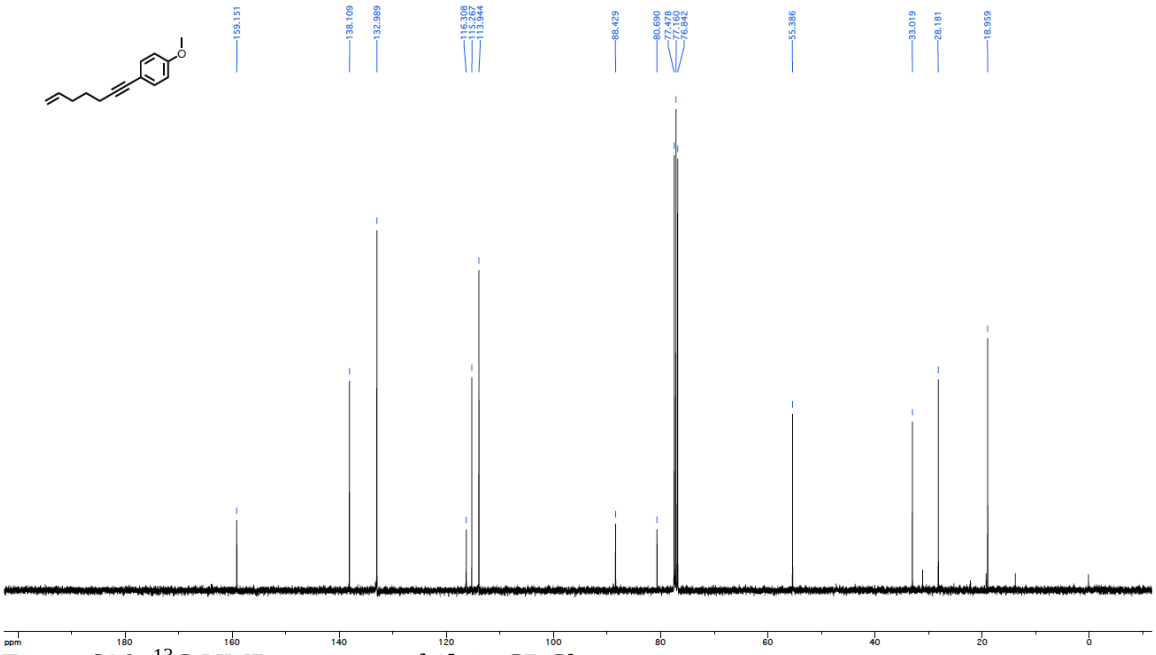
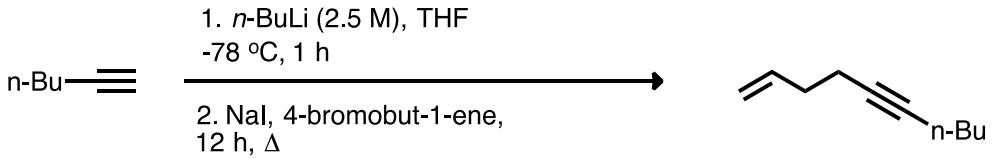


Figure S20: ^{13}C NMR spectrum of **1k** in $CDCl_3$.

Synthesis of dec-1-en-5-yne (1l)



In a glovebox, a 100 mL Schlenk flask with a small stir bar was charged with 40 mL dry THF. The flask was removed from the glovebox, attached to a N_2 Schlenk line, and then cooled to -78 °C. 2.73 g of 1-hexyne (1.5 equiv, 0.0333 mol) was then added and the solution was stirred for 5 minutes. To this was added 13.3 mL n-BuLi (1.47 equiv, 2.5 M in hexanes, 0.03325 mol) dropwise over 15 minutes. The reaction mixture was then left to stir for 1 h. To this were added 3.00 g of 4-bromo-1-butene (1.0 equiv, 0.0222 mol) and 150 mg NaI (0.05 equiv, 0.001 mol). The reaction mixture was then heated to 80 °C for 20 h. The reaction was quenched with 5 mL saturated NH_4Cl and then poured into a separatory funnel containing 100 mL H_2O. The aqueous layer was extracted 3x with hexanes, the organic layers were collected, washed with 50 mL brine, dried over $MgSO_4$, filtered and concentrated on a rotovap to give a yellow oil. The crude yellow oil was passed through a plug of silica using pentane to give **1l** as a clear, colorless oil (1.5 g, 49.6% yield). Spectral data were consistent with literature values.[S12]

^{1}H NMR (400 MHz, $CDCl_3$; δ, ppm): 0.91 (t, J = 7.2 Hz, 3H, -CH_2CH_3), 1.49-1.38 (m, 4H, -$CH_2CH_2CH_2CH_3$), 2.18-2.13 (m, 2H, H_2C=CHCH_2CH_2-), 2.25-2.23 (m, 4H –$CH_2CH_2CCCH_2CH_2$-), 5.03-5.00 (m, 1H, H*H*C=CHCH_2-), 5.10-5.05 (m, 1H, H*H*C=CHCH_2-), 5.92-5.82 (m, 1H, H_2C=C*H*CH_2-).

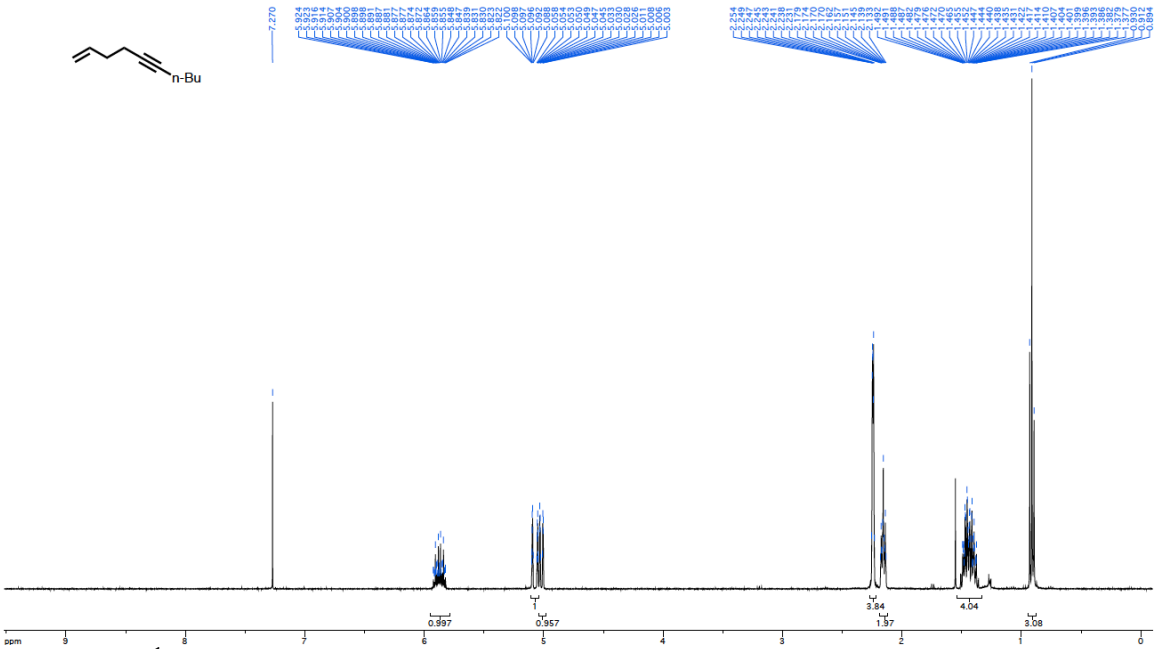
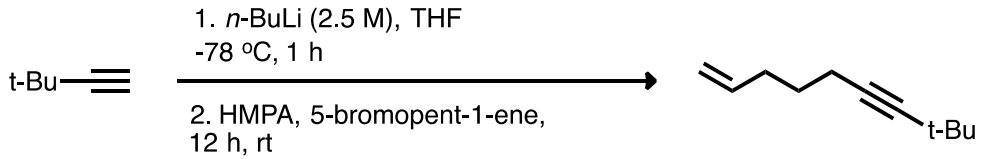


Figure S21: ^{1}H NMR spectrum of **1l** in $CDCl_3$.

Synthesis of 8,8-dimethylnon-1-en-6-yne (1m)



In a glovebox, a 100 mL Schlenk flask with a small stir bar was charged with 20 mL dry THF. The flask was removed from the glovebox, attached to a N_2 Schlenk line, and then cooled to -78 °C. 2.3 g of 3,3-dimethylpropyne (1.4 equiv, 0.0281 mol) was then added and the solution was stirred for 5 minutes. To this was added 11.0 mL n-BuLi (1.36 equiv, 2.5 M in hexanes, 0.0275 mol) dropwise over 15 minutes. The reaction mixture was then left to stir for 1 h. To were added 3.0 g of 5-bromopent-1-ene (1 equiv, 2.53 mL, 0.0201 mol) and 10 mL HMPA. The reaction mixture was stirred overnight at room temperature. The reaction was quenched with 5 mL saturated NH_4Cl and then poured into a separatory funnel containing 100 mL H_2O. The aqueous layer was extracted 3x with pentanes, the organic layers were collected, washed with 25 mL 2 N HCl, 50 mL H_2O, and 50 mL brine, dried over $MgSO_4$, filtered and concentrated on a rotovap to give a yellow oil. The crude yellow oil was then passed through a silica plug using pentanes as the eluent to give **1m** as a clear colorless oil (2.01 g, 66.6% yield).

^{1}H NMR (400 MHz, $CDCl_3$; δ, ppm): 1.20 (s, 9H, $C(CH_3)_3$), 1.57 (quint, J = 7.3 Hz, 2H, -$CH_2CH_2CH_2$-), 2.18-2.12 (m, 4H, -$CH_2CH_2CH_2$-), 4.97 (ddt, J = 10.2, 2.2, 1.1 Hz, 1H, HHC=$CHCH_2$-), 5.04 (dq, J = 17.1, 1.8 Hz, 1H, HHC=$CHCH_2$-), 5.82 (ddt, J = 17.0, 10.2, 6.8 Hz, 1H, H_2C=$CHCH_2$-).

^{13}C NMR (101 MHz, $CDCl_3$; δ, ppm): 18.2, 27.5, 28.5, 31.6, 32.9, 78.2, 89.5, 115.0, 138.4.

GC-HRMS: Calc for $C_{11}H_{18}$ [M^+] 150.1409; found 151.1401.

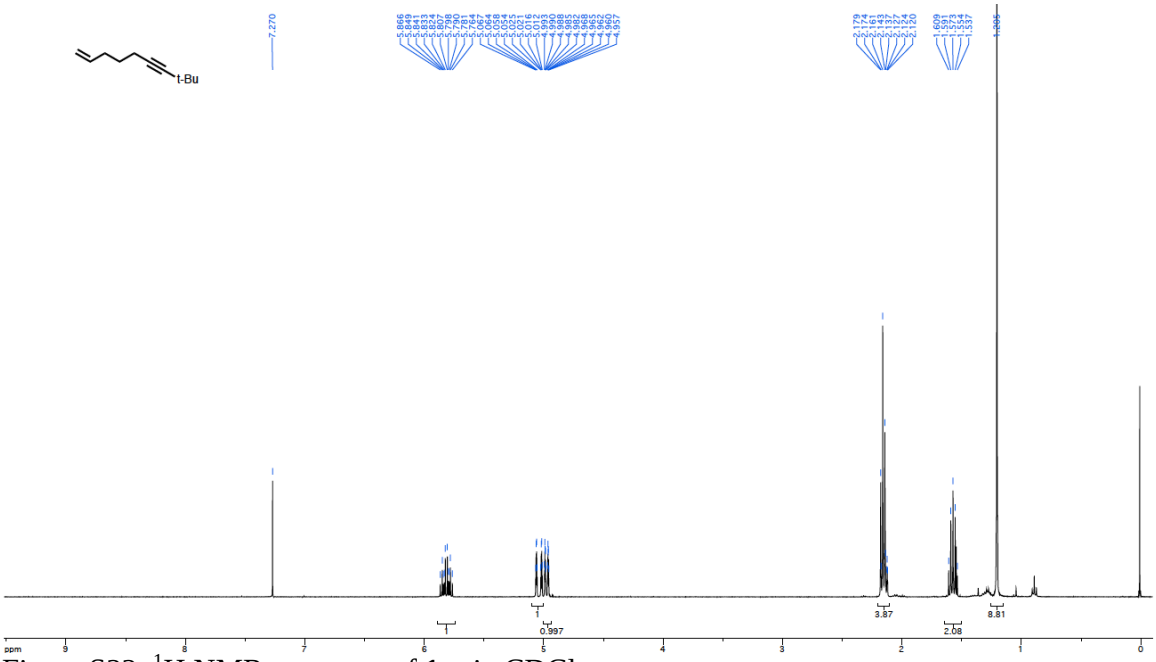


Figure S22: ^{1}H NMR spectrum of **1m** in $CDCl_3$.

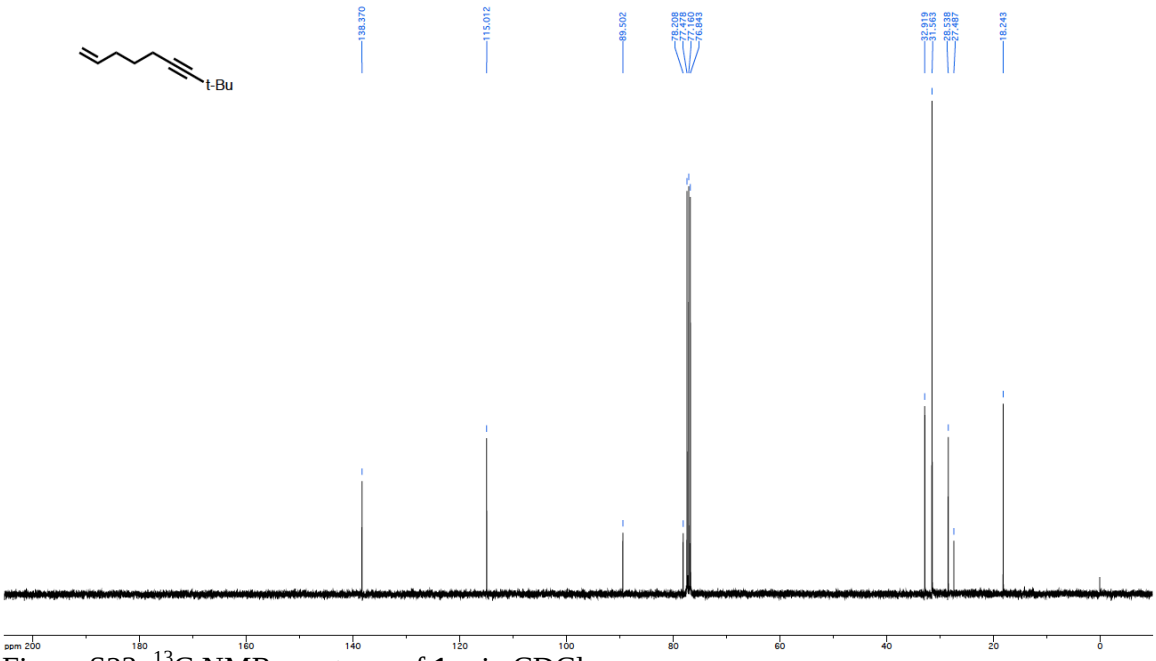
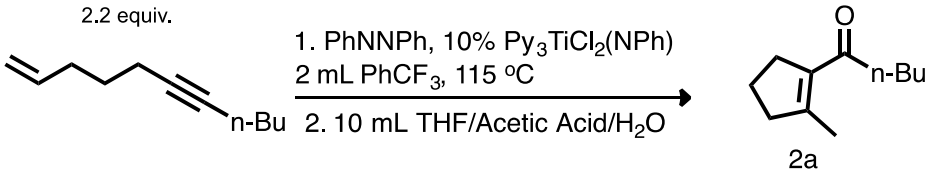


Figure S23: ^{13}C NMR spectrum of **1m** in $CDCl_3$.

Synthesis of 1-(2-methylcyclopent-1-en-1-yl)pentan-1-one (2a)



Following literature procedure:[S2] To a 20 mL scintillation vial were added 19.0 mg $(py)_3TiCl_2(NPh)$ (0.1 equiv, 0.042 mmol), 83.8 mg azobenzene (1 equiv, 0.460 mmol), 160.8 mg dodec-1-en-7-yne (2.1 equiv, 0.985 mmol) and 2 mL α,α,α-trifluorotoluene. The vial was then sealed and heated to 110 °C for 16 h. The reaction was concentrated in vacuo to a brown sticky oil and then diluted with 10 mL THF. To this were added acetic acid (2.5 mL) and DI H_2O (1 mL) and the reaction was left to stir overnight at room temperature (20 h). The reaction mixture was then diluted with 25 mL EtOAc, washed with H_2O (2x 50 mL) and $NaHCO_3$ (50 mL). The organic layer was dried over $MgSO_4$, filtered, and concentrated. The crude orange mixture was purified by column chromatography (neutral alumina) using hexanes as the eluent to give a light yellow oil of **2a** (77 mg, 49.9% yield).

^{1}H NMR (500 MHz, CDCl3; δ, ppm): 0.92 (t, *J* = 7.4 Hz, 3H, -CH_2CH_3), 1.34 (sextet, *J* = 7.47 2H, -$CH_2CH_2CH_3$), 1.59 (quint, *J* = 7.49, 2H, -$CCH_2CH_2CH_2C$-), 1.83 (quint, *J* = 7.55 Hz, 2H, -$CH_2CH_2C(O)$-), 2.08 (s, 3H, -CCH_3), 2.49 (m, 4H, -$CH_2C(O)$- & -CH_2CCH_3), 2.67 (t, *J* = 6.38, 2H, -$CH2CC(O)$-).

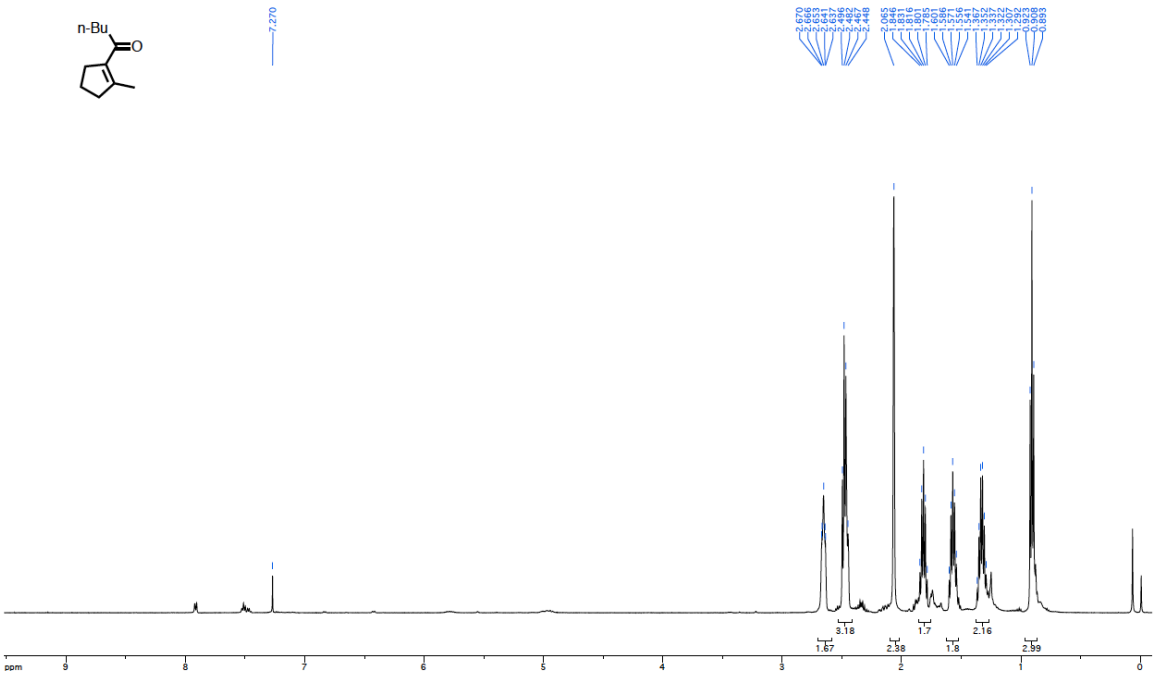


Figure S24: ^{1}H NMR spectrum of **2a** in $CDCl_3$.

NMR Reaction of 1a

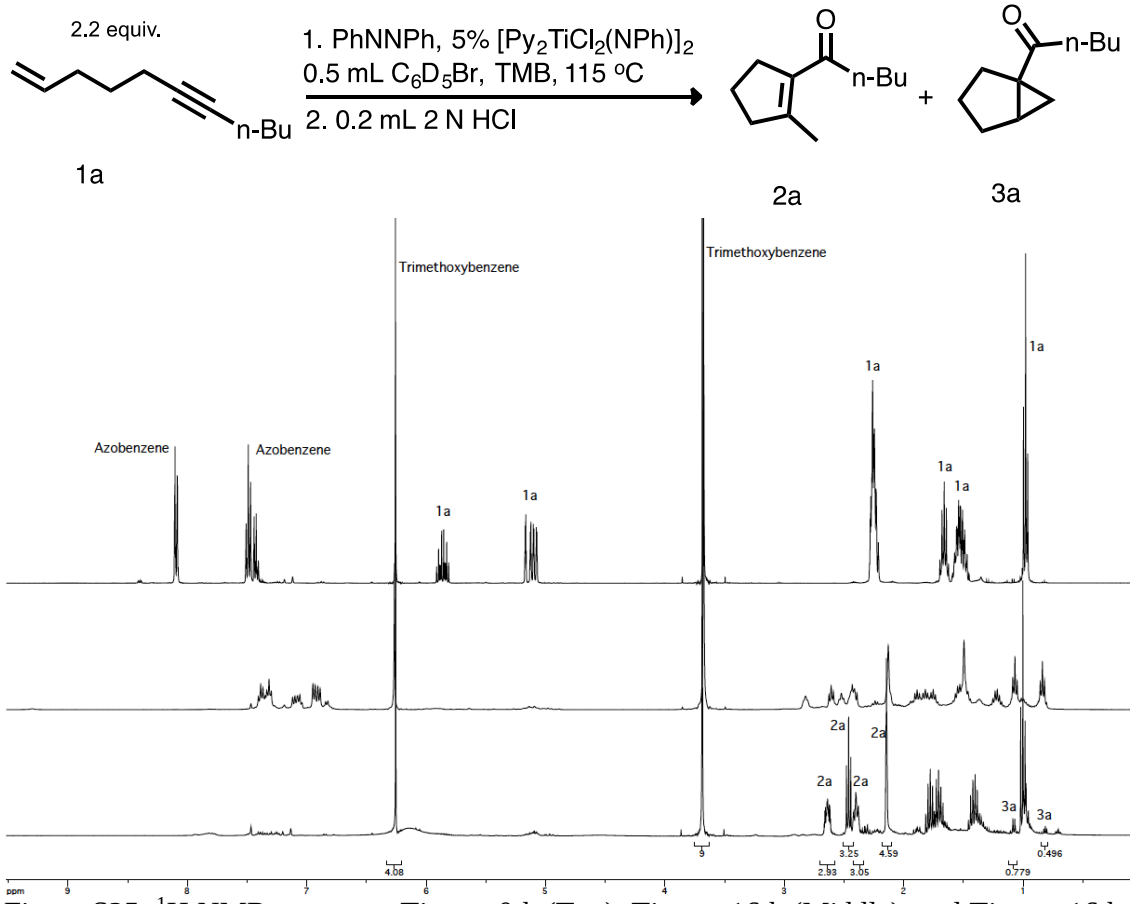
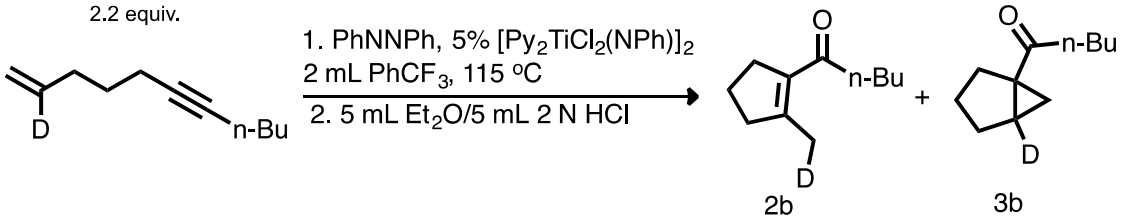


Figure S25: ^{1}H NMR spectra at Time = 0 h (Top), Time = 16 h (Middle), and Time = 16 h (2 N HCl quench, Bottom) of **2a** and **3a**.

Synthesis of 1-(bicyclo[3.1.0]hexan-1-yl-5-*d*)pentan-1-one and 1-(2-(methyl-*d*)cyclopent-1-en-1-yl)pentan-1-one (2b & 3b)



In a glovebox, to a 20 mL scintillation vial with a stir bar were added 101.2 mg azobenzene (1 equiv, 0.555 mmol), 19.9 mg $[Py_2TiCl_2(NPh)]_2$ (0.05 equiv, 0.026 mmol), and 182.6 mg **1b** (2.2 equiv, 1.21 mmol). This mixture was then diluted with 2 mL α,α,α-trifluorotoluene, and the vial was sealed with a Teflon screw cap and removed from the glovebox. The reaction mixture was then heated to 115 °C overnight for 16 h in a preheated oil bath, cooled to room temperature and quenched with 1 mL DI H_2O. The reaction mixture was further diluted with a mixture of 5 mL Et_2O/5 mL 2 N HCl and stirred overnight. The reaction mixture was poured into 20 mL H_2O and extracted 3x with 20 mL Et_2O. The organic layers were collected, washed with 20 mL brine, dried over $MgSO_4$, and concentrated in vacuo. The crude oil was purified by column chromatography using a gradient of 100% hexanes to 10% EtOAc/hexanes at an interval of 1% every 100 mL to give **2b** & **3b** as an off-yellow oil (159.5 mg, 85.9% yield). Spectra of the separated compounds were obtained from the front and tail of the column peak.

2b (82% deuterium labeling):
^{1}H NMR (500 MHz, $CDCl_3$; δ, ppm): 0.91 (t, *J* = 7.4 Hz, 3H, -$CH_2CH_2CH_3$), 1.33 (sextet, *J* = 7.5 Hz, 2H, -$CH_2CH_2CH_3$), 1.57 (quint, *J* = 7.5 Hz, 2H, -$CH_2CH_2CH_2$-), 1.82 (quint, *J* = 7.6 Hz, 2H, -$CH_2CH_2CH_2$-), 2.04 (dqd, *J* = 3.2, 2.2, 1.1 Hz, 2H, -CCH_2D), 2.07 (tt, *J* = 2.0, 1.1 Hz, 3H, protio –CCH_3), 2.50-2.45 (m, 4H, -$C(O)CH_2CH_2$- and -CH_2CH_2C=C-), 2.66 (ddt, *J* = 9.8, 5.2, 2.4 Hz, 2H, -CH_2CH_2C=C-).

^{13}C NMR (126 MHz, $CDCl_3$; δ, ppm): 14.1, 16.6 (t, $^1J_{C\text{-}D}$ = 19.1 Hz), 16.9 (protio), 21.7, 22.6, 26.0, 34.2, 41.0, 42.0, 135.5, 153.7, 201.3.

3b:
^{1}H NMR (500 MHz, $CDCl_3$; δ, ppm): 0.88 (d, *J* = 4.2 Hz, 1H, cyclopropyl -CDC*H*H), 0.90 (t, *J* = 7.4 Hz, 3H, -$CH_2CH_2CH_3$), 1.32-1.20 (m, 3H), 1.33 (d, *J* = 4.6 Hz, 1H, cyclopropyl -CDC*H*H), 1.57-1.51 (m, 2H, -$CH_2CH_2CH_2$-), 1.77-1.66 (m, 4H), 1.88 (dd, *J* = 12.6, 8.0 Hz, 1H, cyclopentyl -CH*H*C=C-), 2.18-2.12 (m, 1H, cyclopentyl -CH*H*C=C-), 2.31 (dt, *J* = 16.5, 7.4 Hz, 1H, -C(O)CH*H*CH_2-), 2.37 (dt, *J* = 16.4, 7.5 Hz, 1H, -C(O)CH*H*CH_2-).

^{13}C NMR (126 MHz, $CDCl_3$; δ, ppm): 14.1, 17.3, 21.2, 22.6, 26.3, 26.8, 27.4, 30.7 (t, $^1J_{C\text{-}D}$ = 25.8 Hz), 38.5, 40.1, 211.0.

GC-HRMS: Calc for $C_{11}H_{17}DO$ [M] 167.1420; found 167.1412 and 167.1414.

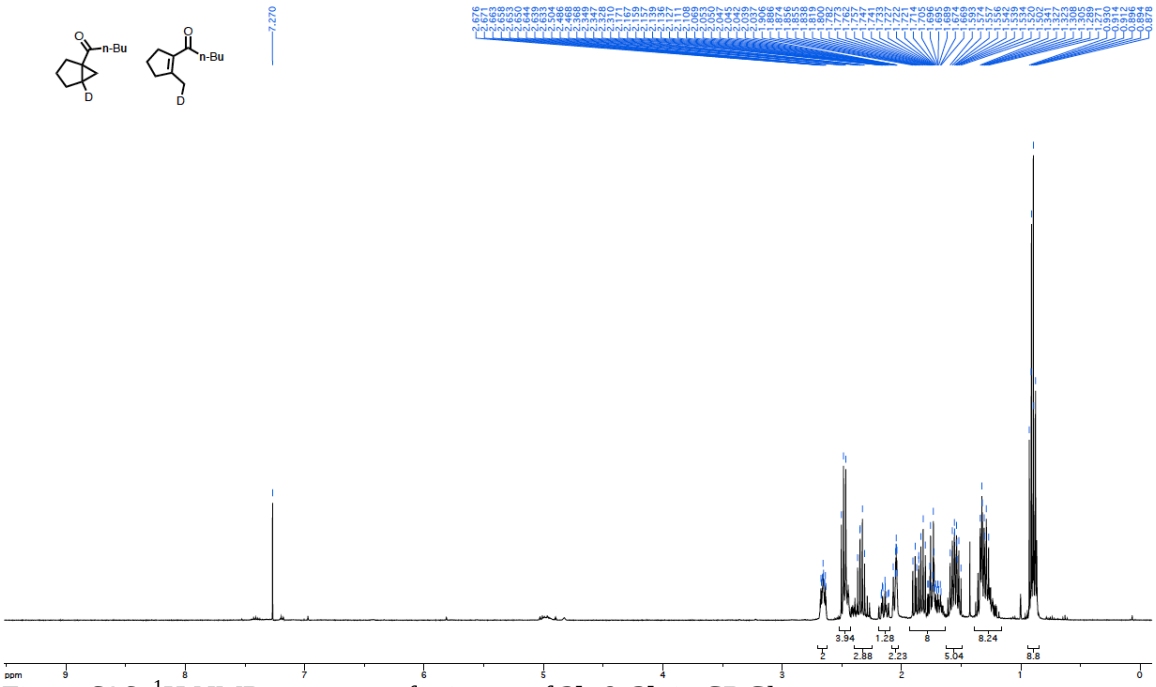


Figure S26: ^{1}H NMR spectrum of mixture of **2b** & **3b** in $CDCl_3$.

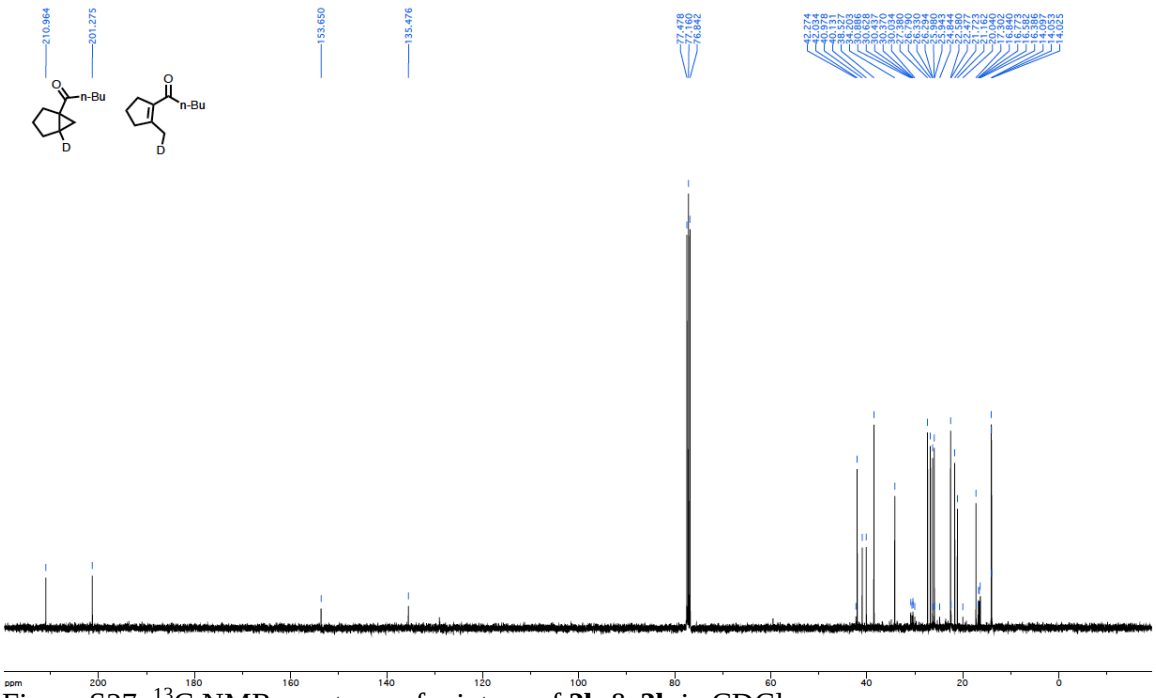


Figure S27: ^{13}C NMR spectrum of mixture of **2b** & **3b** in $CDCl_3$.

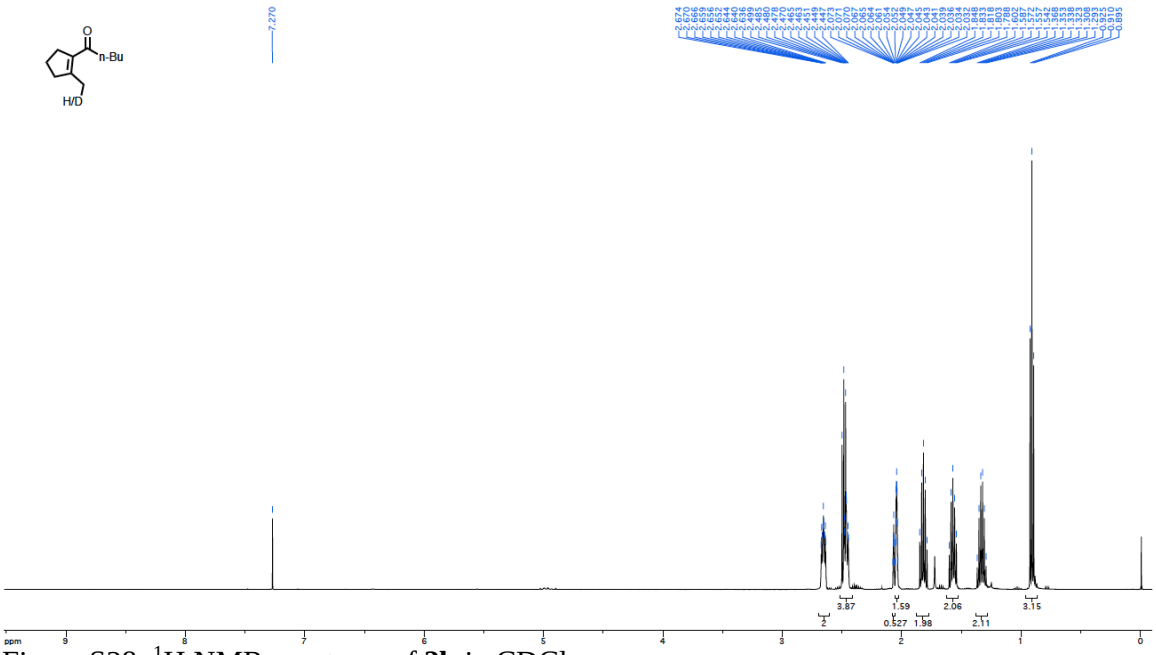


Figure S28: ^{1}H NMR spectrum of **2b** in $CDCl_3$.

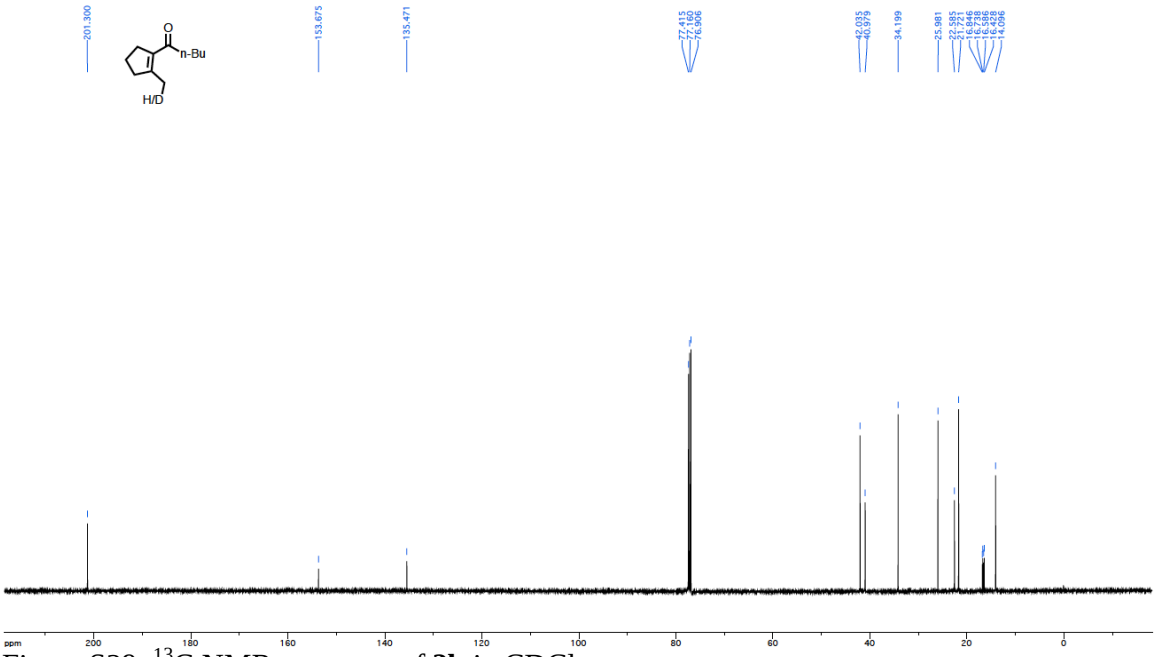


Figure S29: ^{13}C NMR spectrum of **2b** in $CDCl_3$.

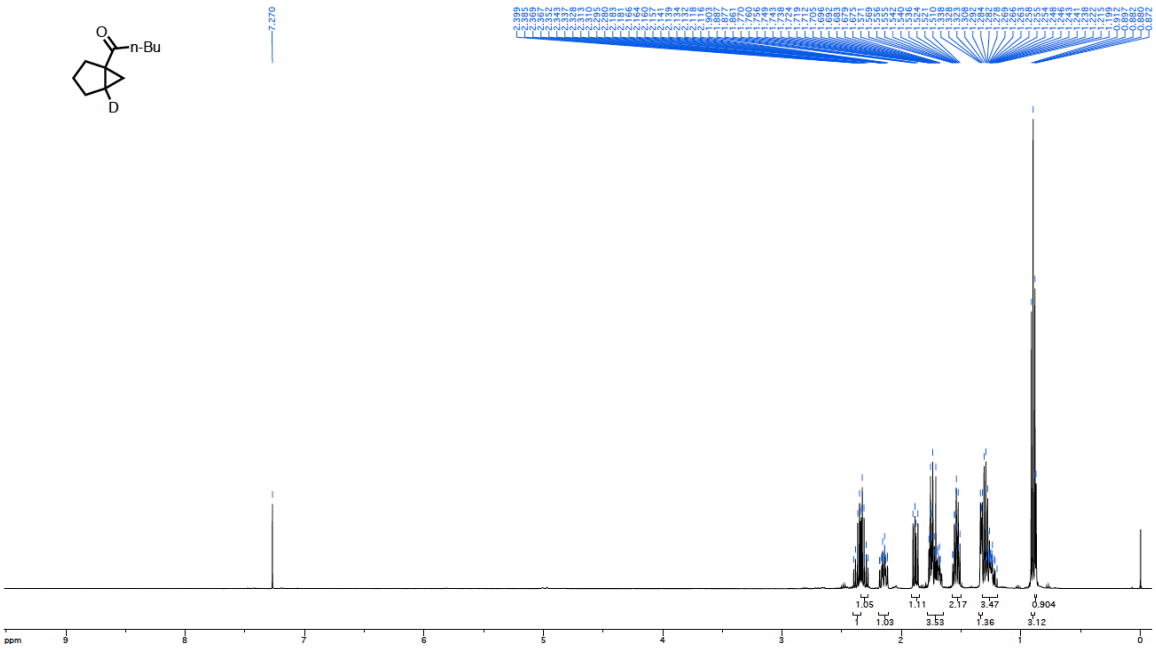


Figure S30: 1H NMR spectrum of **3b** in $CDCl_3$.

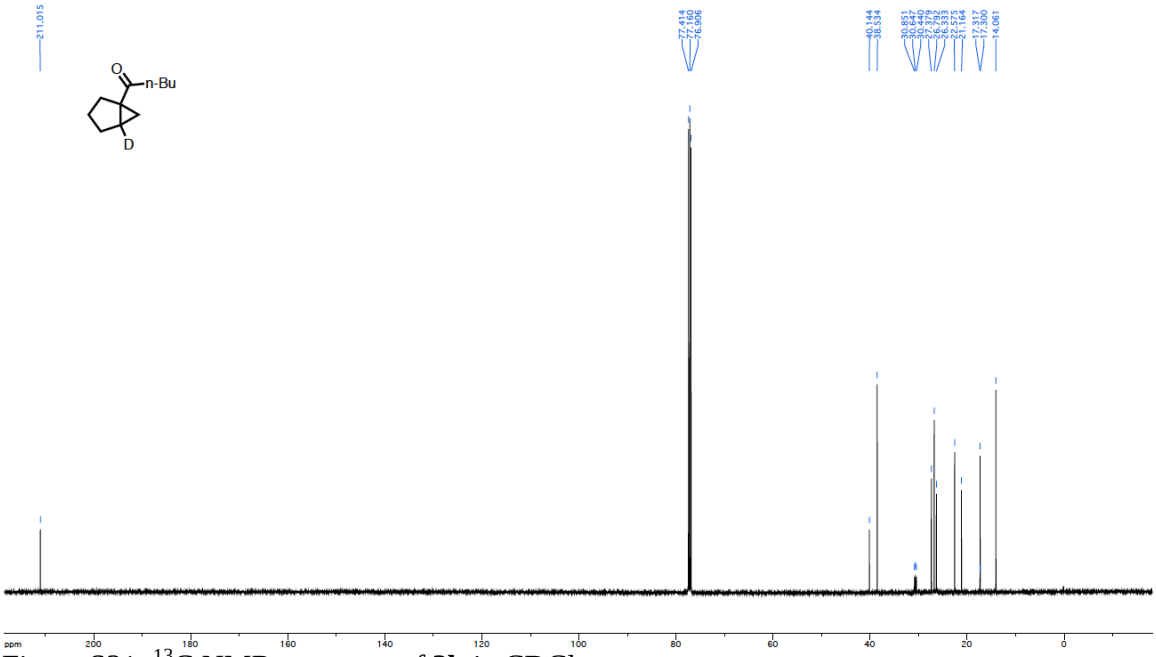


Figure S31: ^{13}C NMR spectrum of **3b** in $CDCl_3$.

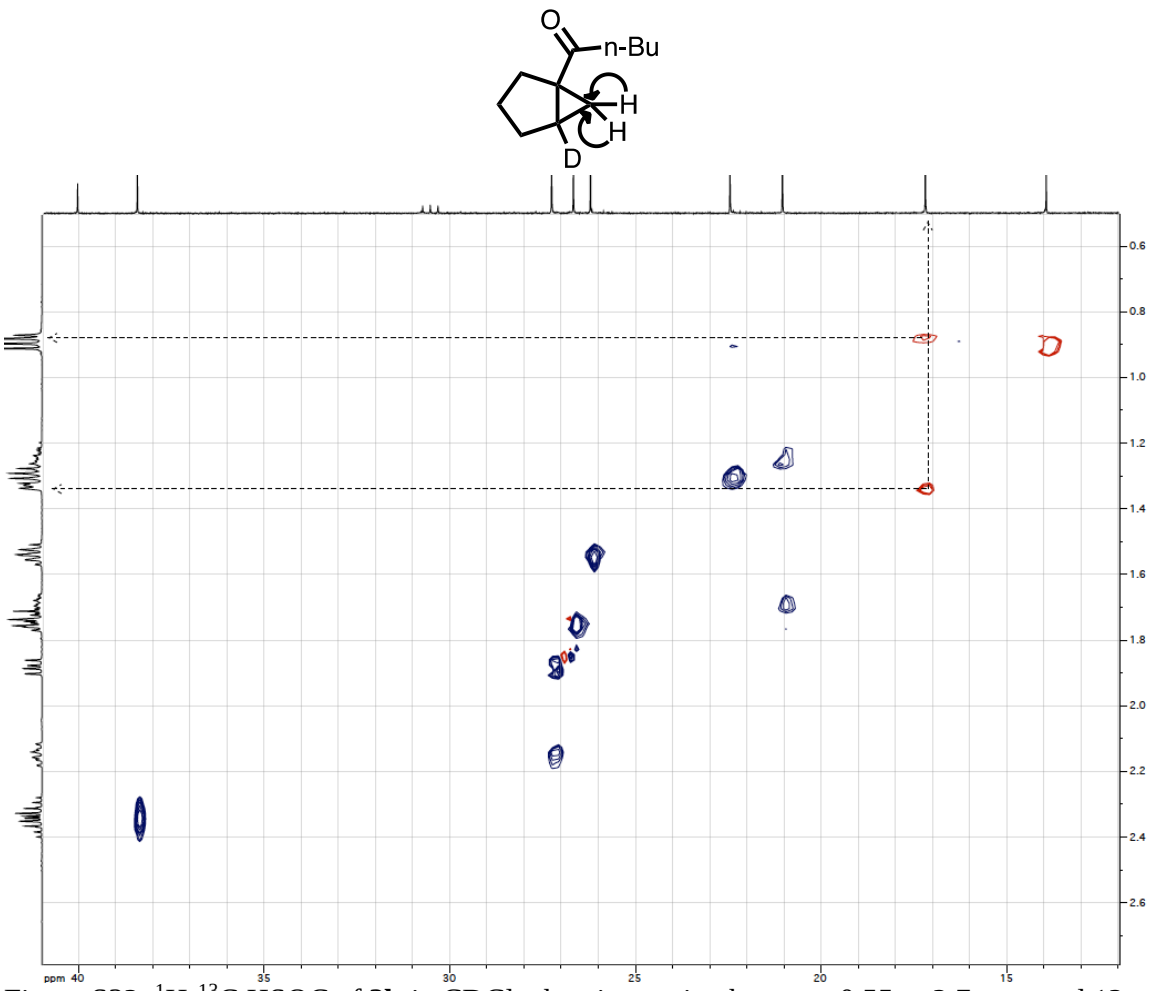
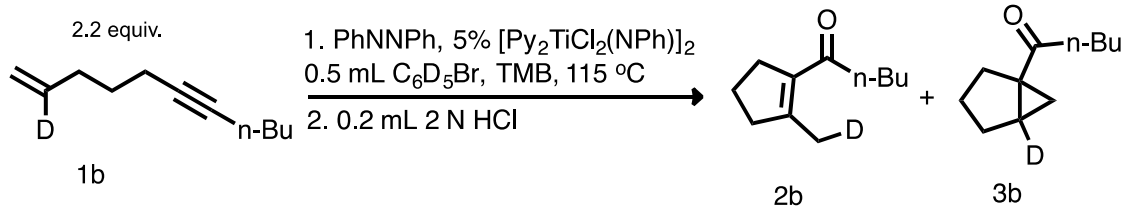


Figure S32: ^{1}H-^{13}C HSQC of **3b** in $CDCl_3$ showing region between 0.55 to 2.7 ppm and 12 to 41 ppm.

NMR Reaction of 1b



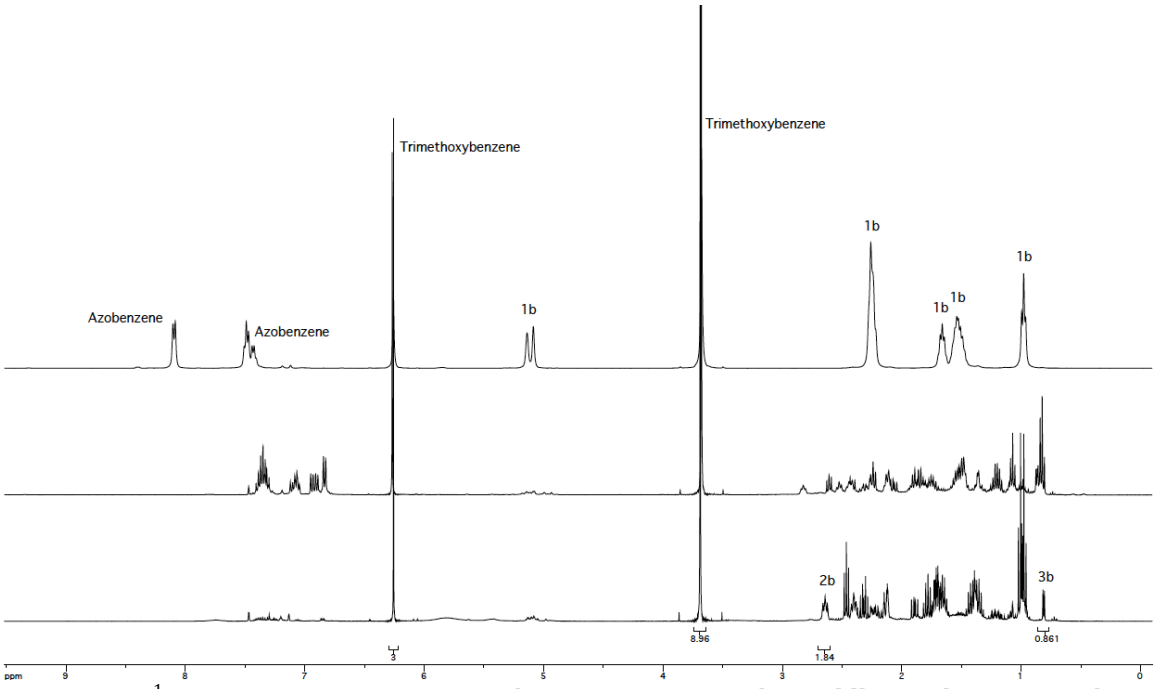
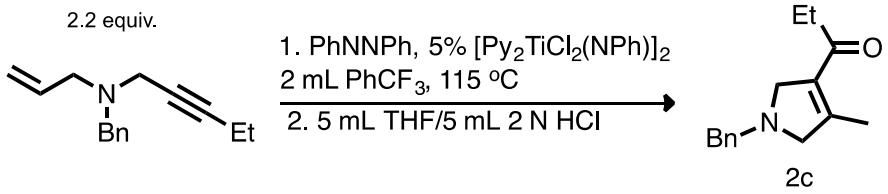


Figure S33: ^{1}H NMR spectra at Time = 0 h (Top), Time = 16 h (Middle), and Time = 16 h (2 N HCl quench, Bottom) of **2b** and **3b**.

Synthesis of 1-(1-benzyl-4-methyl-2,5-dihydro-1*H*-pyrrol-3-yl)propan-1-one (2c)



2c

In a glovebox, to a 20 mL scintillation vial with a stir bar were added 100.5 mg azobenzene (1 equiv, 0.551 mmol), 22.8 mg $[Py_2TiCl_2(NPh)]_2$ (0.05 equiv, 0.031 mmol) and 264.4 mg *N*-allyl-*N*-benzylpent-2-yn-1-amine **1c** (2.2 equiv, 1.24 mmol). The solution was then diluted with 2 mL α,α,α-trifluorotoluene, and the vial was sealed with a Teflon screw cap and removed from the glovebox. The reaction mixture was then heated to 115 °C overnight for 16 h in a preheated oil bath, cooled to room temperature and quenched with 1 mL DI H_2O. The reaction mixture was further diluted with a mixture of 5 mL THF/5 mL 2 N HCl and stirred overnight. The reaction mixture was poured into 20 mL saturated Na_2CO_3 and extracted 3x with 20 mL Et_2O. The organic layers were collected, washed with 20 mL brine, dried over $MgSO_4$, and concentrated in vacuo. The crude oil was purified by column chromatography using 10% EtOAc/hexanes to give **2c** as an orange oil (92.5 mg, 36.4% yield).

^{1}H NMR (400 MHz, $CDCl_3$; δ, ppm): 1.06 (t, *J* = 7.2 Hz, 3H, -CH_2CH_3), 2.07 (t, *J* = 1.0 Hz, 3H, -CCH_3), 2.48 (q, *J* = 7.2 Hz, 2H, -CH_2CH_3), 3.56 (td, *J* = 4.0, 1.1 Hz, 2H, *N*-CH_2(dihydropyrrole)), 3.75 (tq, *J* = 3.9, 1.9 Hz, 2H, *N*-CH_2(dihydropyrrole)), 3.77 (s, 2H, *N*-CH_2-Ph), 7.35-7.25 (m, 5H, CH_2-C_6H_5).

^{13}C NMR (101 MHz, $CDCl_3$; δ, ppm): 7.7, 14.8, 35.5, 60.1, 60.6, 66.3, 127.3, 128.4, 128.6, 128.8, 132.9, 139.0, 149.6, 198.9.

GC-HRMS: Calc for $C_{15}H_{19}NO$ [M^+] 229.1467; found 229.1464.

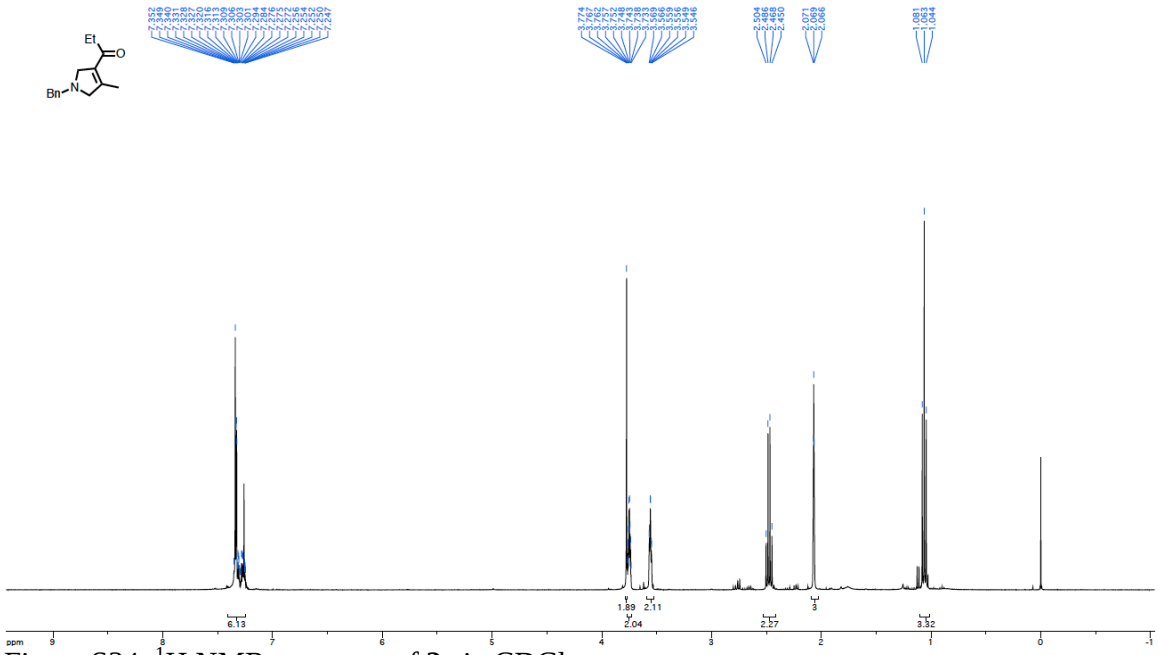


Figure S34: ^{1}H NMR spectrum of **2c** in $CDCl_3$.

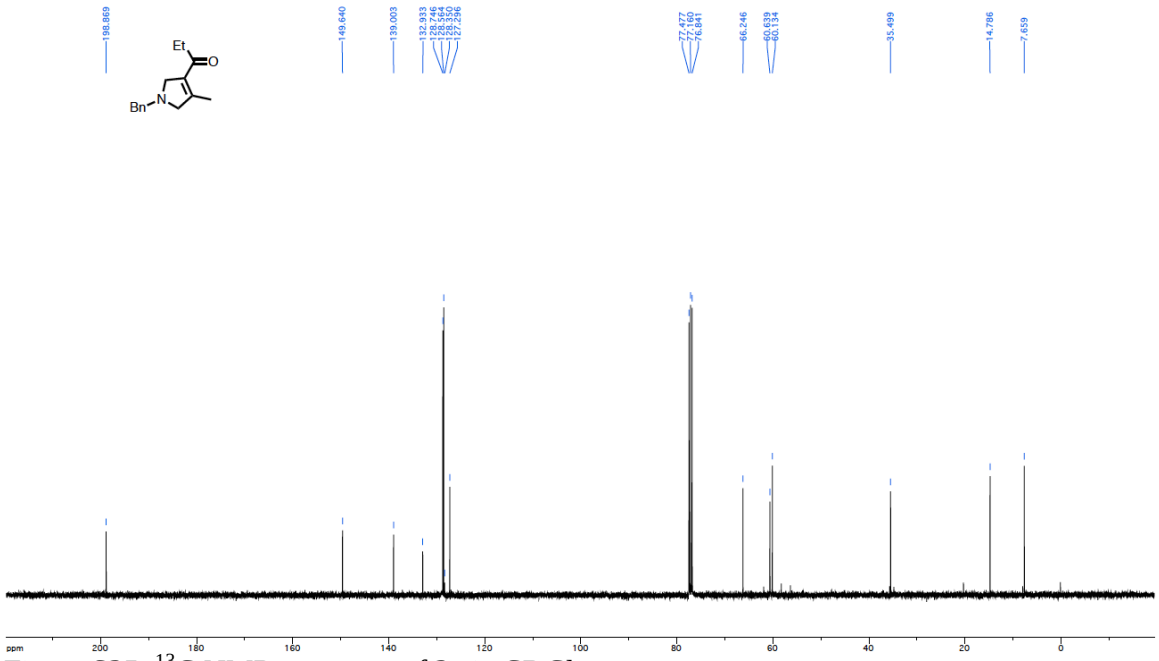


Figure S35: ^{13}C NMR spectrum of **2c** in $CDCl_3$.

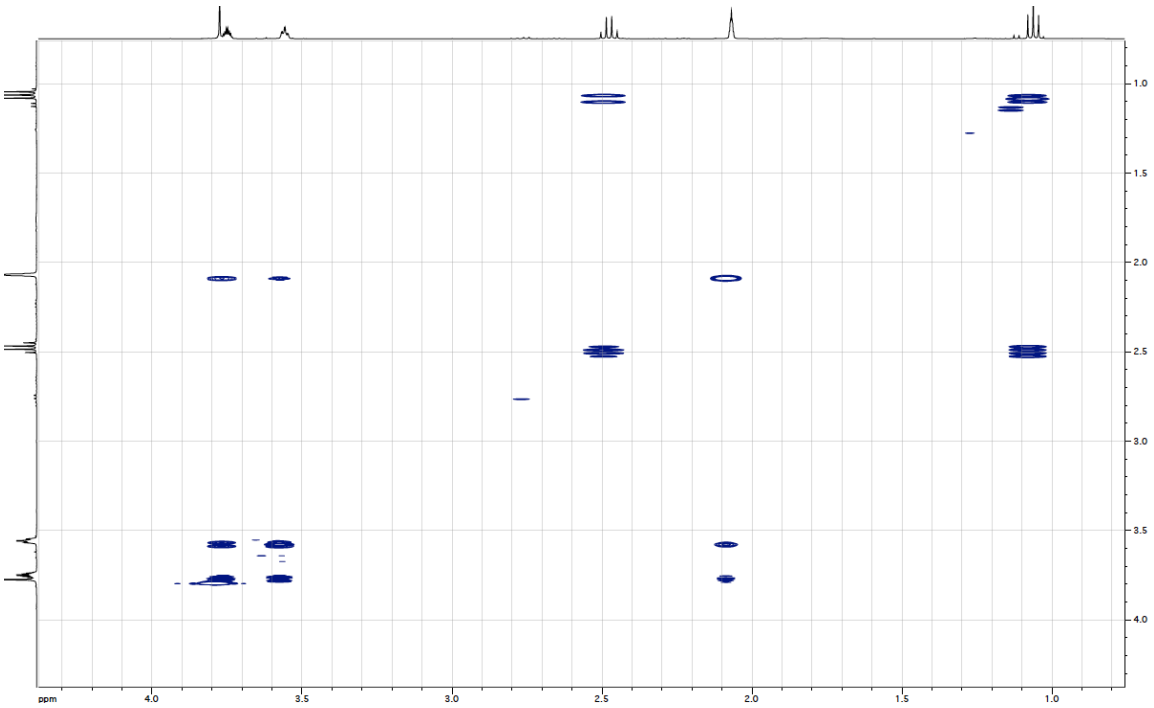
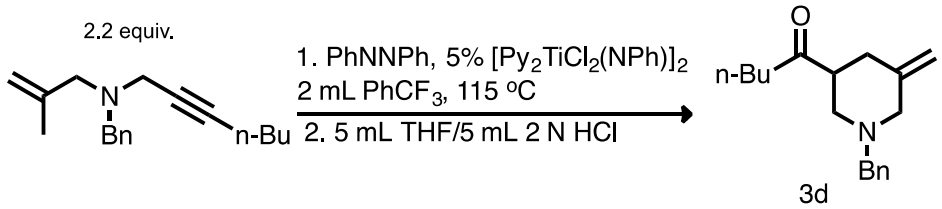


Figure S36: COSY of **2c** in $CDCl_3$ between 0.5 and 4.5 ppm.

Synthesis of 1-(1-benzyl-5-methylenepiperidin-3-yl)pentan-1-one (3d)



In a glovebox, to a 20 mL scintillation vial with a stir bar were added 104.5 mg azobenzene (1 equiv, 0.573 mmol), 21.4 mg $[Py_2TiCl_2(NPh)]_2$ (0.05 equiv, 0.028 mmol), and 275.7 mg **1d** (2.2 equiv, 1.08 mmol). The solution was then diluted with 2 mL α,α,α-trifluorotoluene, and the vial was sealed with a Teflon screw cap and removed from the glovebox. The reaction mixture was then heated to 115 °C overnight for 16 h in a preheated oil bath, cooled to room temperature and quenched with 1 mL DI H_2O. The reaction mixture was further diluted with a mixture of 5 mL THF/5 mL 2 N HCl and stirred overnight. The reaction mixture was poured into 20 mL saturated Na_2CO_3 and extracted 3x with 20 mL Et_2O. The organic layers were collected, washed with 20 mL brine, dried over $MgSO_4$, and concentrated in vacuo. The crude oil was purified by column chromatography using 5% EtOAc/hexanes to give **2d** as a yellow oil (60.5 mg, 19.4% yield).

^{1}H NMR (400 MHz, $CDCl_3$; δ, ppm): 0.89 (t, *J* = 7.3 Hz, 3H, -$CH_2CH_2CH_3$), 1.28 (sextet, *J* = 7.5 Hz, 2H, -$CH_2CH_2CH_3$), 1.53 (quint, *J* = 7.5 Hz, 2H, -$CH_2CH_2CH_2$-), 2.24 (dd, *J* = 13.3, 11.6 Hz, 1H, piperidine -CH*H*-), 2.30 (dd, *J* = 11.6, 10.1 Hz, 1H, piperidine –CH*H*-), 2.47-2.39 (m, 3H), 2.78-2.69 (m, 2H), 2.97 (ddt, *J* = 11.6, 3.3, 1.6 Hz, 1H), 3.19 (d, *J* = 12.0 Hz, 1H), 3.54 (d, *J* = 10.3 Hz, 1H, -NC*H*HPh), 3.59 (d, *J* = 10.3 Hz, 1H, -NC*H*HPh), 4.81 (q, *J* = 1.6 Hz, 1H, -C=CH*H*), 4.83 (dd, *J* = 2.2, 1.4 Hz, 1H, -C=CH*H*), 7.34-7.26 (m, 5H, $NCH_2C_6H_5$).

^{13}C NMR (101 MHz, $CDCl_3$; δ, ppm): 14.0, 22.5, 25.7, 34.9, 41.1, 49.3, 54.6, 59.7, 62.6, 110.7, 127.3, 128.4, 129.3, 138.0, 142.5, 211.7.

GC-HRMS: Calc for $C_{18}H_{25}NO$ [M^+] 271.1936; found 271.1934.

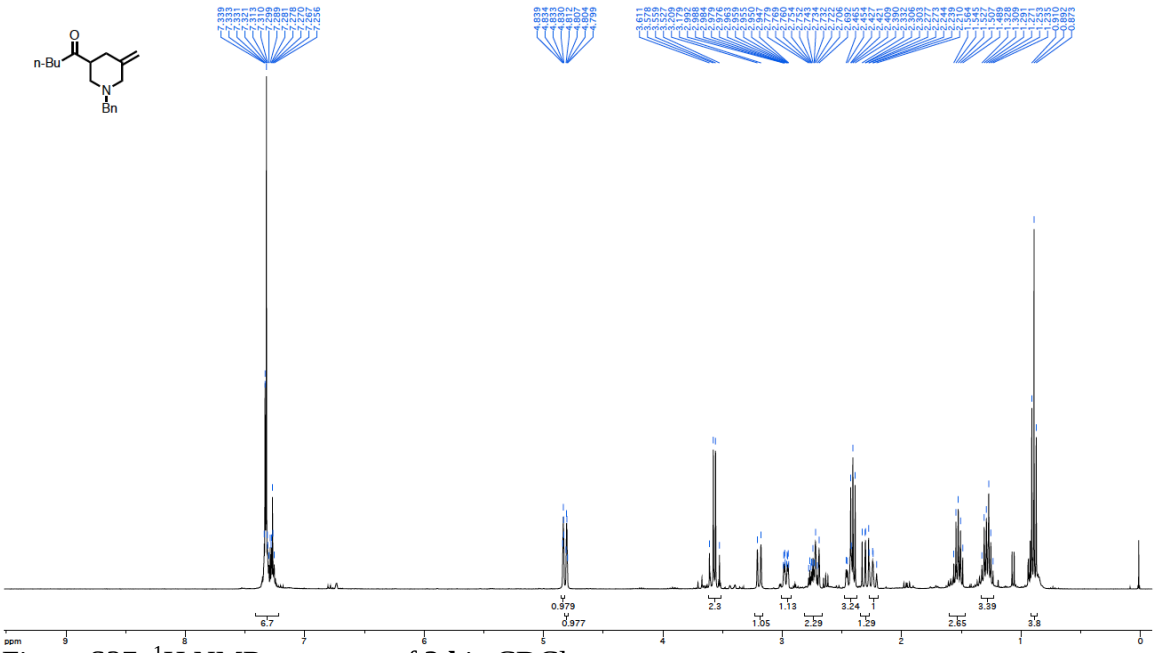


Figure S37: ^{1}H NMR spectrum of **2d** in $CDCl_3$.

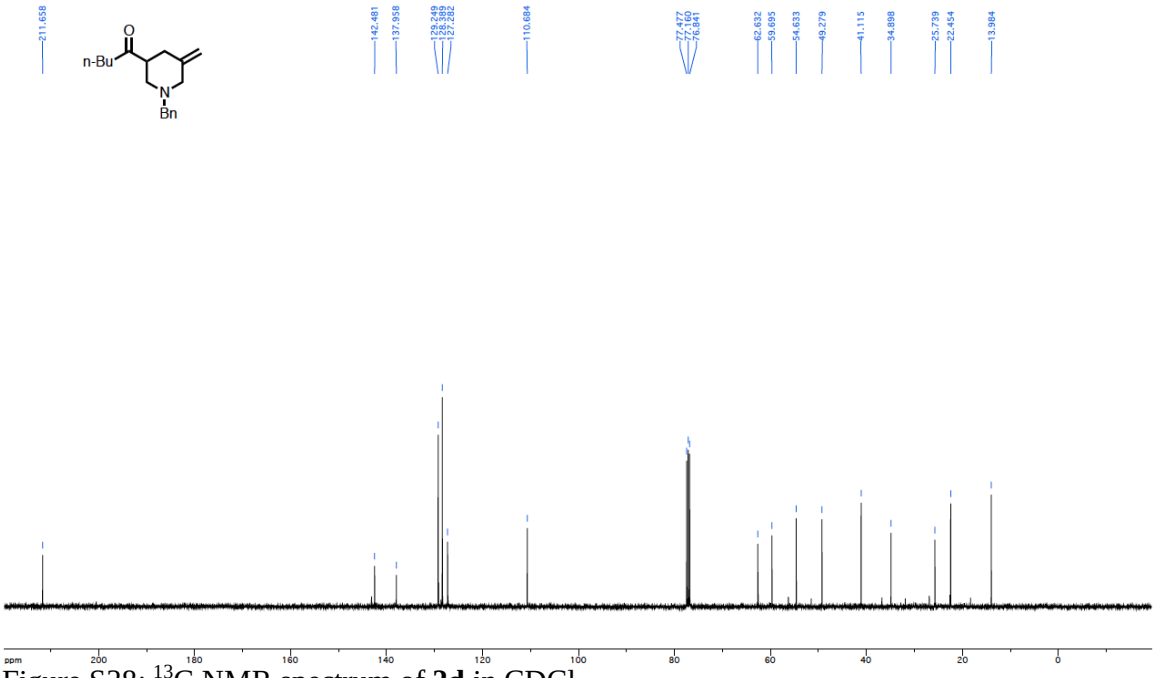


Figure S38: ^{13}C NMR spectrum of **2d** in $CDCl_3$.

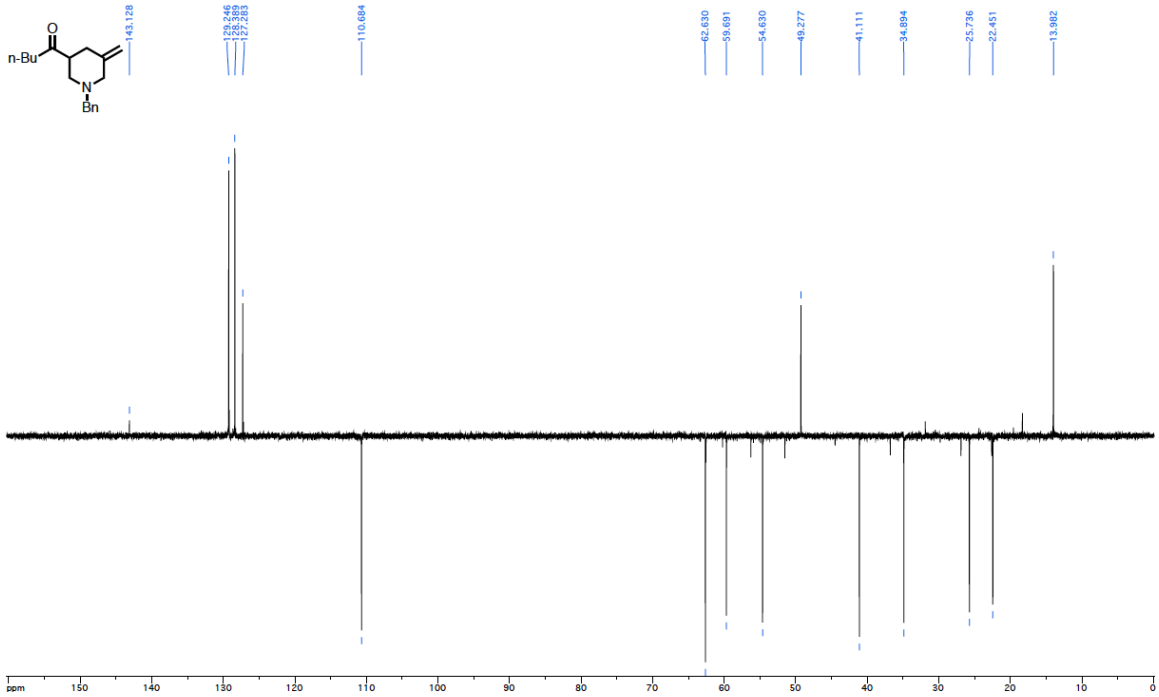


Figure S39: APT of **2d** in $CDCl_3$.

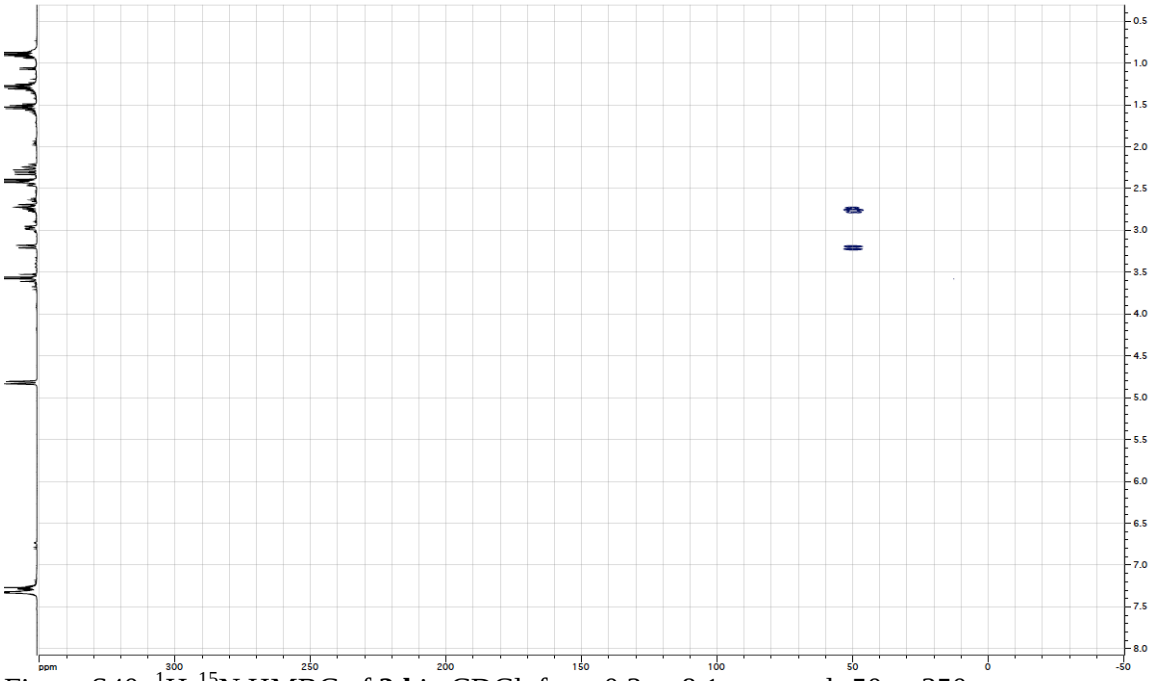


Figure S40: ^{1}H-^{15}N HMBC of **2d** in $CDCl_3$ from 0.3 to 8.1 ppm and -50 to 350 ppm.

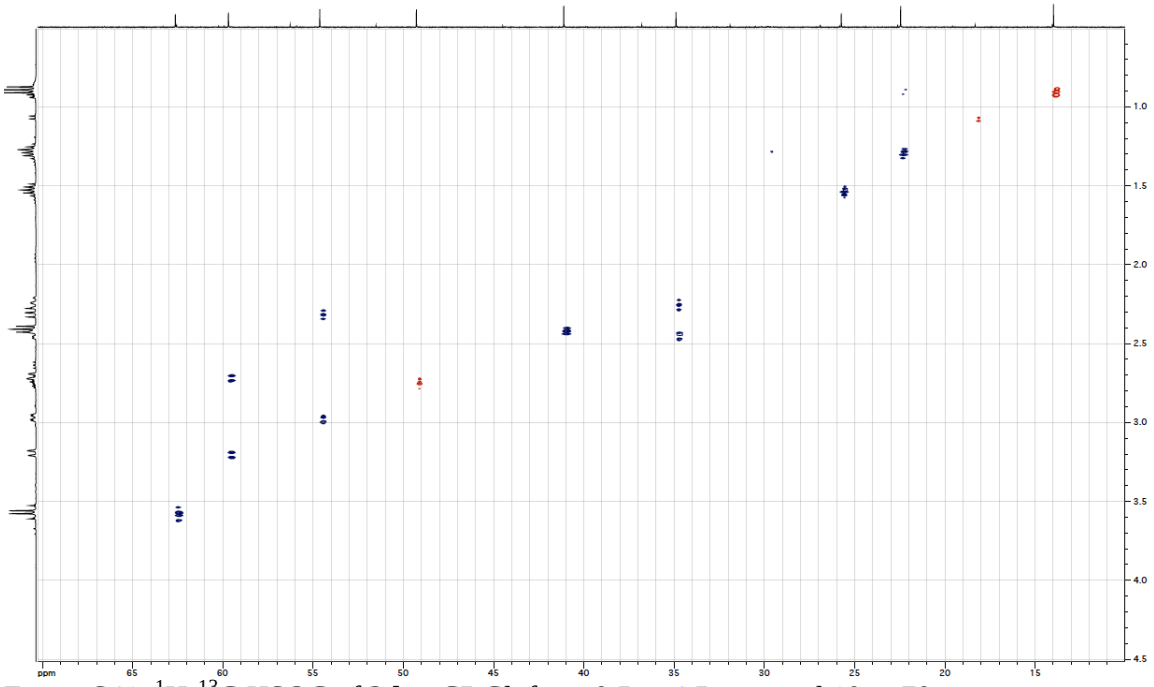
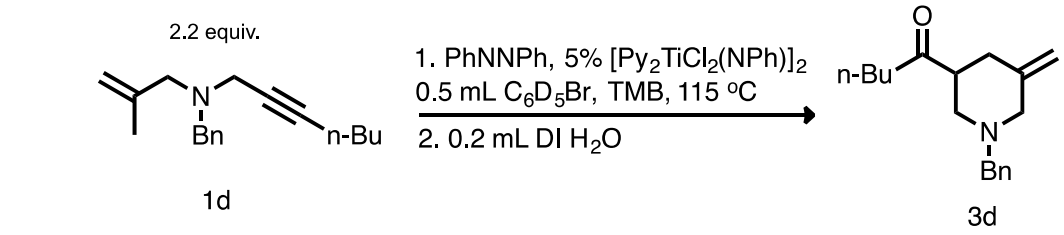


Figure S41: ^{1}H-^{13}C HSQC of **2d** in $CDCl_3$ from 0.5 to 4.5 ppm and 10 to 70 ppm.

NMR Reaction of 1d



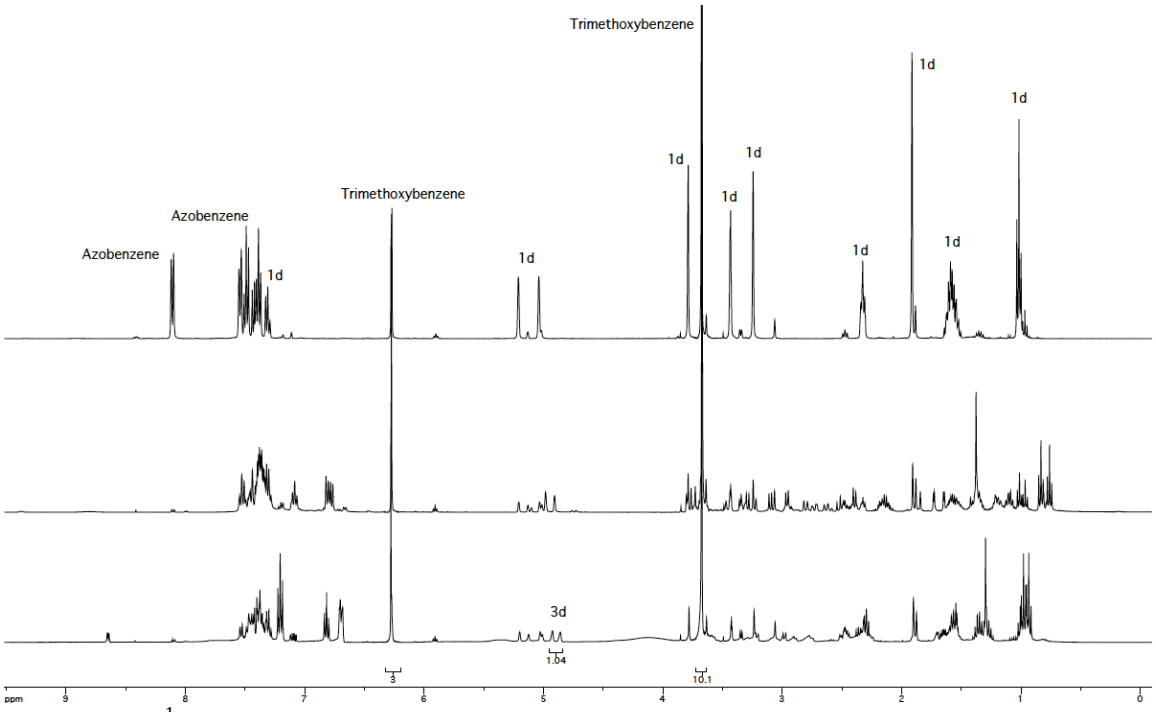
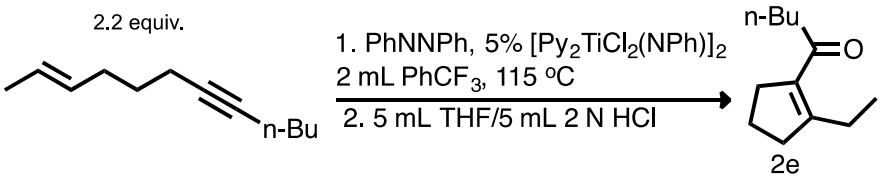


Figure S42: ^{1}H NMR spectra at Time = 0 h (Top), Time = 16 h (Middle), and Time = 16 h (H_2O, Bottom) of **3d**.

Synthesis of 1-(2-ethylcyclopent-1-en-1-yl)pentan-1-one (2e)



In a glovebox, to a 20 mL scintillation vial with a stir bar were added 101.8 mg azobenzene (1 equiv, 0.559 mmol), 20.7 mg $[Py_2TiCl_2(NPh)]_2$ (0.05 equiv, 0.028 mmol) and 206.0 mg **1e** (2.2 equiv, 1.25 mmol). The mixture was then diluted with 2 mL α,α,α-trifluorotoluene, and the vial was sealed with a Teflon screw cap and removed from the glovebox. The reaction mixture was heated to 115 °C overnight for 16 h in a preheated oil bath, cooled to room temperature and quenched with 1 mL DI H_2O. The reaction mixture was further diluted with a mixture of 5 mL THF/5 mL 2 N HCl and stirred overnight. The mixture was poured into 20 mL H_2O and extracted 3x with 20 mL Et_2O. The organic layers were collected, washed with 20 mL brine, dried over $MgSO_4$, and concentrated in vacuo. The crude oil was purified by column chromatography using 2% Et_2O/hexanes to give **2e** as a clear, colorless oil (139.77 mg, 69.4% yield). Spectral data were consistent with literature values.[S13]

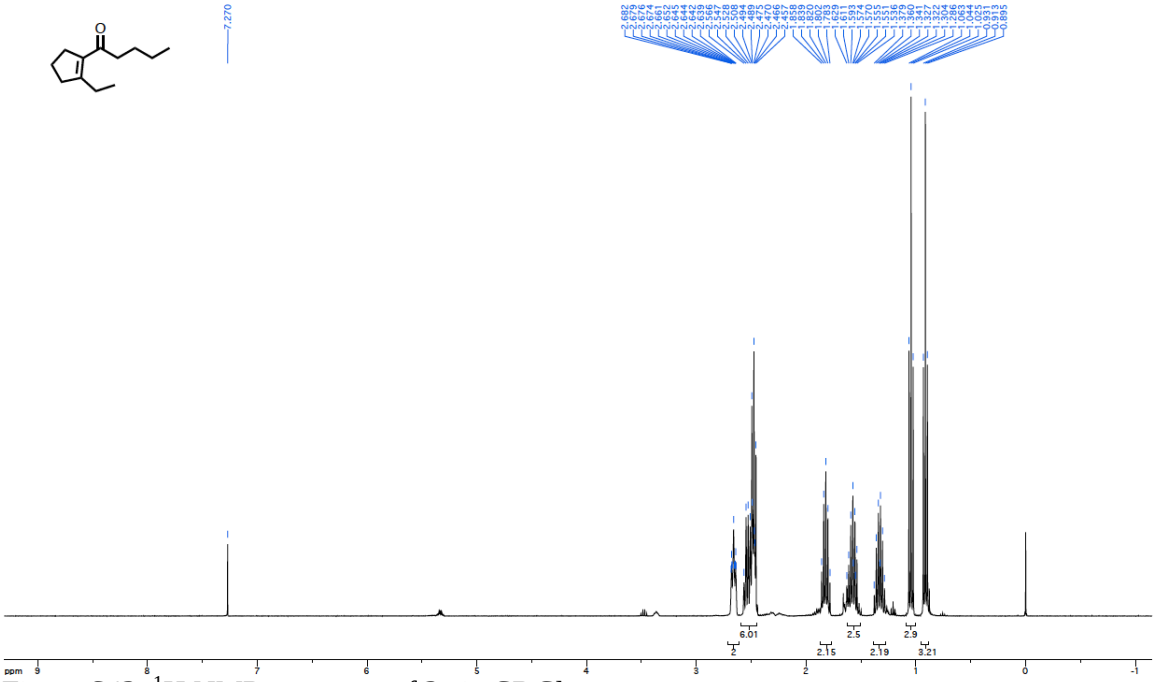


Figure S43: ^1H NMR spectrum of **2e** in $CDCl_3$.

NMR Reaction of 1e

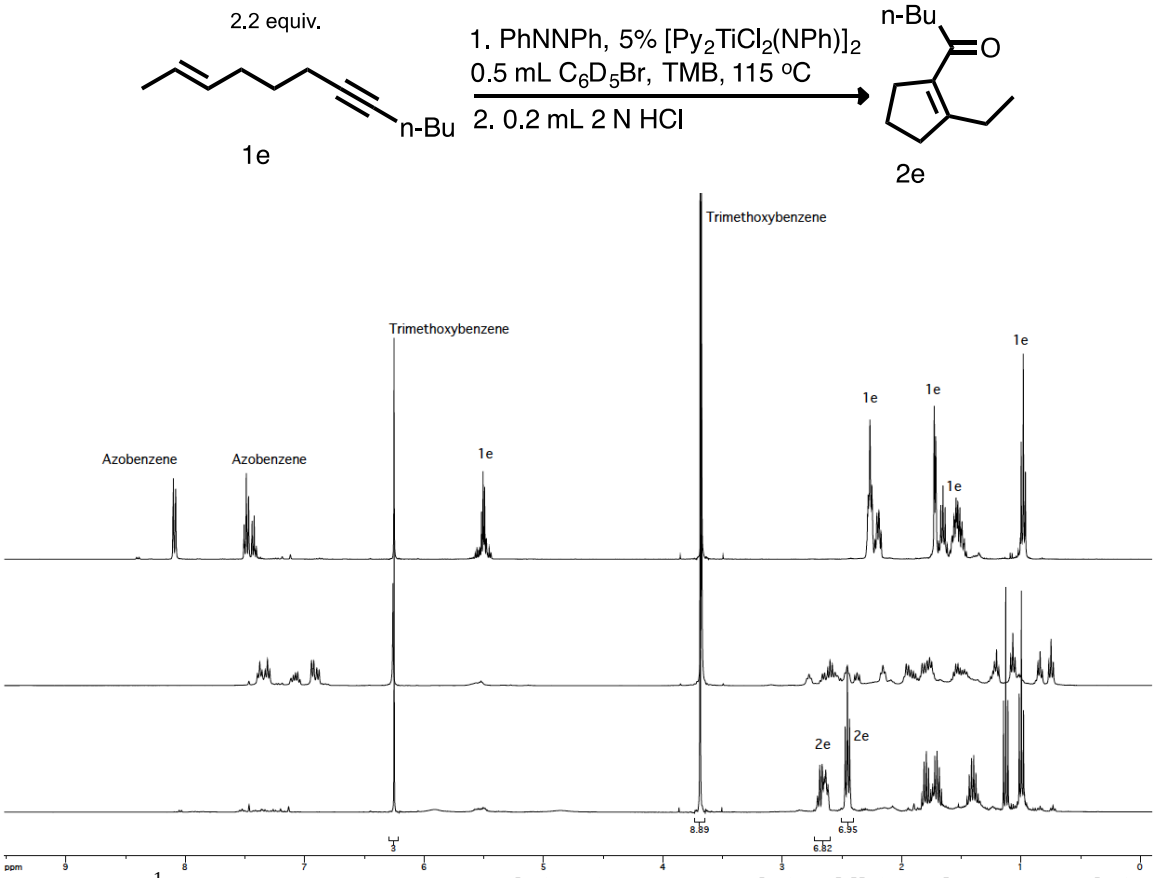
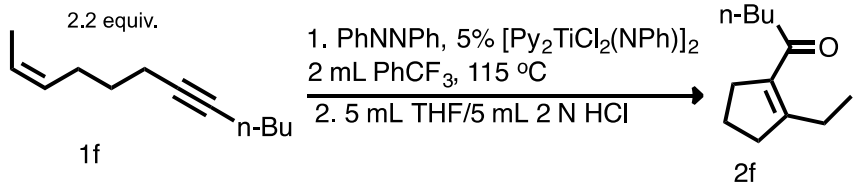


Figure S44: ^{1}H NMR spectra at Time = 0 h (Top), Time = 16 h (Middle), and Time = 16 h (2 N HCl quench, Bottom) of **2e**.

Synthesis of 1-(2-ethylcyclopent-1-en-1-yl)pentan-1-one (2f)



In a glovebox, to a 20 mL scintillation vial with a stir bar were added 102.5 mg azobenzene (1 equiv, 0.563 mmol), 20.1 mg $[Py_2TiCl_2(NPh)]_2$ (0.05 equiv, 0.027 mmol), and 201.5 mg **1f** (2.2 equiv, 1.22 mmol). The solution was then diluted with 2 mL α,α,α-trifluorotoluene, and the vial was sealed with a Teflon screw cap and removed from the glovebox. The reaction mixture was heated to 115 °C overnight for 16 h in a preheated oil bath, cooled to room temperature and quenched with 1 mL DI H_2O. The reaction mixture was further diluted with a mixture of 5 mL THF/5 mL 2 N HCl and stirred overnight. The mixture was poured into 20 mL H_2O and extracted 3x with 20 mL Et_2O. The organic layers were collected, washed with 20 mL brine, dried over $MgSO_4$, and concentrated in vacuo. The crude oil was purified by column chromatography using 2% Et_2O/hexanes to give **2f** as a clear, colorless oil (122 mg, 60.3% yield). Spectral data were consistent with literature values.[S13]

^{1}H NMR (400 MHz, $CDCl_3$; δ, ppm): 0.91 (t, *J* = 7.3 Hz, 3H, -$CH_2CH_2CH_3$), 1.04 (t, *J* = 7.6 Hz, 3H, -CH_2CH_3), 1.33 (sextet, *J* = 7.5 Hz, 2H, -$CH_2CH_2CH_3$), 1.57 (quint, *J* = 7.5 Hz, 2H, -$CH_2CH_2CH_2$-), 1.82 (quint, *J* = 7.5 Hz, 2H, -$CH_2CH_2CH_2$-), 2.65-2.46 (m, 6H), 2.68-2.64 (m, 2H, -CH_2CH_2C=C-).

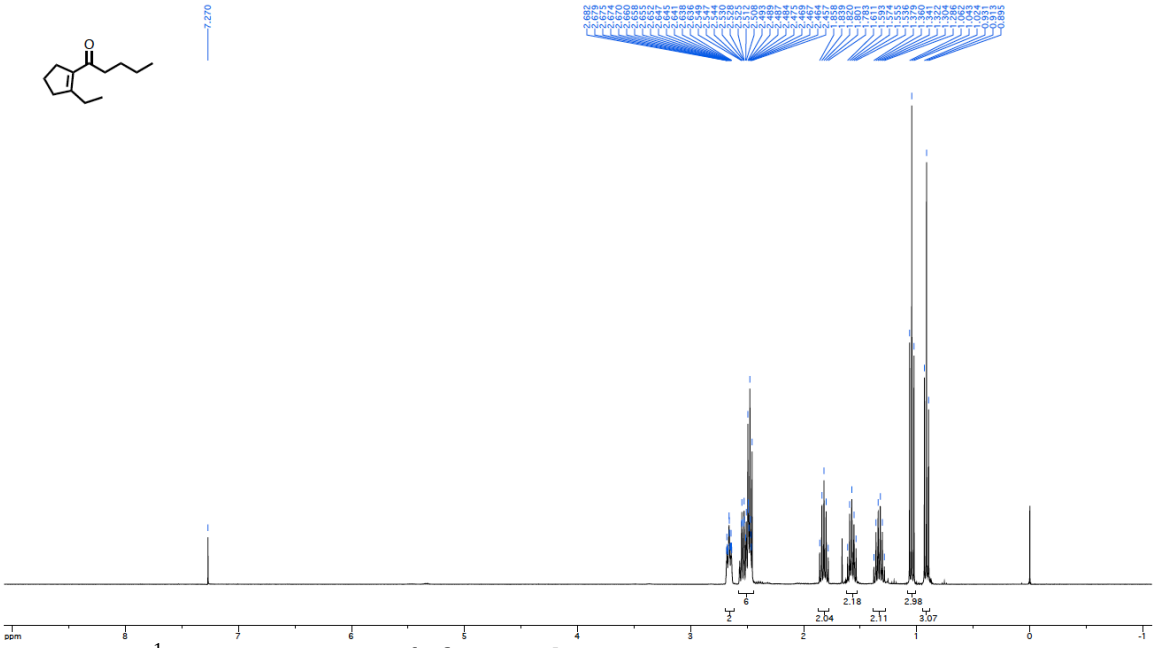


Figure S45: ^{1}H NMR spectrum of **2f** in $CDCl_3$.

NMR Reaction of 1f

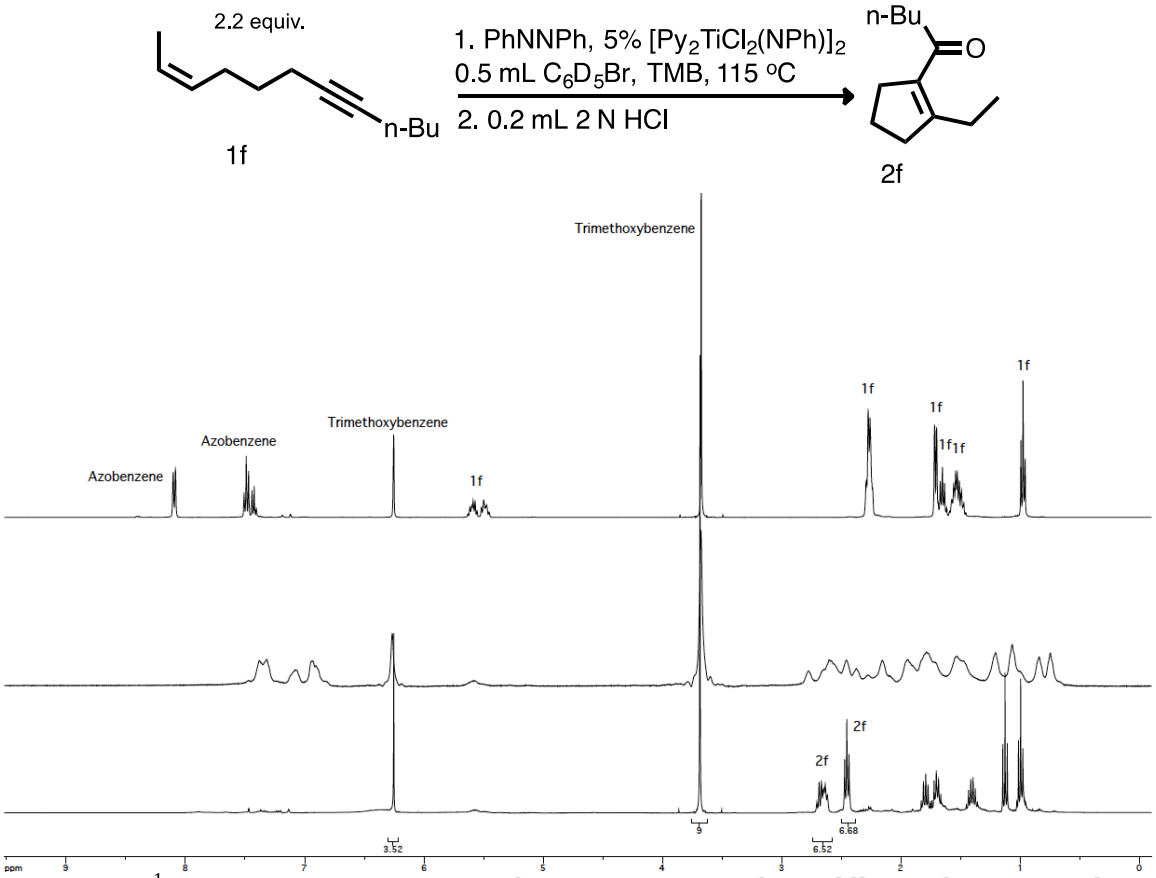
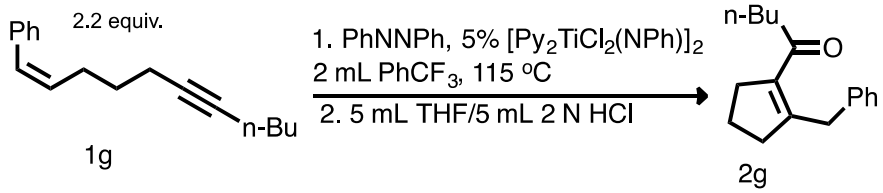


Figure S46: ^{1}H NMR spectra at Time = 0 h (Top), Time = 16 h (Middle), and Time = 16 h (2 N HCl quench, Bottom) of **2f**.

Synthesis of 1-(2-benzylcyclopent-1-en-1-yl)pentan-1-one (2g)



In a glovebox, to a 20 mL scintillation vial with a stir bar were added 109.5 mg azobenzene (1 equiv, 0.600 mmol), 23.4 mg $[Py_2TiCl_2(NPh)]_2$ (0.05 equiv, 0.032 mmol), and 285.4 mg **1g** (2.2 equiv, 1.26 mmol). The mixture was then diluted with 2 mL α,α,α-trifluorotoluene, and the vial was sealed with a Teflon screw cap and removed from the glovebox. The reaction mixture was heated to 115 °C overnight for 16 h in a preheated oil bath, cooled to room temperature and quenched with 1 mL DI H_2O. The reaction mixture was further diluted with a mixture of 5 mL THF/5 mL 2 N HCl and stirred overnight. The mixture was poured into 20 mL H_2O and extracted 3x with 20 mL Et_2O. The organic layers were collected, washed with 20 mL brine, dried over $MgSO_4$, and concentrated in vacuo. The crude oil was purified by column chromatography using 2% Et_2O/hexanes to give **2g** as an off-yellow oil (132.1 mg, 49.0% yield).

^{1}H NMR (400 MHz, $CDCl_3$; δ, ppm): 0.94 (t, *J* = 7.3 Hz, 3H, -$CH_2CH_2CH_3$), 1.37 (sextet, *J* = 7.5 Hz, 2H, -$CH_2CH_2CH_3$), 1.63 (quint, *J* = 7.5 Hz, 2H, -$CH_2CH_2CH_2$-), 1.80 (quint, *J* = 7.5 Hz, 2H, -$CH_2CH_2CH_2$-), 2.41-2.36 (m, 2H, -CH_2CH_2C=C-), 2.54 (t, *J* = 7.4 Hz, 2H, -C(O)CH_2CH_2-), 2.74-2.69 (m, 2H, -CH_2CH_2C=C-), 3.90 (s, 2H, -C=C-CH_2Ph), 7.29-7.20 (m, 5H, -C_6H_5).

^{13}C NMR (101 MHz, $CDCl_3$; δ, ppm): 14.1, 21.8, 22.6, 25.9, 34.4, 36.3, 37.8, 42.2, 126.2, 128.5, 129.1, 136.0, 139.4, 155.0, 201.4.

GC-HRMS: Calc for $C_{17}H_{22}O$ [M^+] 242.1671; found 242.1664.

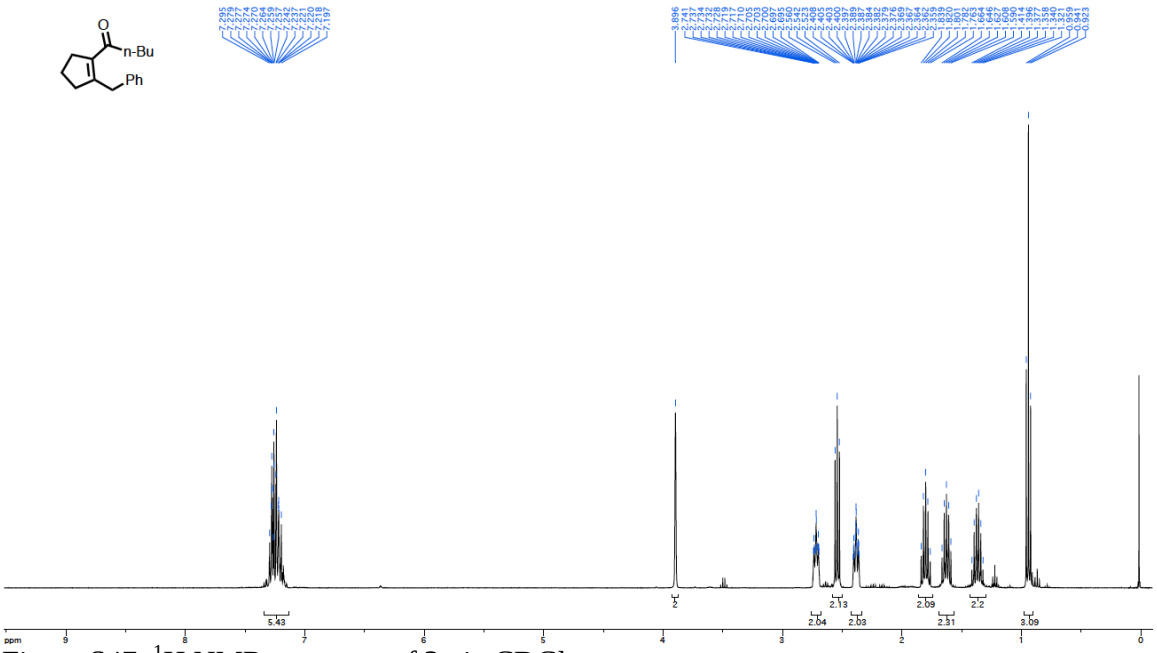


Figure S47: ^{1}H NMR spectrum of **2g** in $CDCl_3$.

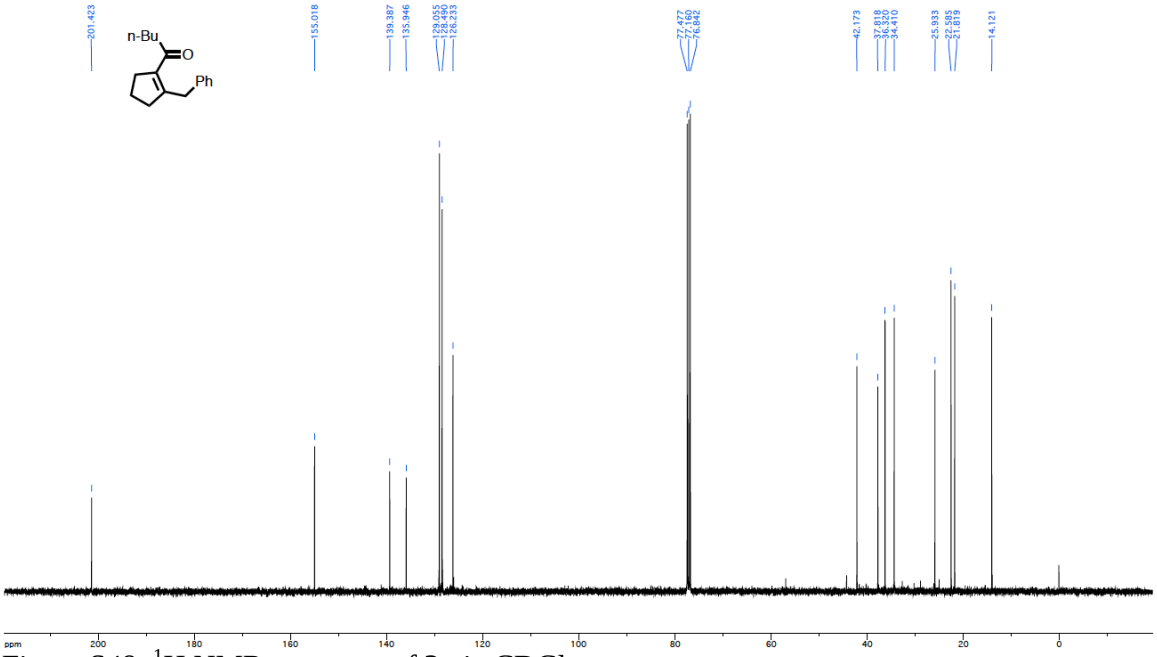
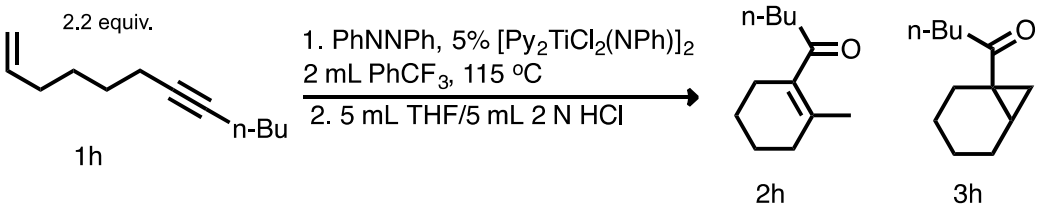


Figure S48: ^{1}H NMR spectrum of **2g** in $CDCl_3$.

Synthesis of 1-(2-methylcyclohex-1-en-1-yl)pentan-1-one and 1-(bicyclo[4.1.0]heptan-1-yl)pentan-1-one (2h & 3h)



In a glovebox, to a 20 mL scintillation vial with a stir bar were added 104.4 mg azobenzene (1 equiv, 0.573 mmol), 20.1 mg $[Py_2TiCl_2(NPh)]_2$ (0.05 equiv, 0.027 mmol), and 210.7 mg **1h** (2.2 equiv, 1.26 mmol). The mixture was then diluted with 2 mL α,α,α-trifluorotoluene, and the vial was sealed with a Teflon screw cap and removed from the glovebox. The reaction mixture was heated to 115 °C overnight for 16 h in a preheated oil bath, cooled to room temperature and quenched with 1 mL DI H_2O. The reaction mixture was further diluted with a mixture of 5 mL THF/5 mL 2 N HCl and stirred overnight. The reaction mixture was poured into 20 mL H_2O and extracted 3x with 20 mL Et_2O. The organic layers were collected, washed with 20 mL brine, dried over $MgSO_4$, and concentrated in vacuo. The crude oil was purified by column chromatography using 2% Et_2O/hexanes to give **2h** & **3h** as an off-yellow oil (111 mg, 54.0% yield) which could not be further separated.

^{1}H NMR (400 MHz, $CDCl_3$; δ, ppm): 0.68 (dd, *J* = 6.8, 4.1 Hz, 1H, **3h** cyclopropyl -CHCH*H*C-), 0.91 (t, *J* = 7.3, 6.0 Hz, 6H, **2h**&**3h** -CH_2CH_3), 1.36-1.25 (m, 9H, **2h&3h**), 1.64-1.49 (m, 9H, **2h**&**3h**), 1.74-1.67 (m, 2H, **2h**&**3h**), 1.79 (tt, *J* = 1.8, 0.9 Hz, 3H, **2h** C=CC*H*$_3$), 1.90 (td, *J* = 13.4, 6.8 Hz, 1H, **3h**), 2.07-2.05 (m, 2H, **2h** cyclohexyl - CH_2CH_2C=C-), 2.21 (tquint, *J* = 5.9, 2.0 Hz, 2H, **2h** cyclohexyl - CH_2CH_2C=C-), 2.37-2.33 (t, 2H, **3h** –C(O)C*H*$_2$CH$_2$-), 2.52-2.46 (m, 3H, **2h**&**3h**).

^{13}C NMR (101 MHz, $CDCl_3$; δ, ppm): 14.1, 20.7, 21.4, 21.5, 21.7, 22.5 (2), 22.6 (2), 23.5, 24.6, 26.3, 26.6, 26.7, 31.0, 32.7, 37.4, 41.4, 133.6, 138.7, 208.0, 211.8.

GC-HRMS: Calc for $C_{12}H_{20}O$ [M^+] 180.1514; found 180.1510 and 180.1499.

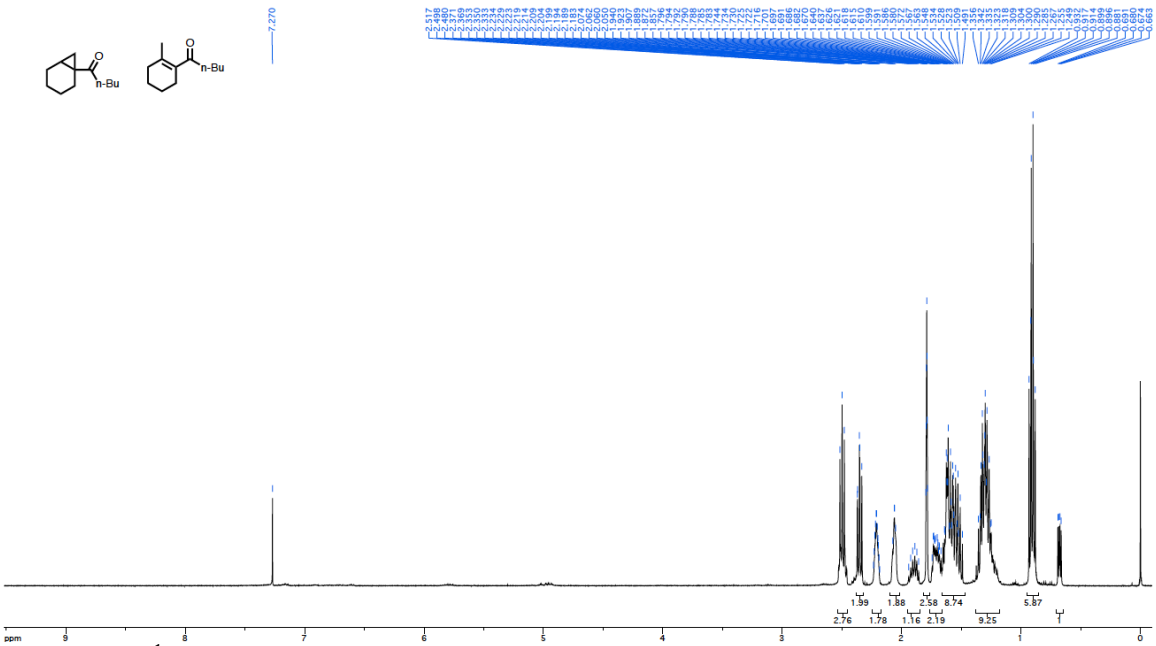


Figure S49: ^{1}H NMR spectrum of the mixture of **2h** & **3h** in $CDCl_3$.

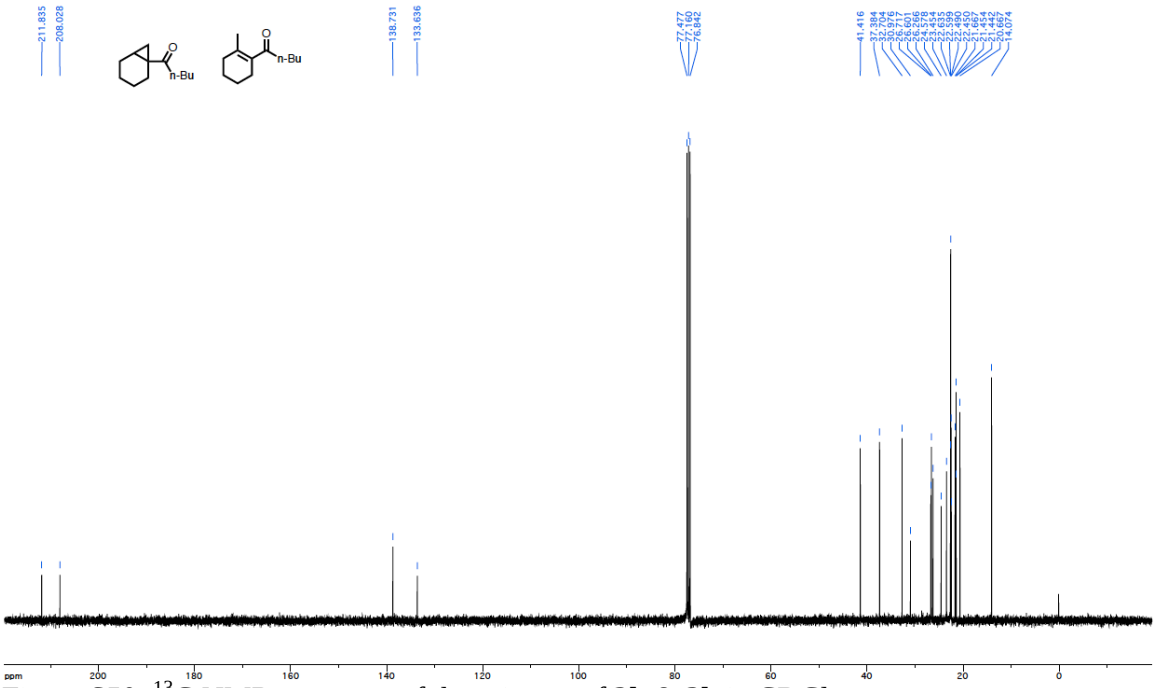


Figure S50: ^{13}C NMR spectrum of the mixture of **2h** & **3h** in $CDCl_3$.

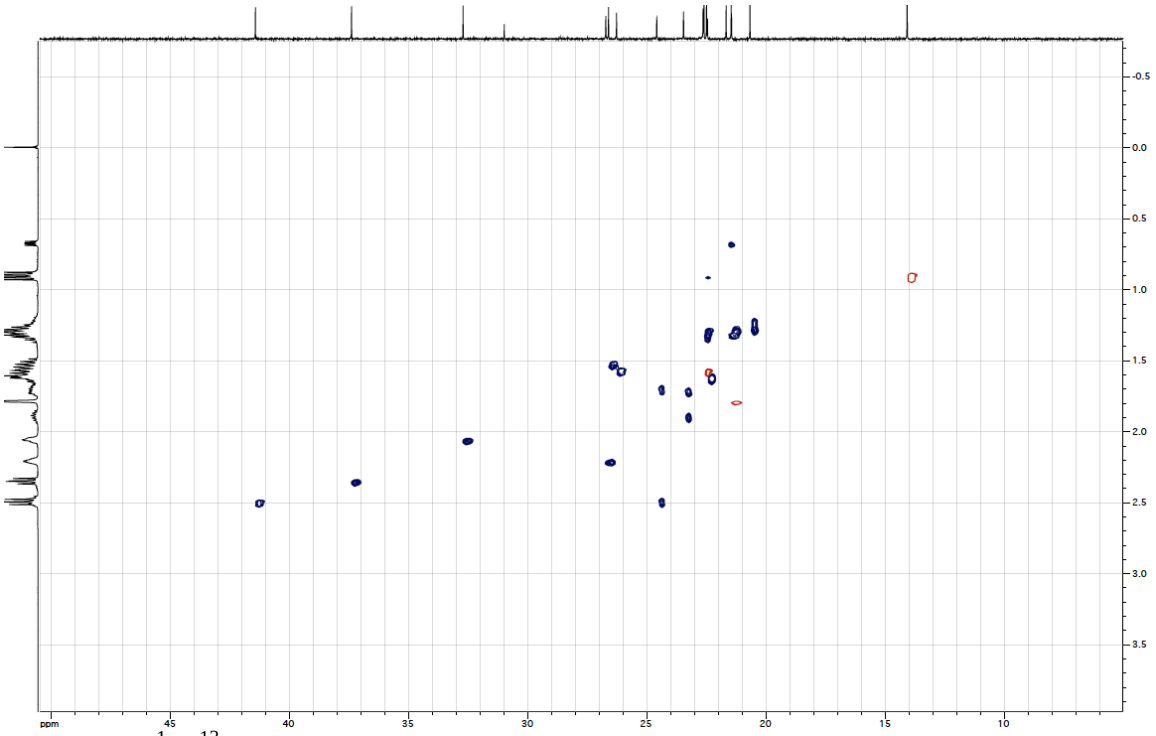
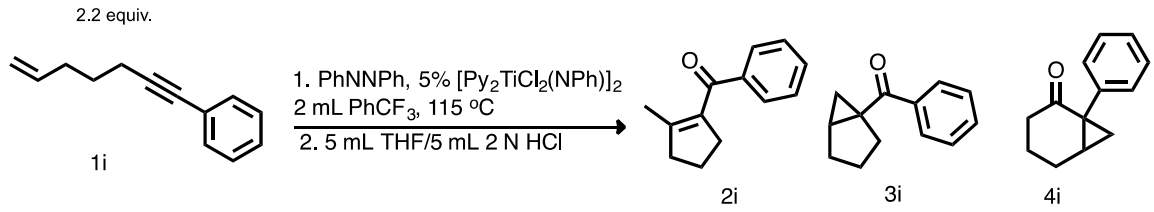


Figure S51: ^{1}H-^{13}C HSQC of the mixture of **2h** & **3h** in $CDCl_3$ between 0.2 to 4.0 ppm and 5 to 51 ppm.

Synthesis of bicyclo[3.1.0]hexan-1-yl(phenyl)methanone, (2-methylcyclopent-1-en-1-yl)(phenyl)methanone, and 1-phenylbicyclo[4.1.0]heptan-2-one (2i, 3i & 4i)



In a glovebox, to a 20 mL scintillation vial with a stir bar were added 103.6 mg azobenzene (1 equiv, 0.569 mmol), 23.4 mg $[Py_2TiCl_2(NPh)]_2$ (0.05 equiv,0.0306 mmol), and 191.37 mg **1i** (2.2 equiv, 1.12 mmol). The mixture was then diluted with 2 mL α,α,α-trifluorotoluene, and the vial was sealed with a Teflon screw cap and removed from the glovebox. The reaction mixture was heated to 115 °C overnight for 16 h in a preheated oil bath, cooled to room temperature and quenched with 1 mL DI H_2O. The reaction mixture was further diluted with a mixture of 5 mL THF/5 mL 2 N HCl and stirred overnight. The mixture was poured into 20 mL saturated Na_2CO_3, and extracted 3x with 20 mL Et_2O. The organic layers were collected, washed with 20 mL brine, dried over $MgSO_4$, and concentrated in vacuo. The crude oil was purified by column chromatography using a 2-8% gradient of EtOAc/hexanes, to give **2i** & **3i** as well as the hydroaminated product **8i** (this results from hydrolysis of the azatitanacyclobutene upon workup) as a yellow oil (66.7 mg, 31.1% yield) and then **4i** was separated and collected as a yellow oil (36.3 mg, 17.2% yield).

2i and **3i** and hydroaminated product (**8i**):
^{1}H NMR (400 MHz, $CDCl_3$; δ, ppm): 1.02 (t, *J* = 4.9 Hz, 1H, **3i** cyclopropyl -CHC*H*H), 1.45-1.32 (m, 2H, **3i**), 1.95-1.74 (m, 3H, **3i**), 2.13-2.08 (m, 3H, **3i**), 2.47 (t, *J* = 7.4 Hz, 3H, **8i** –CH_2CH_2C(O)CH_2-), 2.56-2.52 (m, 2H, **2i** cyclohexyl-CH_2CH_2C=C-), 2.77 (ddt, 2H, **2i** cyclohexyl-CH_2CH_2C=C-), 3.68 (s, 3H, **8i** -CH_2C(O)CH_2Ph), 3.99-3.93 (m, 2H, **8i** H_2C=CHCH_2-), 5.74 (ddt, *J* = 17.0, 10.3, 6.7 Hz, **8i** H_2C=C*H*CH_2-), 7.21 (dt, 2H, *J* = 7.3, 0.6 Hz, **8i** -CH_2-*o*-$H_2C_6H_4$), 7.27 (m, 1H, **8i** -CH_2-*p*-HC_6H_5), 7.35-7.31 (m, 1H, **8i** -CH_2-*m*-$H_2C_6H_4$), 7.44-7.40 (m, 2H, **3i** -C(O)-*m*-$H_2C_6H_3$), 7.51-7.46 (m, 1H, **3i** -C(O)-*p*-HC_6H_4), 7.73 (dd, *J* = 8.3, 1.4 Hz, 2H, **3i** -C(O)-*o*-$H_2C_6H_3$).

^{13}C NMR (101 MHz, $CDCl_3$; δ, ppm): 17.7, 21.9, 26.8, 30.2, 39.0, 115.3, 128.0, 128.2, 131.5, 139.0, 204.5.

4i:
^{1}H NMR (500 MHz, $CDCl_3$; δ, ppm): 1.47 (dd, *J* = 8.3, 5.4 Hz, 1H, cyclopropyl -CHC*H*H), 1.65 (t, *J* = 5.7 Hz, 1H, cyclopropyl -CHC*H*H), 1.87-1.75 (m, 2H, cyclohexyl -$CH_2CH_2CH_2$-), 2.02-1.98 (m, 1H, cyclohexyl -CH_2CH*H*CH_2-), 2.08 (dtd, *J* = 13.5, 4.9, 2.8 Hz, 1H, cyclopropyl –CH_2CH*H*CH_2), 2.18-2.13 (m, 1H, cyclohexyl -CH_2CH*H*CH_2-), 2.22 (ddd, *J* = 17.8, 10.8, 6.9 Hz, 1H, cyclohexyl –C(O)CH*H*CH_2-), 2.46 (dt, *J* = 17.9, 4.9 Hz, 1H, cyclohexyl –C(O)CH*H*CH_2-), 7.29-7.24 (m, 3H, -CH_2-(*o*,*p*-$H_3C_6H_2$)), 7.34-7.31 (m, 2H, -CH_2-(*m*-$H_2C_6H_3$)).

^{13}C NMR (126 MHz, $CDCl_3$; δ, ppm): 17.2, 19.3, 22.1, 25.6, 37.4, 39.6, 127.1, 128.3, 130.1, 140.6, 207.8.

GC-HRMS: Calc for $C_{13}H_{14}O$ [M^+] 186.1045; found 186.1028, 186.1030, and 186.1052.

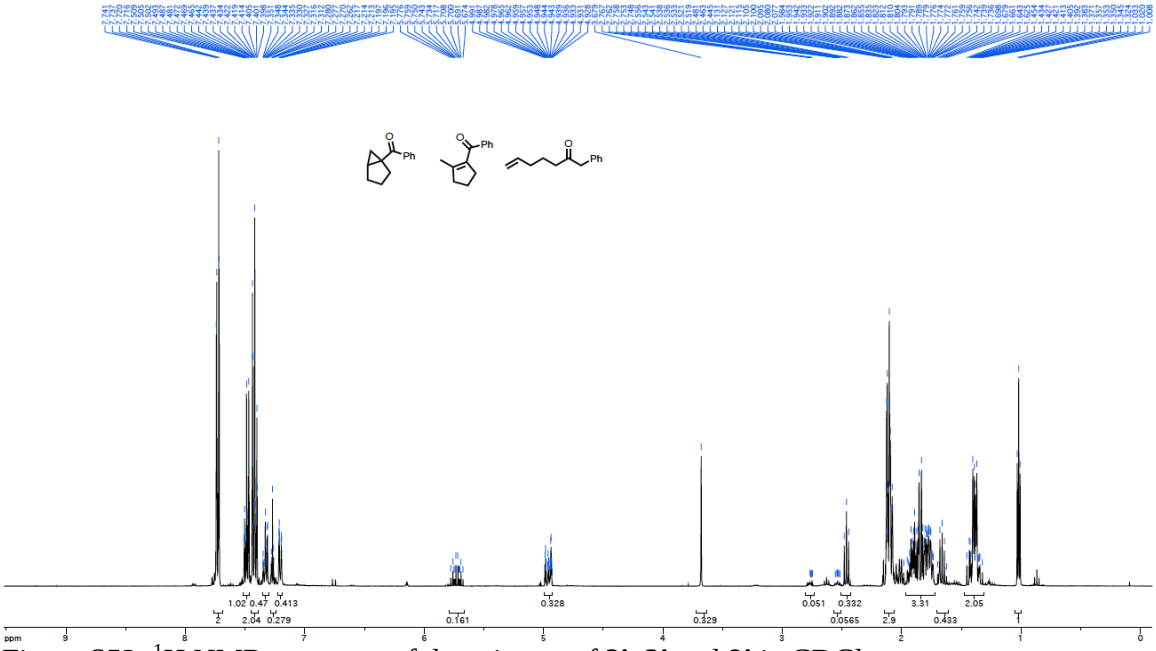


Figure S52: ^{1}H NMR spectrum of the mixture of **2i**, **3i** and **8i** in $CDCl_3$.

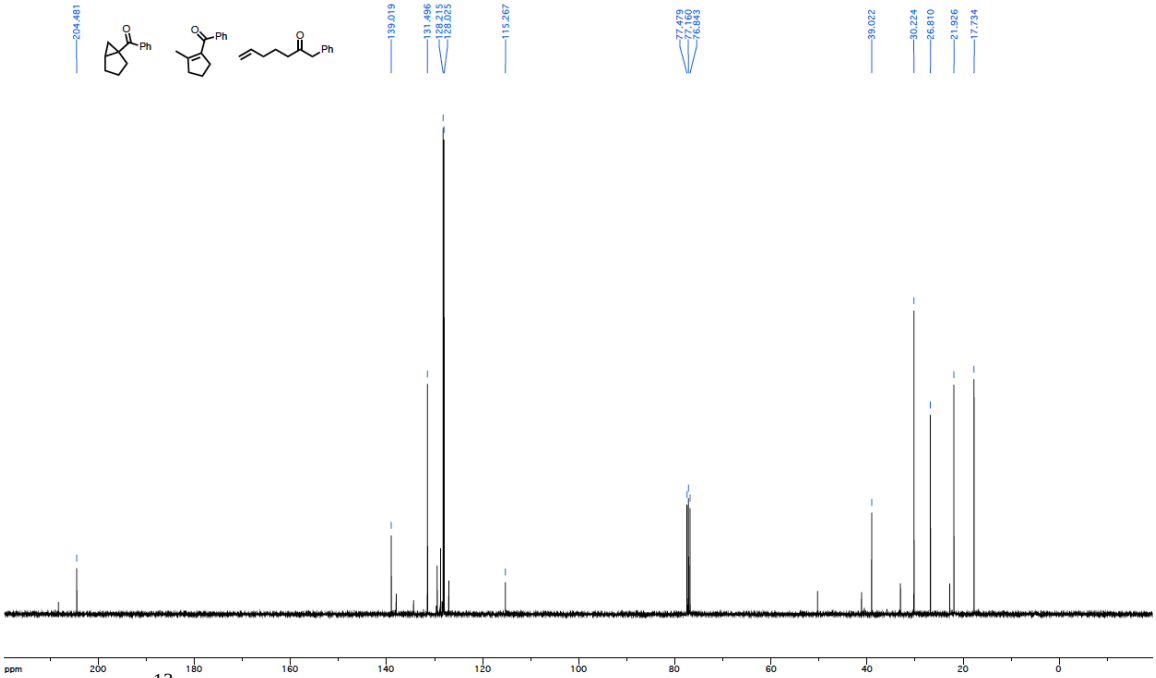


Figure S53: ^{13}C NMR spectrum of the mixture of **2i, 3i** and **8i** in $CDCl_3$.

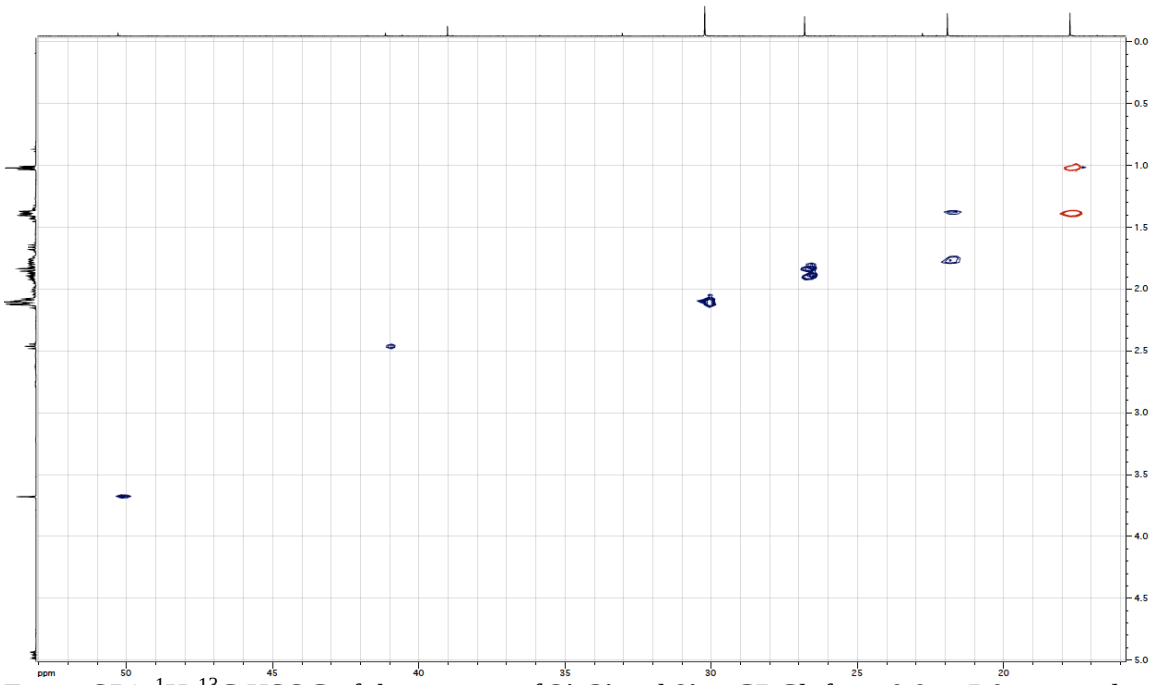


Figure S54: ^{1}H-^{13}C HSQC of the mixture of **2i**, **3i** and **8i** in $CDCl_3$ from 0.0 to 5.0 ppm and 10 to 60 ppm.

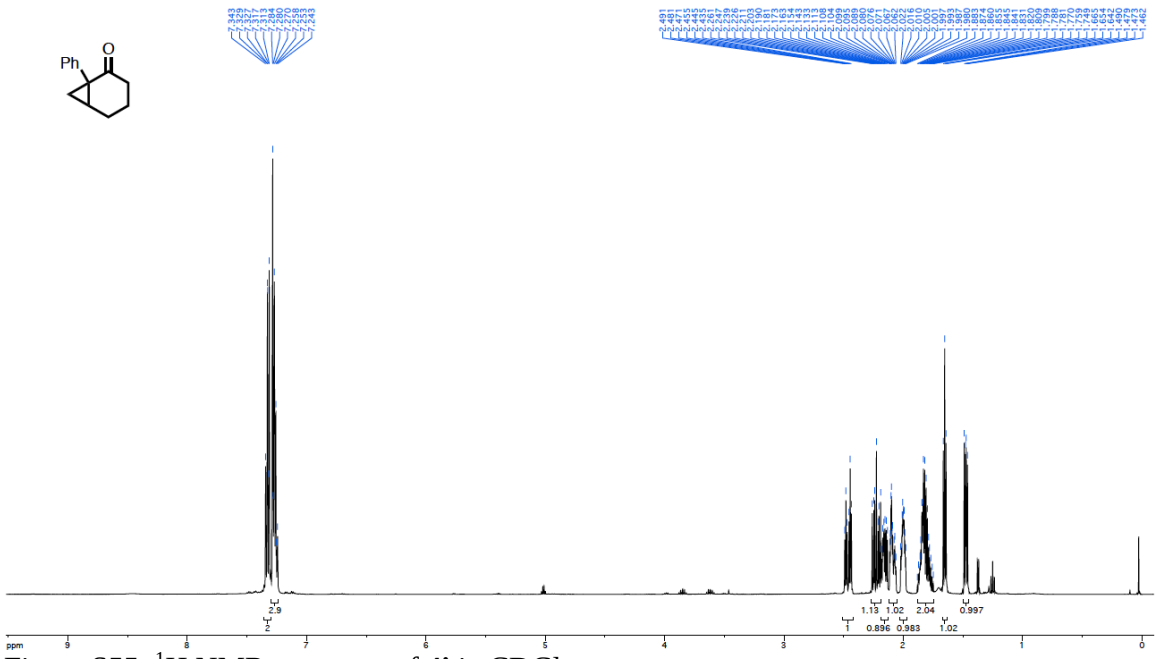


Figure S55: ^{1}H NMR spectrum of **4i** in $CDCl_3$.

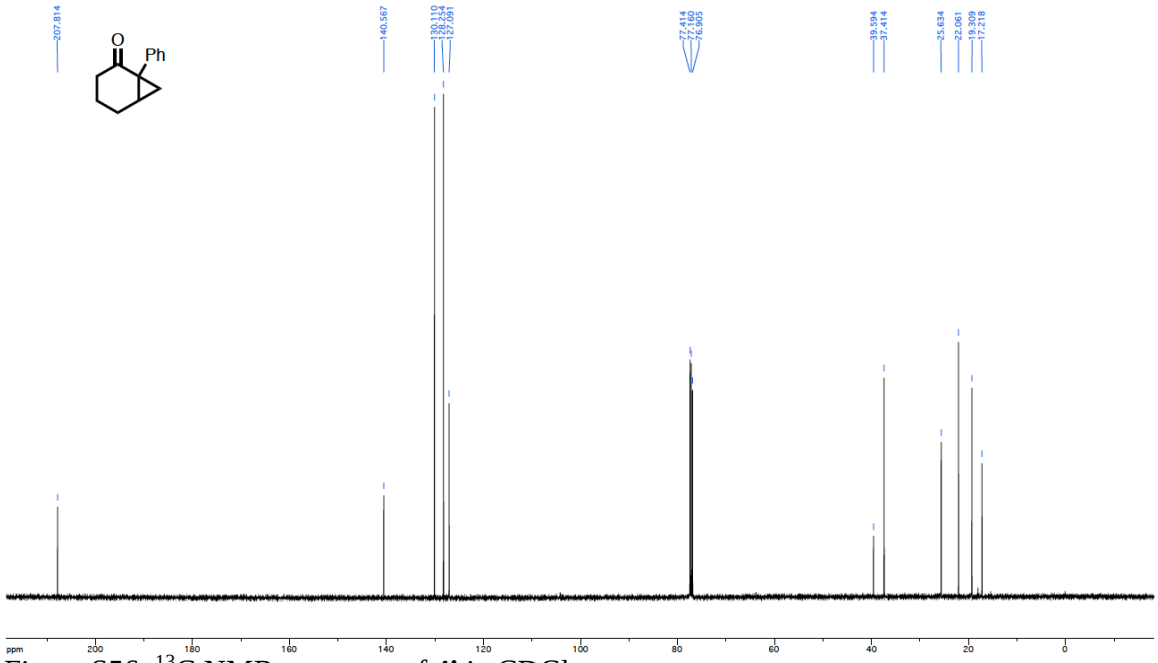


Figure S56: ^{13}C NMR spectrum of **4i** in $CDCl_3$.

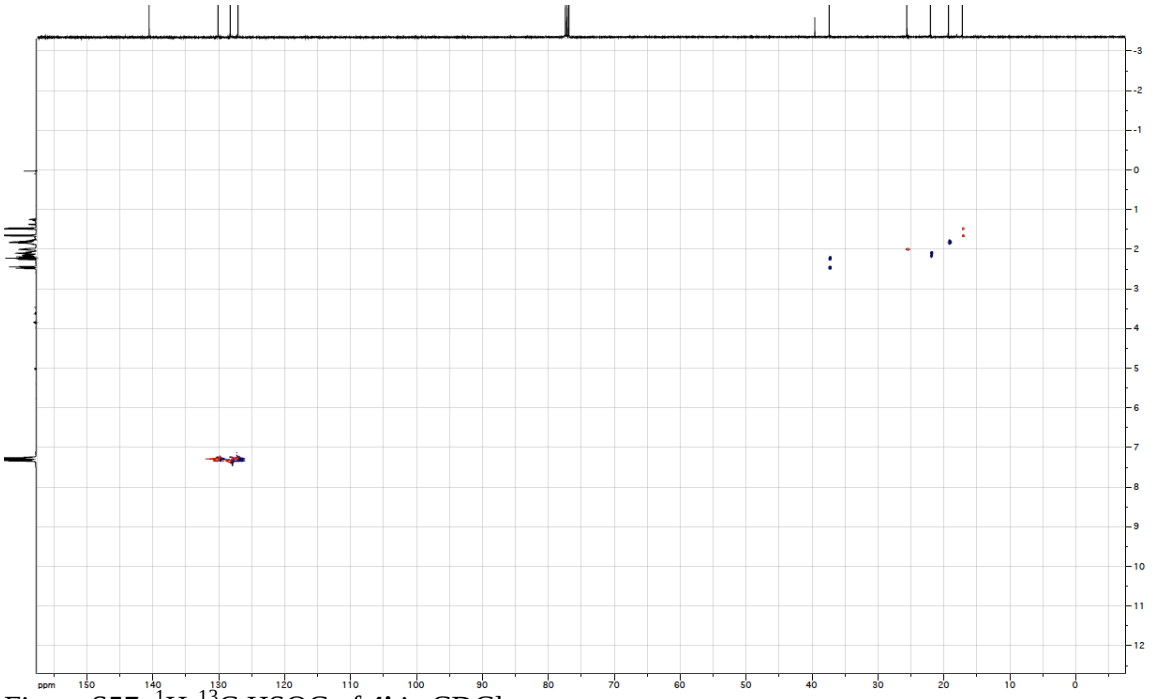


Figure S57: ^{1}H-^{13}C HSQC of **4i** in $CDCl_3$.

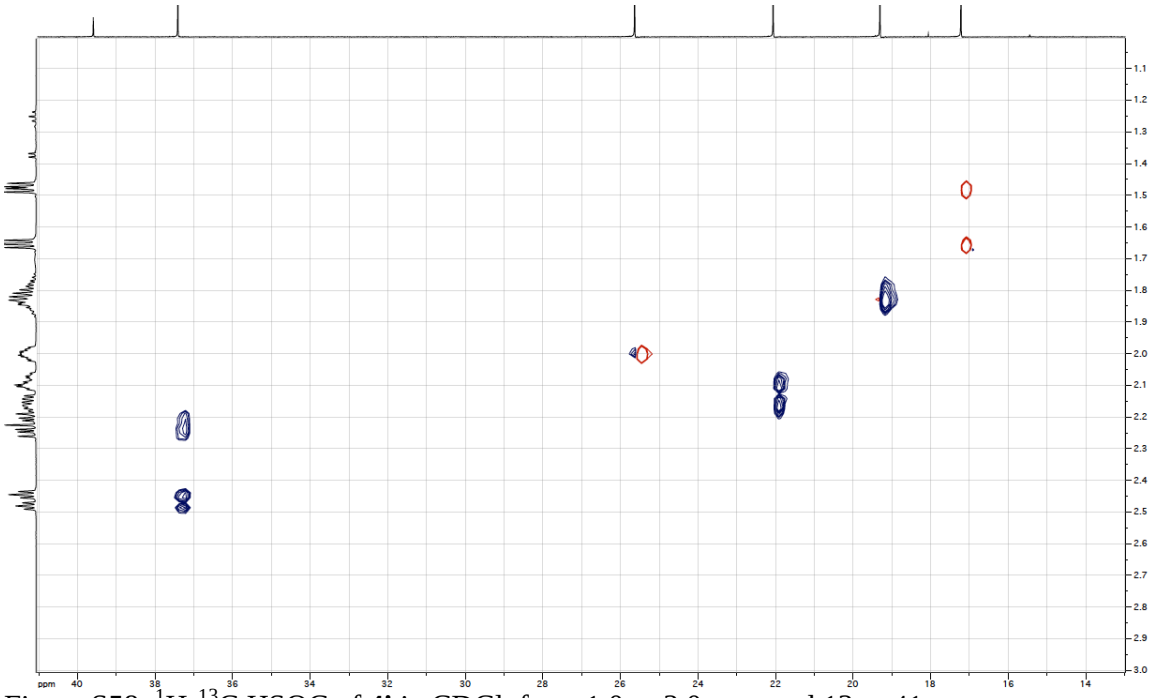


Figure S58: ^{1}H-^{13}C HSQC of **4i** in $CDCl_3$ from 1.0 to 3.0 ppm and 13 to 41 ppm.

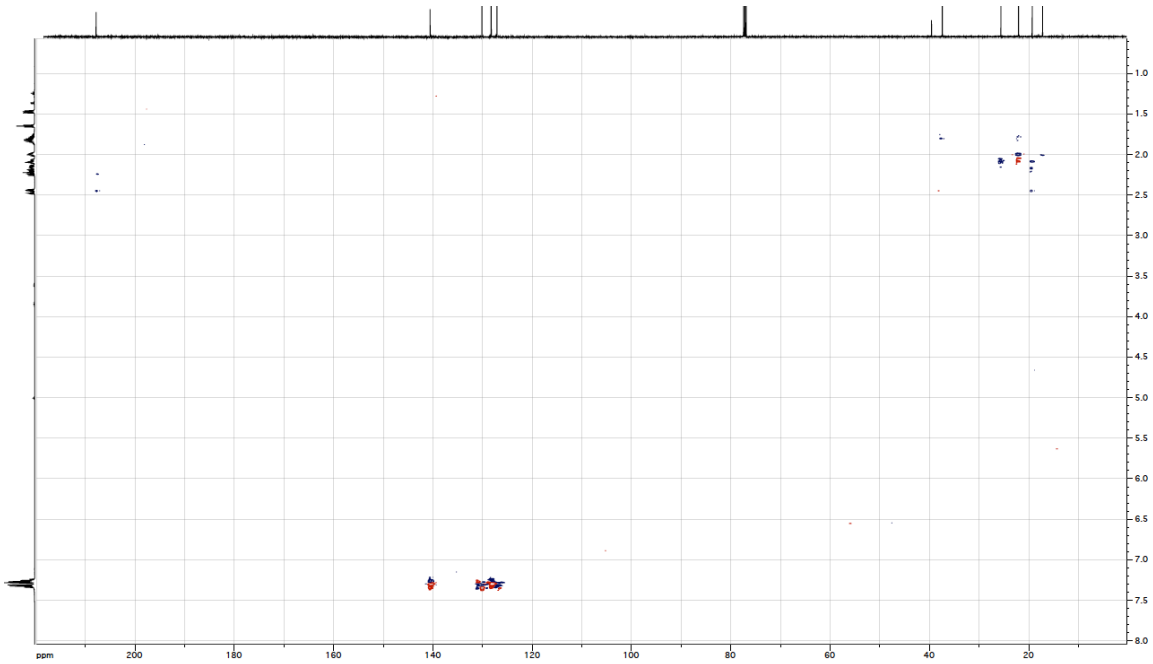


Figure S59: 1,1-ADEQUATE of **4i** in $CDCl_3$.

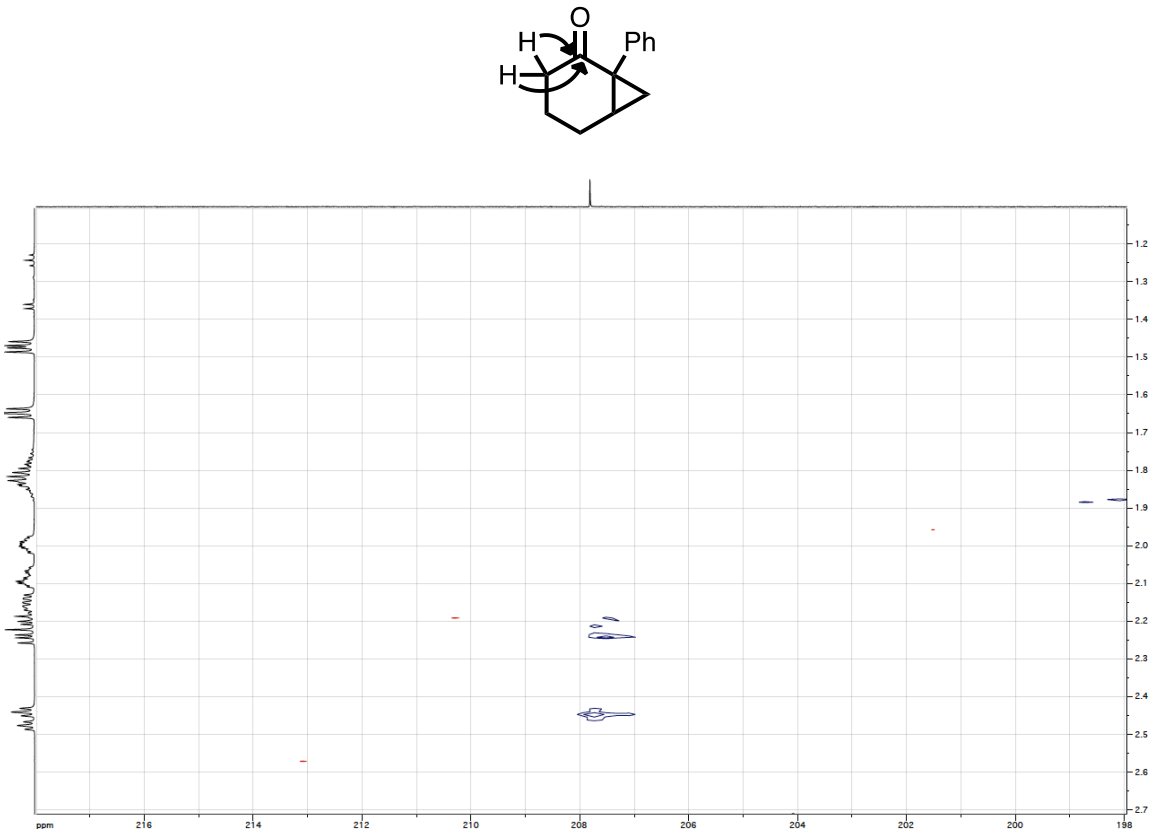
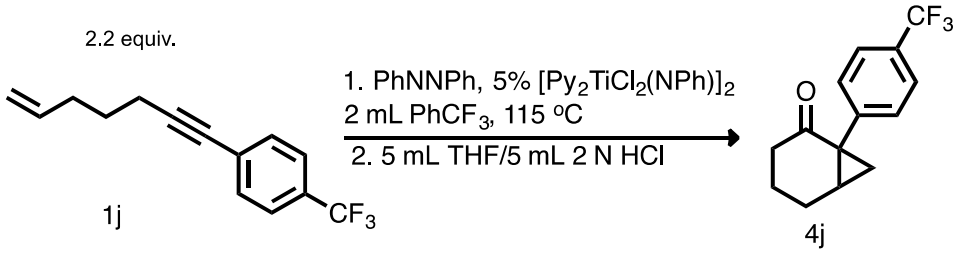


Figure S60: 1,1-ADEQUATE of **4i** in $CDCl_3$ from 1.1 to 2.7 ppm and 198 to 217 ppm.

Synthesis of 1-(4-(trifluoromethyl)phenyl)bicyclo[4.1.0]heptan-2-one (4j)



In a glovebox, to a 20 mL scintillation vial with a stir bar were added 104.5 mg azobenzene (1 equiv, 0.573 mmol), 21.4 mg $[Py_2TiCl_2(NPh)]_2$ (0.05 equiv, 0.03 mmol), and 268.034 mg **1j** (2.2 equiv, 1.13 mmol). The mixture was diluted with 2 mL α,α,α-trifluorotoluene, and the vial was sealed with a Teflon screw cap and removed from the glovebox. The reaction mixture was then heated to 115 °C overnight for 16 h in a preheated oil bath, cooled to room temperature and quenched with 1 mL DI H_2O. The reaction mixture was further diluted with a mixture of 5 mL THF/5 mL 2 N HCl and stirred overnight. The mixture was poured into 20 mL saturated Na_2CO_3 and extracted 3x with 20 mL Et_2O. The organic layers were collected, washed with 20 mL brine, dried over $MgSO_4$, and concentrated in vacuo. The crude oil was purified by column chromatography using a 2-8% gradient of EtOAc/hexanes to give **4j** as a yellow oil (100.8 mg, 35.5% yield).

^{1}H NMR (400 MHz, $CDCl_3$; δ, ppm): 1.47 (dd, *J* = 8.4, 5.5 Hz, 1H, cyclopropyl –CHC*H*HC-), 1.71 (t, *J* = 5.8 Hz, 1H, -CHC*H*HC-), 1.87-1.78 (m, 2H, cyclohexyl –CH_2-), 2.04-1.99 (m, 1H, cyclopropyl CH_2(C*H*CH_2C)-), 2.18-2.06 (m, 2H), 2.23 (ddd, *J* = 17.9, 10.7, 7.0 Hz, 1H, cyclohexyl –CH_2C*H*HC(O)-), 2.47 (dt, *J* = 18.0, 4.9 Hz, 1H, –CH_2C*H*HC(O)-), 7.37 (d, *J* = 0.7 Hz, 2H, -C(O)(*o*-$H_2C_6H_2$-CF_3)), 7.57 (dd, *J* = 8.6, 0.6 Hz, 2H, -C(O)(*m*-$H_2C_6H_2$-CF_3)).

^{3}C NMR (101 MHz, $CDCl_3$; δ, ppm): 17.4, 19.2, 21.9, 25.8, 37.4, 39.3, 124.3 (q, $^1J_{C\text{-}F}$ = 272.0 Hz), 125.2 (q, $^3J_{C\text{-}F}$ = 3.9 Hz), 129.3 (q, $^2J_{C\text{-}F}$ = 32.3 Hz), 130.5, 144.5, 207.1.

^{19}F NMR (470 MHz, $CDCl_3$; δ, ppm): -61.4 (s, CF_3).

GC-HRMS: Calc for $C_{14}H_{13}OF_3$ [M^+] 254.0918; found 254.0912.

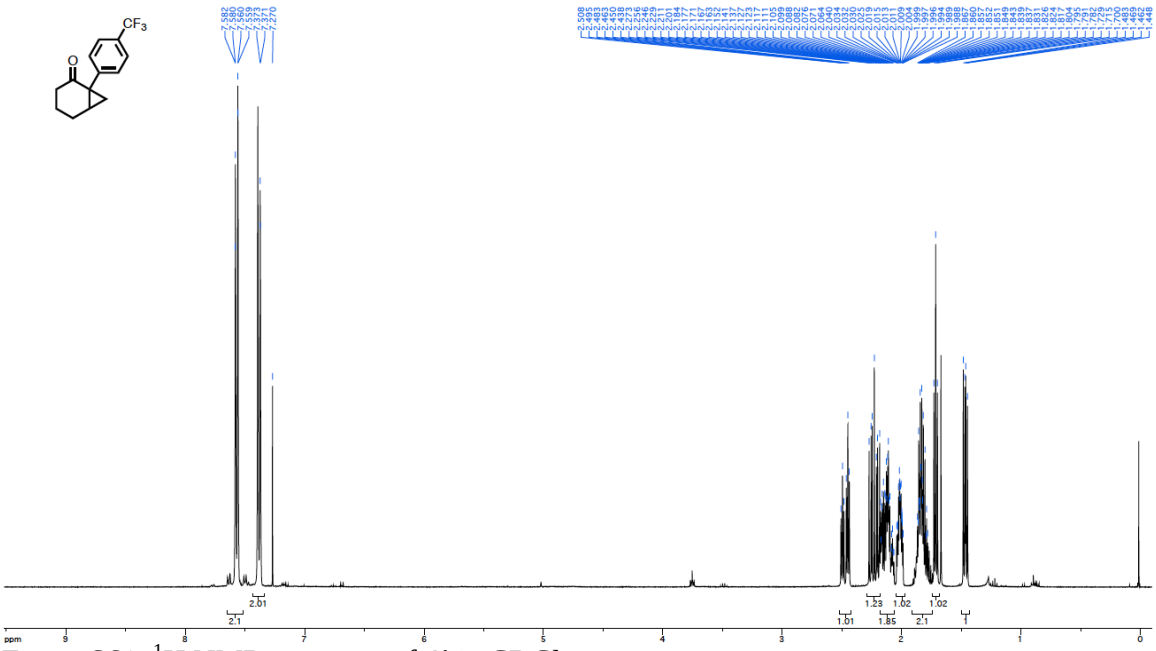


Figure S61: ^{1}H NMR spectrum of **4j** in $CDCl_3$.

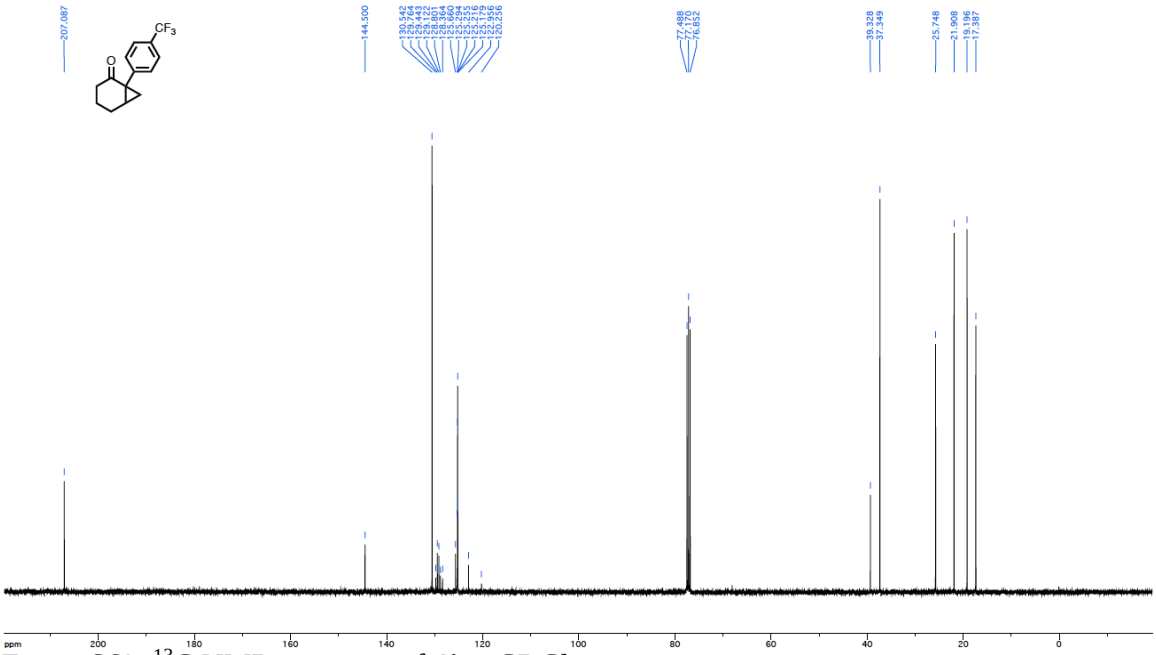


Figure S62: ^{13}C NMR spectrum of **4j** in $CDCl_3$.

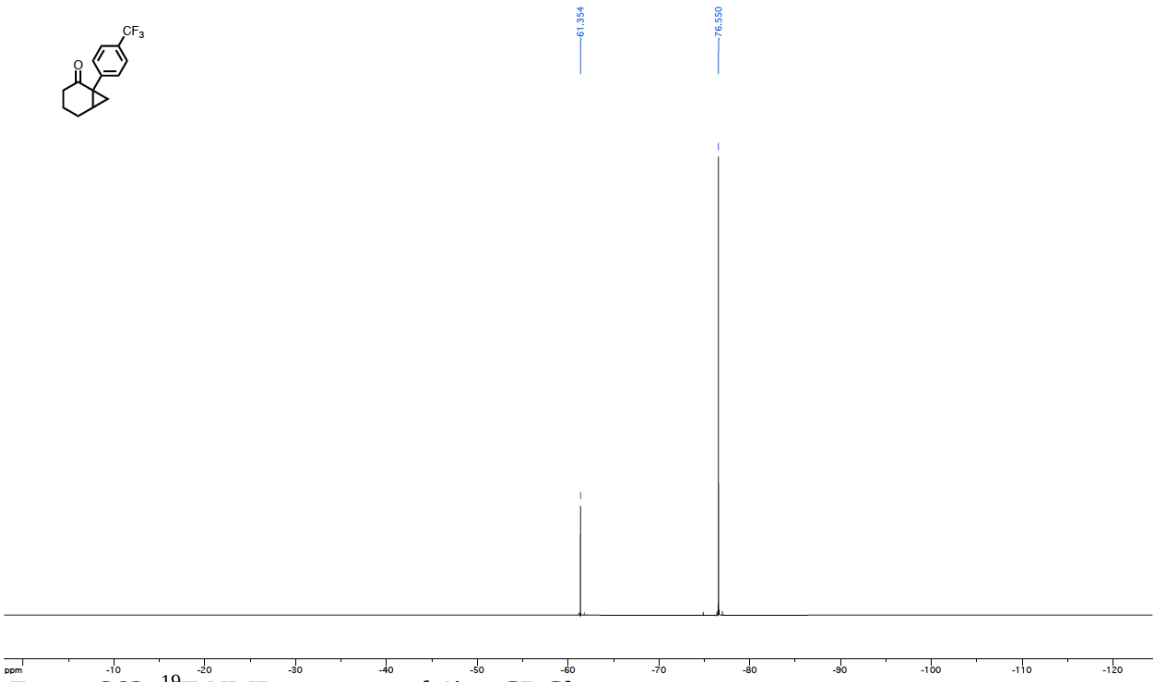


Figure S63: ^{19}F NMR spectrum of **4j** in $CDCl_3$.

NMR Reaction of 1j

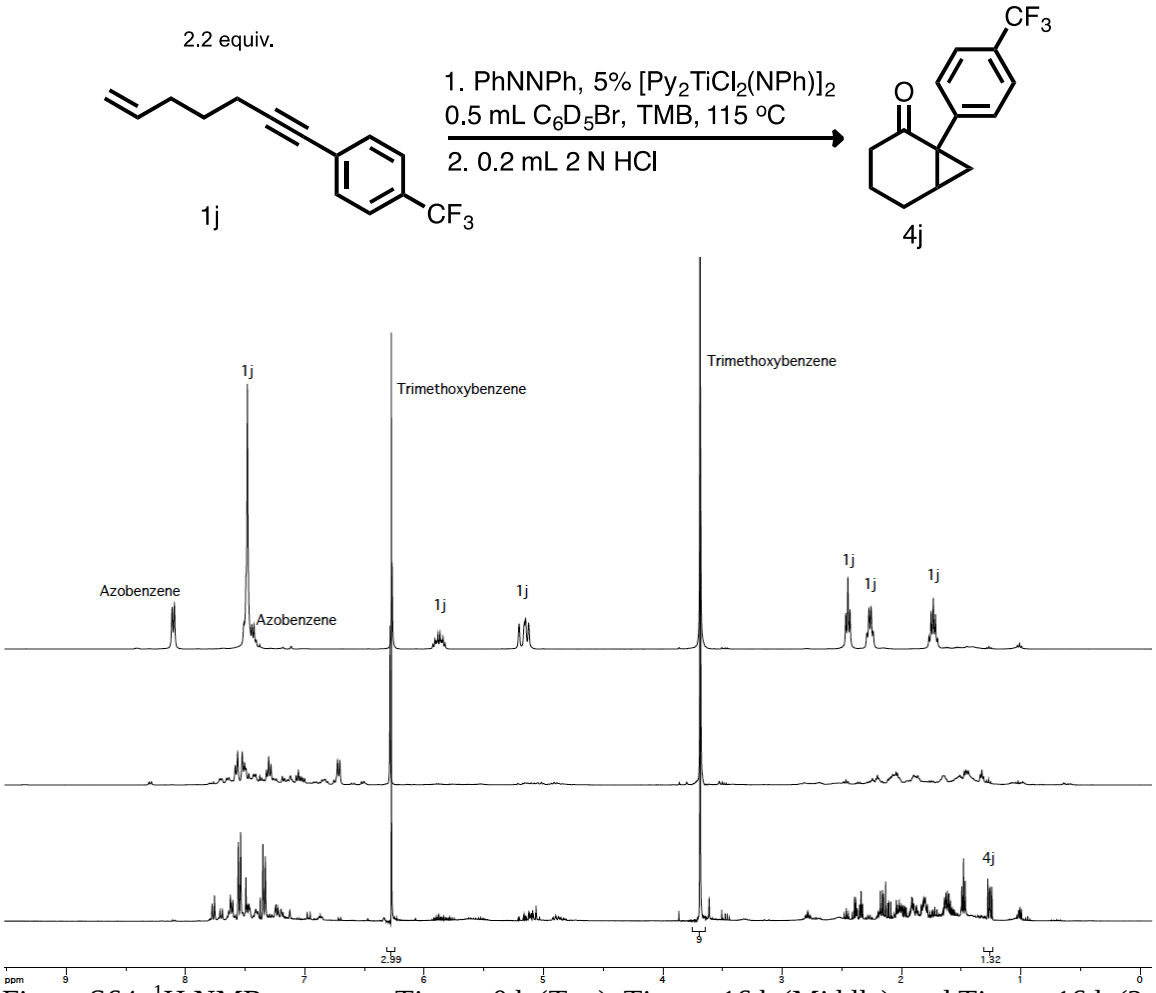
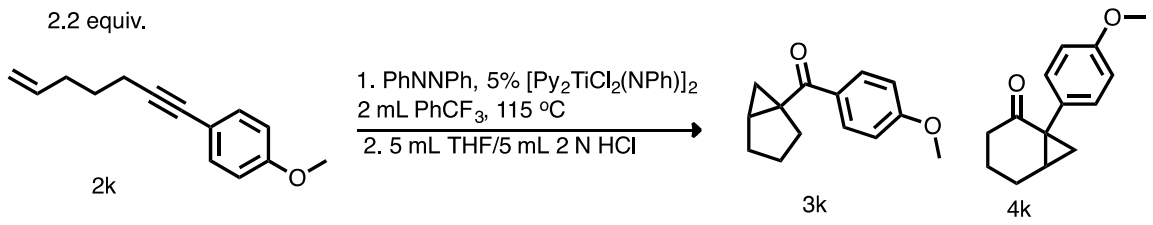


Figure S64: ^{1}H NMR spectra at Time = 0 h (Top), Time = 16 h (Middle), and Time = 16 h (2 N HCl quench, Bottom) of **4j**.

Synthesis of bicyclo[3.1.0]hexan-1-yl(4-methoxyphenyl)methanone and 1-(4-methoxyphenyl)bicyclo[4.1.0]heptan-2-one (3k &4k)



In a glovebox, to a 20 mL scintillation vial with a stir bar were added 100.0 mg azobenzene (1 equiv, 0.548 mmol), 20.1 mg $[Py_2TiCl_2(NPh)]_2$ (0.05 equiv, 0.027 mmol), and 225.3 mg **1k** (2.2 equiv, 1.122 mmol). The mixture was then diluted with 2 mL α,α,α-trifluorotoluene, and the vial was sealed with a Teflon screw cap and removed from the glovebox. The reaction mixture was heated to 115 °C overnight for 16 h in a preheated oil bath, cooled to room temperature and quenched with 1 mL DI H_2O. The reaction mixture was further diluted with a mixture of 5 mL THF/5 mL 2 N HCl and stirred overnight. The mixture was poured into 20 mL saturated Na_2CO_3 and extracted 3x with 20 mL Et_2O. The organic layers were collected, washed with 20 mL brine, dried over $MgSO_4$, and concentrated in vacuo. The crude oil was then purified by column chromatography using a 2-8% gradient of EtOAc/hexanes to give **3k** as a yellow oil (70.3 mg, 29.6% yield) and **4k** as a yellow oil (18.0 mg, 7.5% yield).

3k:

^{1}H NMR (400 MHz, $CDCl_3$; δ, ppm): 0.97 (t, *J* = 4.8 Hz, 1H, cyclopropyl -CHC*H*HC-), 1.28 (dd, *J* = 8.5, 4.7 Hz, 1H, cyclopropyl -CHC*H*HC-), 1.40 (dtt, *J* = 13.4, 11.0, 8.3 Hz, 1H, cyclopentyl –CHC*H*HCH$_2$-), 1.86-1.75 (m, 2H, -CH$_2$C*H$_2$*CH$_2$-), 1.92 (tdd, *J* = 12.1, 7.9, 4.3 Hz, 1H cyclopropyl –CH$_2$(C*H*CH$_2$C)-), 2.11-2.04 (m, 2H), 2.15 (ddd, *J* = 12.5, 8.4, 1.3 Hz, 1H, cyclopentyl –CH$_2$C*H*HCC(O)-), 3.87 (s, 3H, -OC*H$_3$*), 6.92 (d, *J* = 8.9 Hz, 2H, -C(O)-(*o*-*H$_2$*C$_6$H$_2$-OCH$_3$)), 7.81 (d, *J* = 8.9 Hz, 2H, -C(O)-(*m*-*H$_2$*C$_6$H$_2$-OCH$_3$)).

^{13}C NMR (101 MHz, $CDCl_3$; δ, ppm): 17.1, 22.0, 26.9, 29.0, 30.9, 38.6, 55.5, 113.5, 130.7, 131.4, 162.6, 202.3.

4k:

^{1}H NMR (400 MHz, $CDCl_3$; δ, ppm): 1.42 (dd, *J* = 8.3, 5.3 Hz, 1H, cyclopropyl -CHC*H*HC-), 1.62 (t, *J* = 5.7 Hz, 1H, cyclopropyl -CHC*H*HC-), 1.86-1.72 (m, 2H, cyclohexyl –C*H$_2$*-), 1.99-1.94 (m, 1H, -CH$_2$(C*H*CH$_2$C)-), 2.15-2.05 (m, 2H, cyclohexyl –C*H$_2$*-), 2.20 (ddd, *J* = 17.8, 10.6, 7.1 Hz, 1H, cyclohexyl –CH$_2$C*H*HC(O)-), 2.44 (dt, *J* = 17.9, 4.9 Hz, 1H, cyclohexyl –CH$_2$C*H*HC(O)-), 3.80 (s, 3H, -OC*H$_3$*), 6.86 (d, *J* = 8.8 Hz, 2H, -(*o*-*H$_2$*C$_6$H$_2$-OCH$_3$)), 7.19 (d, *J* = 8.8 Hz, 2H, -(*m*-*H$_2$*C$_6$H$_2$-OCH$_3$)).

^{13}C NMR (101 MHz, $CDCl_3$; δ, ppm): 17.5, 19.4, 22.1, 25.8, 37.4, 39.0, 55.4, 113.7, 131.2, 132.8, 158.6, 208.2.

GC-HRMS: Calc for $C_{14}H_{16}O_2$ [M^+] 216.1150; found 216.1140, 216.1157, and 216.1137.

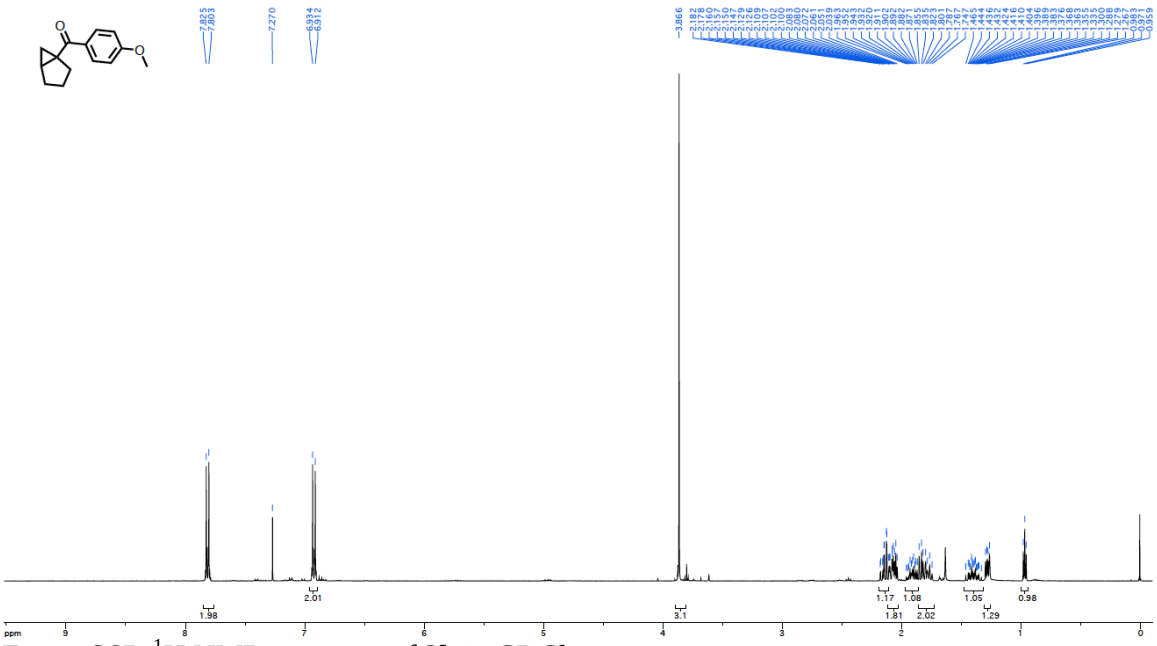


Figure S65: ^{1}H NMR spectrum of **3k** in $CDCl_3$.

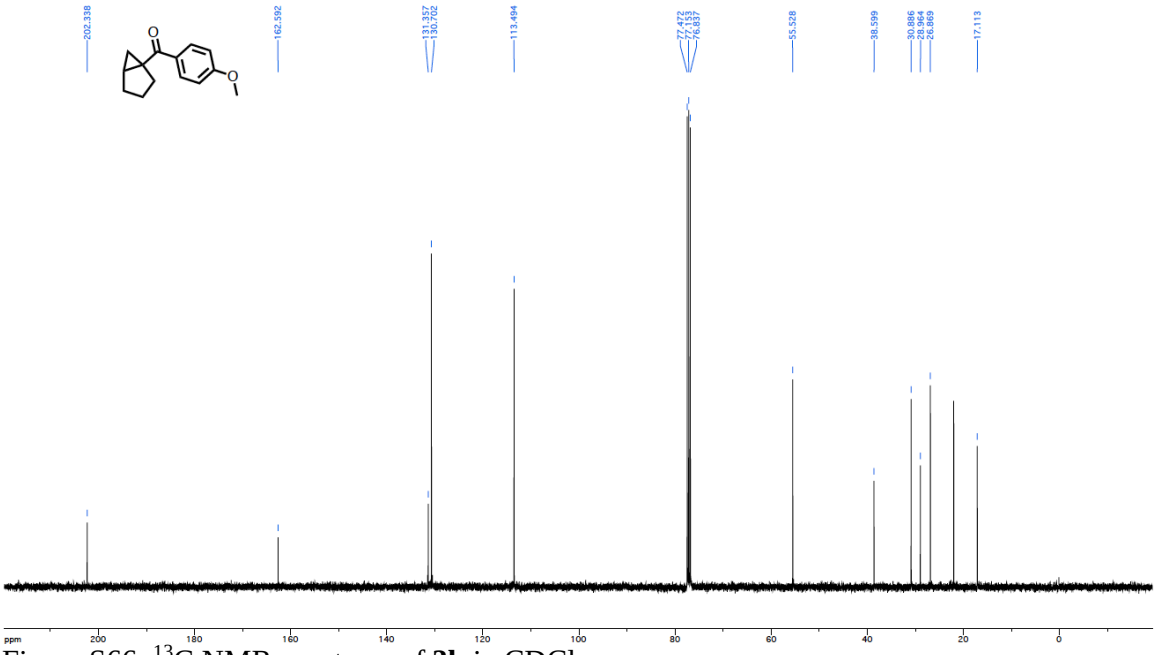


Figure S66: ^{13}C NMR spectrum of **3k** in $CDCl_3$.

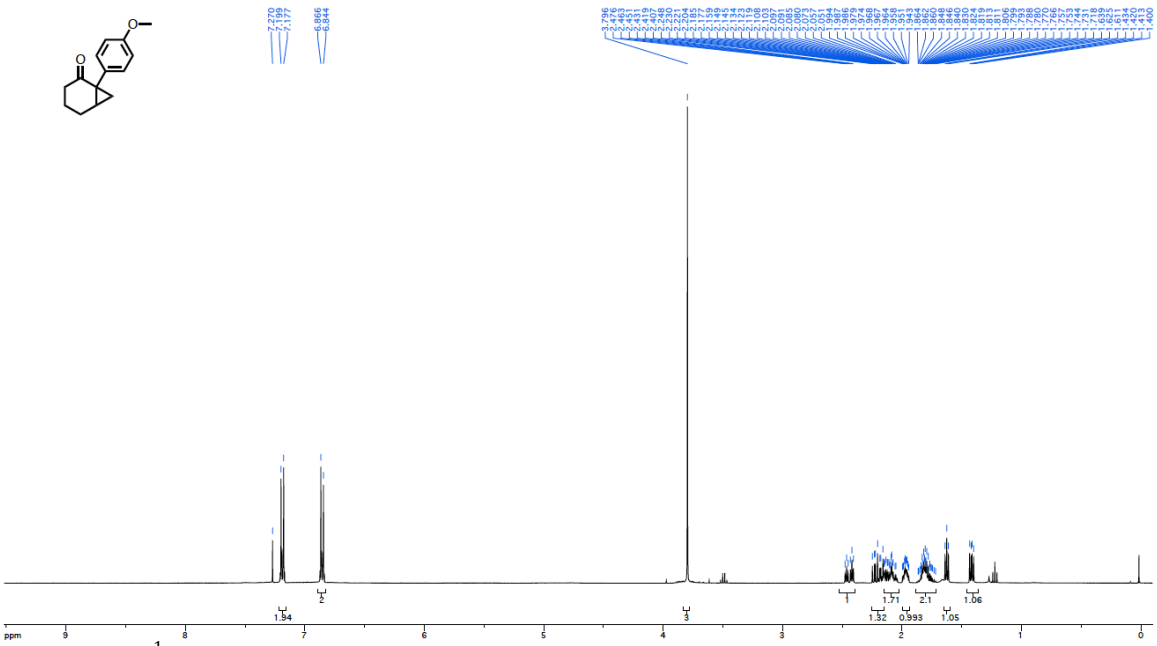


Figure S67: ^{1}H NMR spectrum of **4k** in $CDCl_3$.

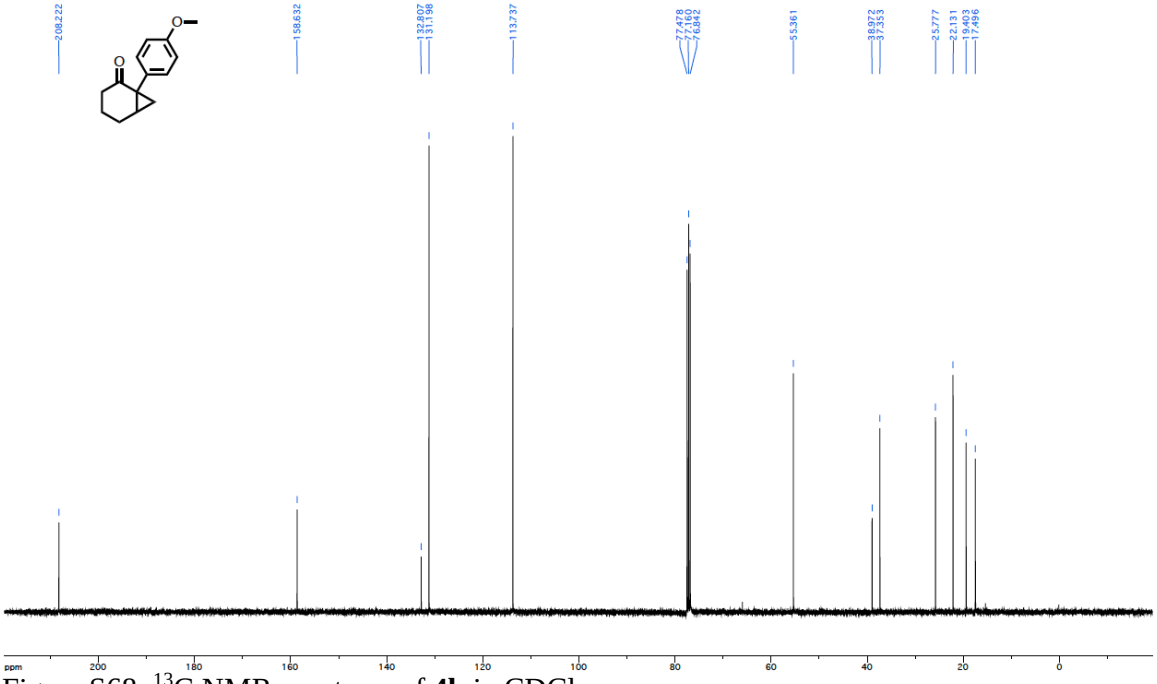
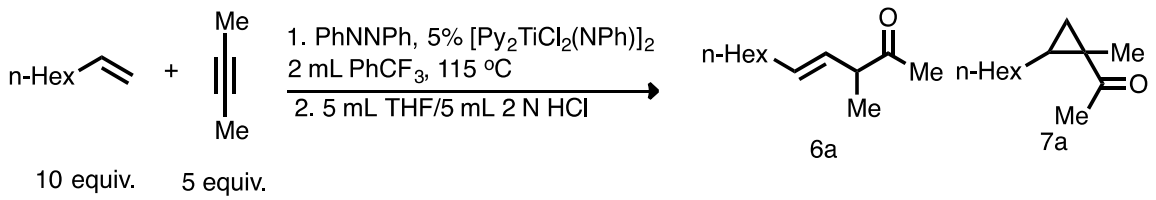


Figure S68: ^{13}C NMR spectrum of **4k** in $CDCl_3$.

Synthesis of (*E*)-3-methylundec-4-en-2-one and 1-(2-hexyl-1-methylcyclopropyl)ethan-1-one (6a & 7a)



10 equiv. 5 equiv.

In a glovebox, to a 20 mL scintillation vial with a stir bar were added 104.0 mg azobenzene (1 equiv, 0.057 mmol), 22.3 mg $[Py_2TiCl_2(NPh)]_2$ (0.05 equiv, 0.0302 mmol), 150 mg 2-butyne (5 equiv, 0.217 mL, 2.77 mmol), and 615.96 mg 1-octene (10 equiv, 0.861 mL, 5.49 mmol). The mixture was diluted with 2 mL α,α,α-trifluorotoluene, and the vial was sealed with a Teflon screw cap and removed from the glovebox. The reaction mixture was heated to 115 °C overnight for 16 h in a preheated oil bath, cooled to room temperature and quenched with 1 mL DI H_2O. The reaction mixture was further diluted with a mixture of 5 mL THF/5 mL 2 N HCl and stirred overnight. The mixture was poured into 20 mL saturated Na_2CO_3 and extracted 3x with 20 mL Et_2O. The organic layers were collected, washed with 20 mL brine, dried over $MgSO_4$, and concentrated in vacuo. The crude oil was purified by column chromatography using a 0-5% gradient of EtOAc/hexanes to give **6a** as a clear, colorless oil (45.8 mg, 22.0% yield) and **7a** as a clear, colorless oil (63.4 mg, 30.4% yield)

6a:

^{1}H NMR (400 MHz, $CDCl_3$; δ, ppm): 0.88 (t, *J* = 6.8 Hz, 3H, -CH_2CH_3), 1.15 (d, *J* = 6.9 Hz, 3H, $CHCH_3$), 1.38-1.29 (m, 12H), 2.02 (q, *J* = 6.9 Hz, 2H, -CH2CH_2CH=CH-), 2.14 (s, 3H, -C(O)CH_3), 3.14 (quint, *J* = 7.3 Hz, 1H, -CH=CHC*H*(C(O)-)CH_3), 5.38 (ddt, *J* = 15.3, 8.2, 1.3 Hz, 1H, -CH_2C*H*=CHCH-), 5.59 (dt, *J* = 15.1, 7.0 Hz, 1H, -CH_2C*H*=C*H*CH-).

^{13}C NMR (101 MHz, $CDCl_3$; δ, ppm): 14.2, 16.2, 22.8, 28.0, 28.9, 29.3, 31.8, 32.7, 51.3, 129.0, 133.8, 210.4.

7a:

^{1}H NMR (400 MHz, $CDCl_3$; δ, ppm): 0.43 (dd, *J* = 5.5, 3.3 Hz, 1H, cyclopropyl (*n*-hex)CHCH*H*C), 0.89 (t, *J* = 7.0 Hz, 3H, -$CH_2CH_2CH_3$), 1.42-1.28 (m, 16H), 2.09 (s, 3H, -C(O)CH_3).

^{13}C NMR (101 MHz, $CDCl_3$; δ, ppm): 14.2, 14.8, 22.8, 24.2, 26.2, 29.2, 29.3, 29.3, 29.8, 31.4, 31.9, 210.6.

GC-HRMS: Calc for $C_{12}H_{22}O$ [M^+] 182.1671; found 182.1665 and 182.1660.

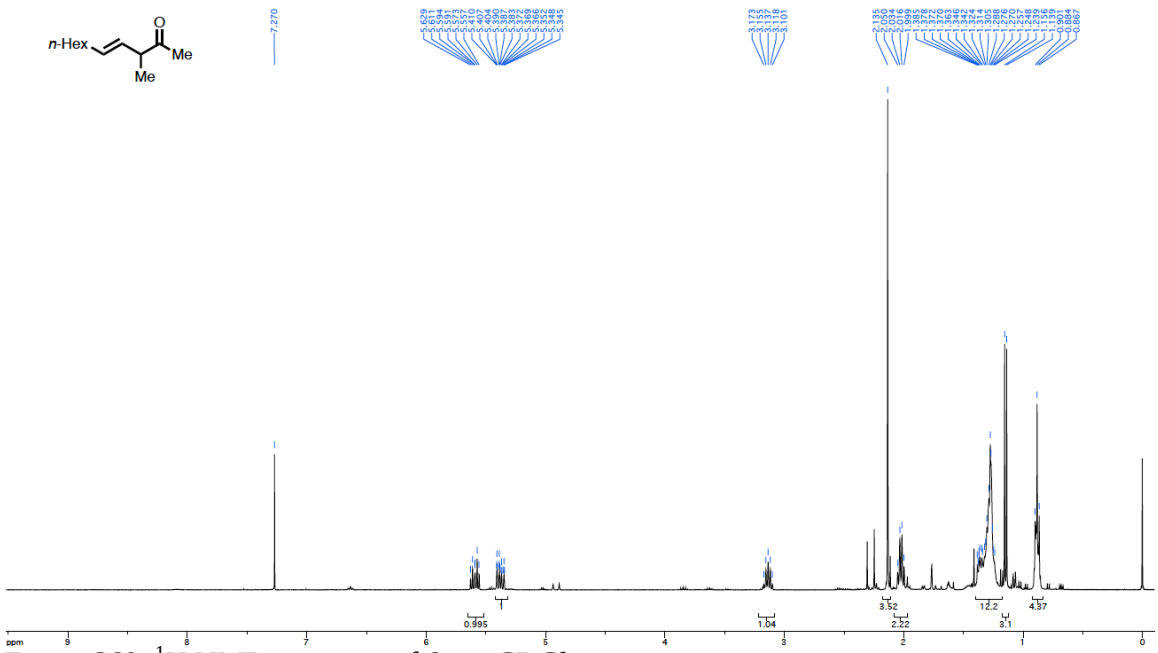


Figure S69: ^{1}H NMR spectrum of **6a** in $CDCl_3$.

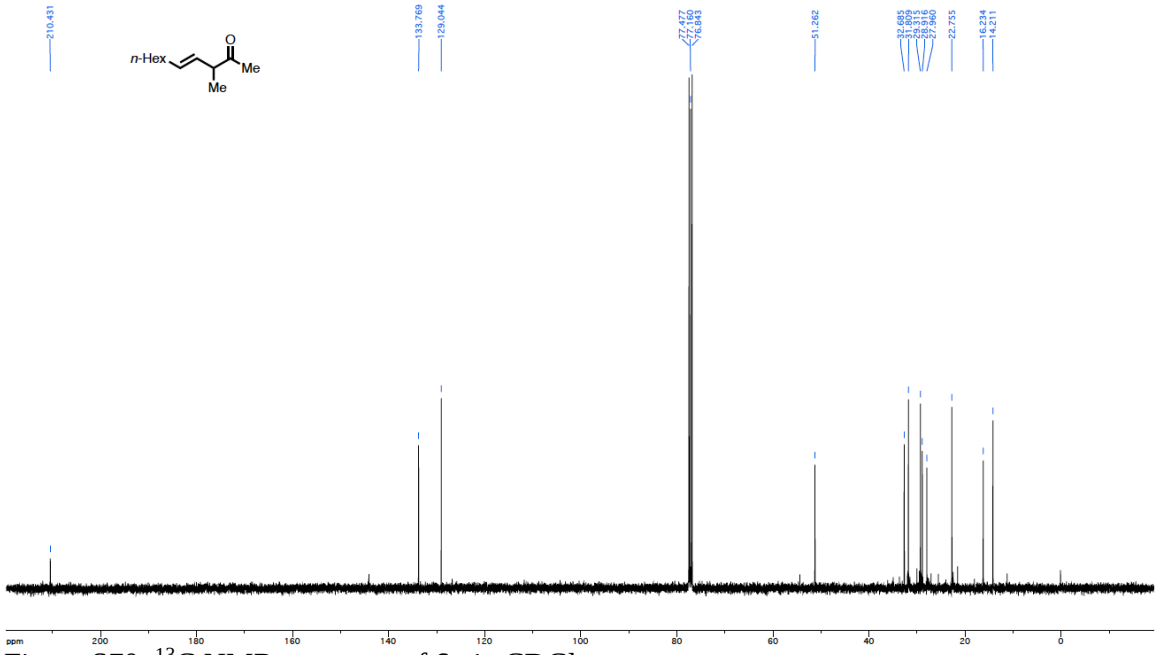


Figure S70: ^{13}C NMR spectrum of **6a** in $CDCl_3$.

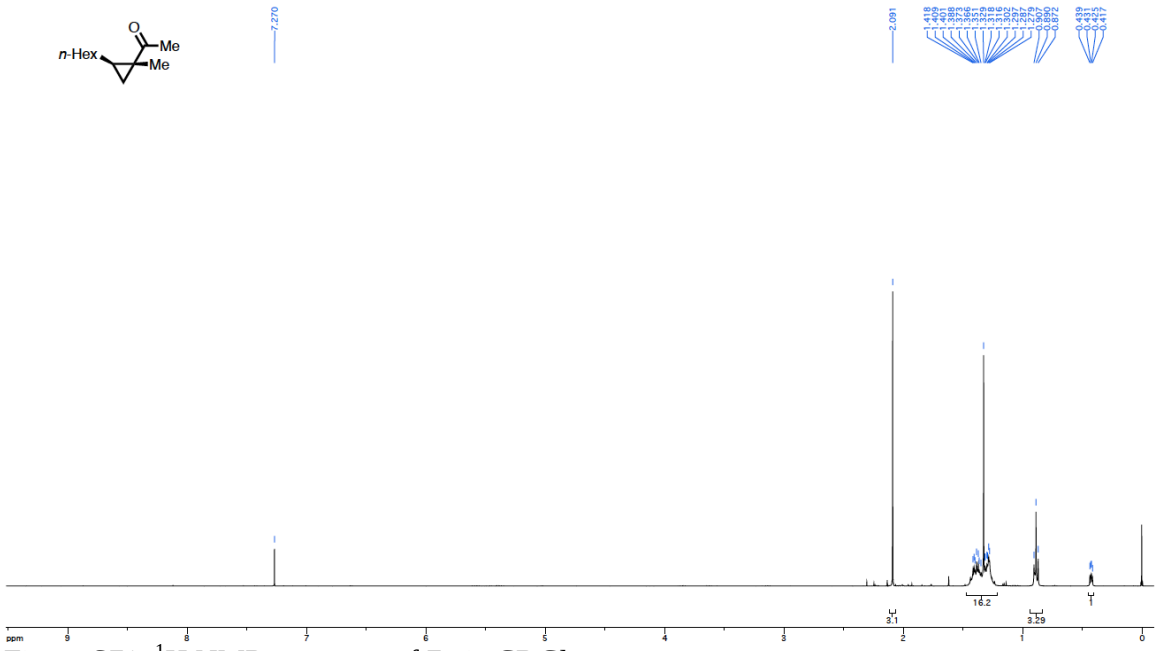


Figure S71: ^{1}H NMR spectrum of **7a** in $CDCl_3$.

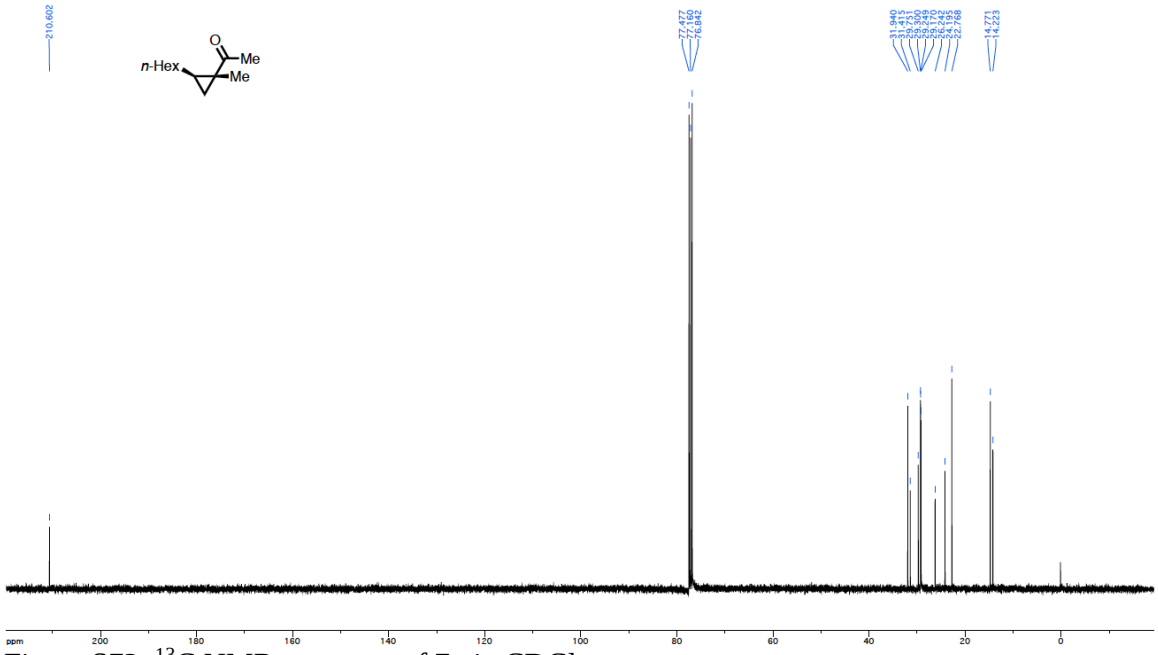
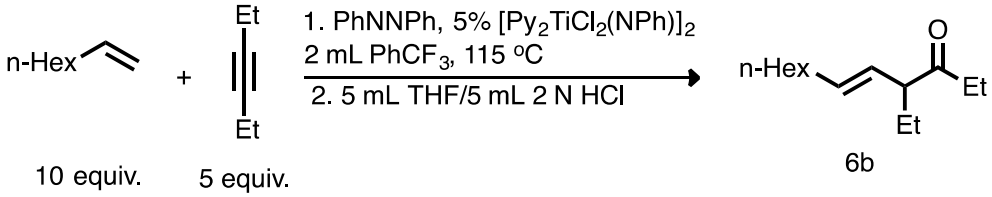


Figure S72: ^{13}C NMR spectrum of **7a** in $CDCl_3$.

Synthesis of (*E*)-4-ethyldodec-5-en-3-one (6b)



In a glovebox, to a 20 mL scintillation vial with a stir bar were added 102.1 mg azobenzene (1 equiv, 0.560 mmol), 21.8 mg $[Py_2TiCl_2(NPh)]_2$ (0.05 equiv, 0.0296 mmol), 224.0 mg 3-hexyne (5 equiv, 0.313 mL, 2.72 mmol), and 615.96 mg 1-octene (10 equiv, 0.861 mL, 5.487 mmol). The mixture was then diluted with 2 mL α,α,α-trifluorotoluene, and the vial was sealed with a Teflon screw cap and removed from the glovebox. The reaction mixture was heated to 115 °C overnight for 16 h in a preheated oil bath, cooled to room temperature and quenched with 1 mL DI H_2O. The reaction mixture was further diluted with a mixture of 5 mL THF/5 mL 2 N HCl and stirred overnight. The mixture was poured into 20 mL saturated Na_2CO_3 and extracted 3x with 20 mL Et_2O. The organic layers were collected, washed with 20 mL brine, dried over $MgSO_4$, and concentrated in vacuo. The crude oil was purified by column chromatography using a 0-5% gradient of EtOAc/hexanes to give **6b** as a yellow oil (145.5 mg, 61.7% yield)

^{1}H NMR (500 MHz, $CDCl_3$; δ, ppm): 0.84 (t, *J* = 7.4 Hz, 3H, -$CH_2CH_2CH_3$), 0.88 (t, *J* = 7.0 Hz, 3H, -$CHCH_2CH_3$), 1.02 (t, *J* = 7.3 Hz, 3H, -$C(O)CH_2CH_3$), 1.37-1.25 (m, 9H), 1.49-1.40 (m, 1H, -$CHCHHCH_3$), 1.72 (dquint, *J* = 14.0, 7.0 Hz, 1H, -$CHCHHCH_3$), 2.01 (qd, *J* = 7.2, 1.0 Hz, 2H, -CH_2CH_2CH=CH-), 2.39 (dq, *J* = 17.7, 7.3 Hz, 1H, -$C(O)CHHCH_3$), 2.52 (dq, *J* = 17.7, 7.3 Hz, 1H, -$C(O)CHHCH_3$), 2.94 (td, *J* = 8.1, 6.9 Hz, 1H, CH=CHC*H*(CH_2CH_3)C(O)-), 5.27 (ddt, *J* = 15.3, 9.0, 1.3 Hz, 1H, -CH_2CH=CHCH-), 5.55 (dt, *J* = 14.8, 7.2 Hz, 1H, -CH_2CH=C*H*CH-).

^{13}C NMR (126 MHz, $CDCl_3$; δ, ppm): 7.9, 11.9, 14.2, 22.8, 24.5, 28.9, 29.4, 31.8, 32.7, 34.6, 58.3, 128.2, 134.5, 212.8.

GC-HRMS: Calc for $C_{14}H_{26}O$ [M^+] 210.1984; found 210.1980.

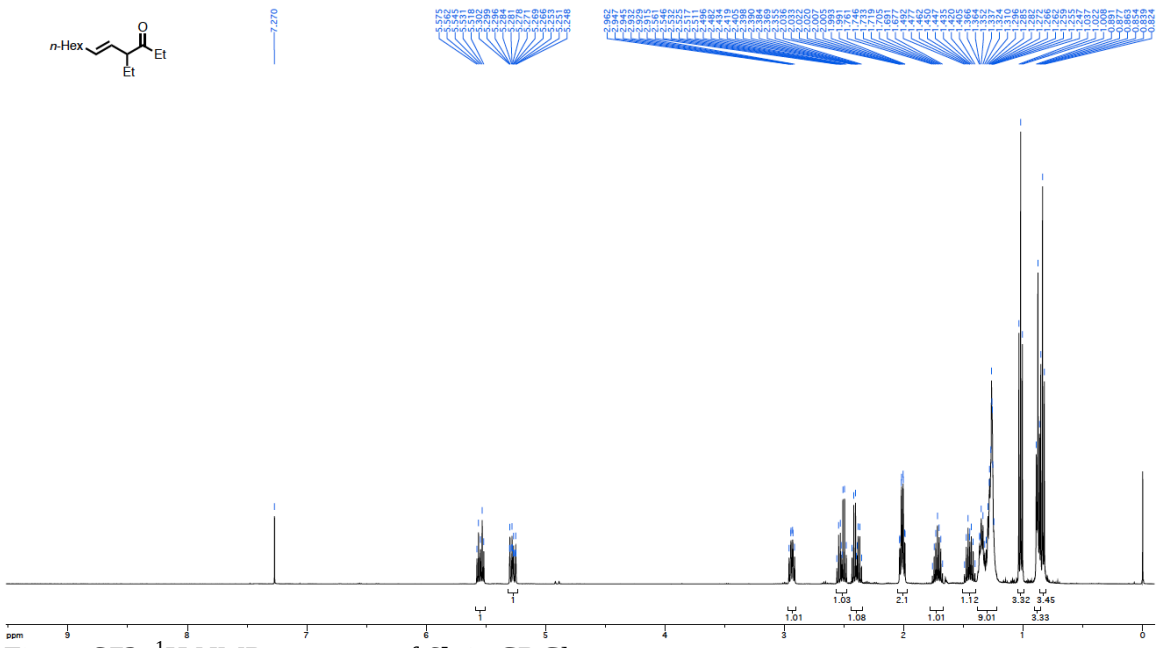


Figure S73: ^{1}H NMR spectrum of **6b** in $CDCl_3$.

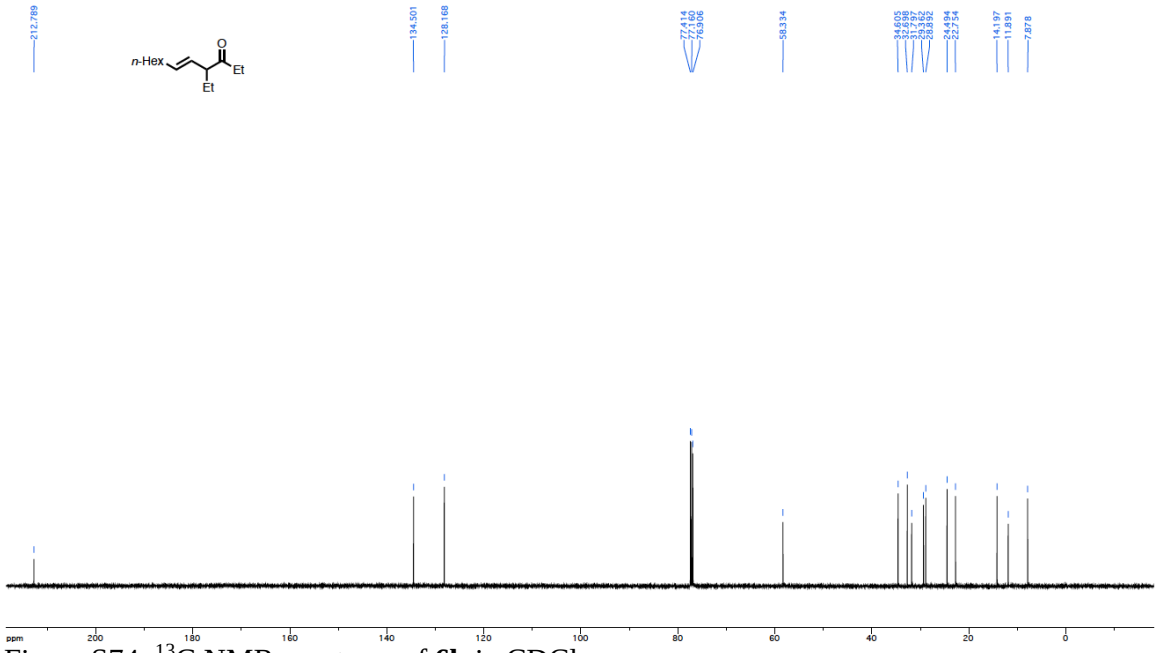


Figure S74: ^{13}C NMR spectrum of **6b** in $CDCl_3$.

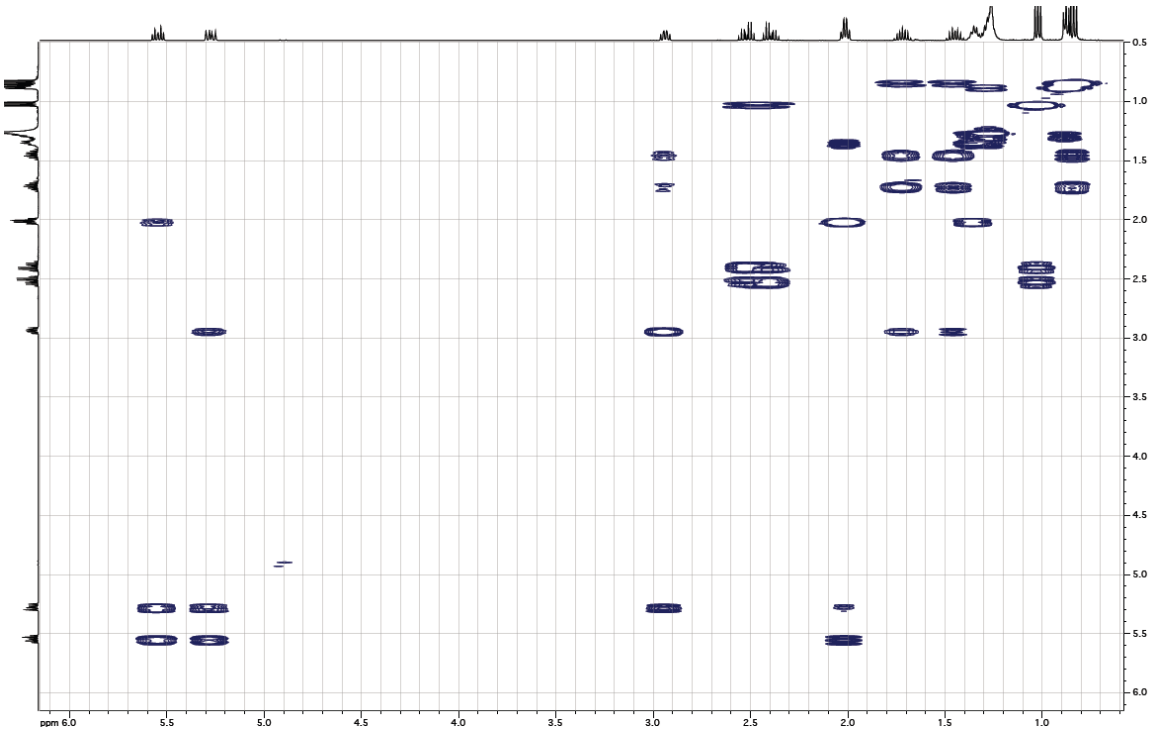
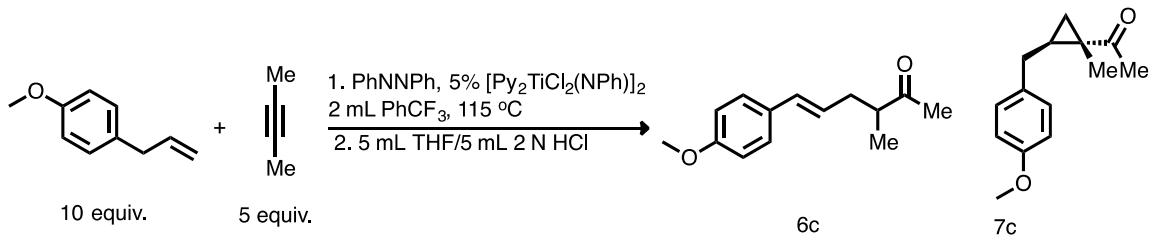


Figure S75: COSY of **6b** in $CDCl_3$ from 0.5 to 6.0 ppm and 0.5 to 6.2 ppm.

Synthesis of (*E*)-6-(4-methoxyphenyl)-3-methylhex-5-en-2-one and 1-(2-(4-methoxybenzyl)-1-methylcyclopropyl)ethan-1-one (6c & 7c)



In a glovebox, to a 20 mL scintillation vial with a stir bar were added 101.1 mg azobenzene (1 equiv, 0.554 mmol), 20.4 mg $[Py_2TiCl_2(NPh)]_2$ (0.05 equiv, 0.0277 mmol), 162.4 mg 2-butyne (5 equiv, 0.235 mL, 3.00 mmol), and 826.3 mg 4-allylanisole (10 equiv, 0.856 mL, 5.57 mmol). The mixture was then diluted with 2 mL α,α,α-trifluorotoluene, and the vial was sealed with a Teflon screw cap and removed from the glovebox. The reaction mixture was heated to 115 °C overnight for 16 h in a preheated oil bath, cooled to room temperature and quenched with 1 mL DI H_2O. The reaction mixture was further diluted with a mixture of 5 mL THF/5 mL 2 N HCl and stirred overnight. The mixture was poured into 20 mL saturated Na_2CO_3 and extracted 3x with 20 mL Et_2O. The organic layers were collected, washed with 20 mL brine, dried over $MgSO_4$, and concentrated in vacuo. The crude oil was purified by column chromatography using a 0-5% gradient of EtOAc/hexanes to give a mixture of **6c** & **7c** as a yellow oil (151.1 mg, 51.4% yield).

^{1}H NMR (500 MHz, $CDCl_3$; δ, ppm): 0.62 (dd, *J* = 6.7, 4.2 Hz, 1H, **7c** cyclopropyl –CHCH*H*C-), 1.15 (d, *J* = 7.0 Hz, 2H, **6c** -CHC*H*$_3$), 1.41 (s, 3H, **7c** -CC*H*$_3$), 1.52 (dd, *J* = 9.1, 4.2 Hz, 1H, **7c** cyclopropyl –CHCH*H*C-), 1.70 (dq, *J* = 9.2, 7.1 Hz, 1H, **7c** cyclopropyl –CH_2C*H*CH_2C-), 2.10 (s, 3H, **7c** –C(O)C*H*$_3$), 2.17 (s, 3H, **6c** -C(O)C*H*$_3$), 2.67 (dd, *J* = 15.2, 7.4 Hz, 1H, **7c** $H_3COC_6H_4$-C*H*HCH), 2.73 (dd, *J* = 15.2, 7.0 Hz, 1H, **7c** $H_3COC_6H_4$-C*H*HCH-), 3.80 (s, 3H, **7c** -OC*H*$_3$), dt, *J* = 15.7, 7.3 Hz, **6c** *Ar*-CH=C*H*CH_2-), 6.36 (d, *J* = 15.8 Hz, 1H, **6c** *Ar*-C*H*=$CHCH_2$-), 6.85 (d, *J* = 8.7 Hz, 2H, **7c** -CH_2-(*o*-*H*$_2C_6H_2$-OCH_3)), 7.14 (d, *J* = 8.8 Hz, 2H, **7c** -CH_2-(*m*-*H*$_2C_6H_2$-OCH_3)).

^{13}C NMR (101 MHz, $CDCl_3$; δ, ppm): 15.0, 16.2, 24.0, 26.2, 28.6, 29.5, 31.7, 36.3, 47.4, 55.4, 114.0, 125.2, 127.3, 129.1, 130.2, 131.6, 133.0, 158.1, 159.0, 210.1, 212.1.

GC-HRMS: Calc for $C_{14}H_{18}O_2$ [M^+] 218.1307; found 218.1305 and 218.1297.

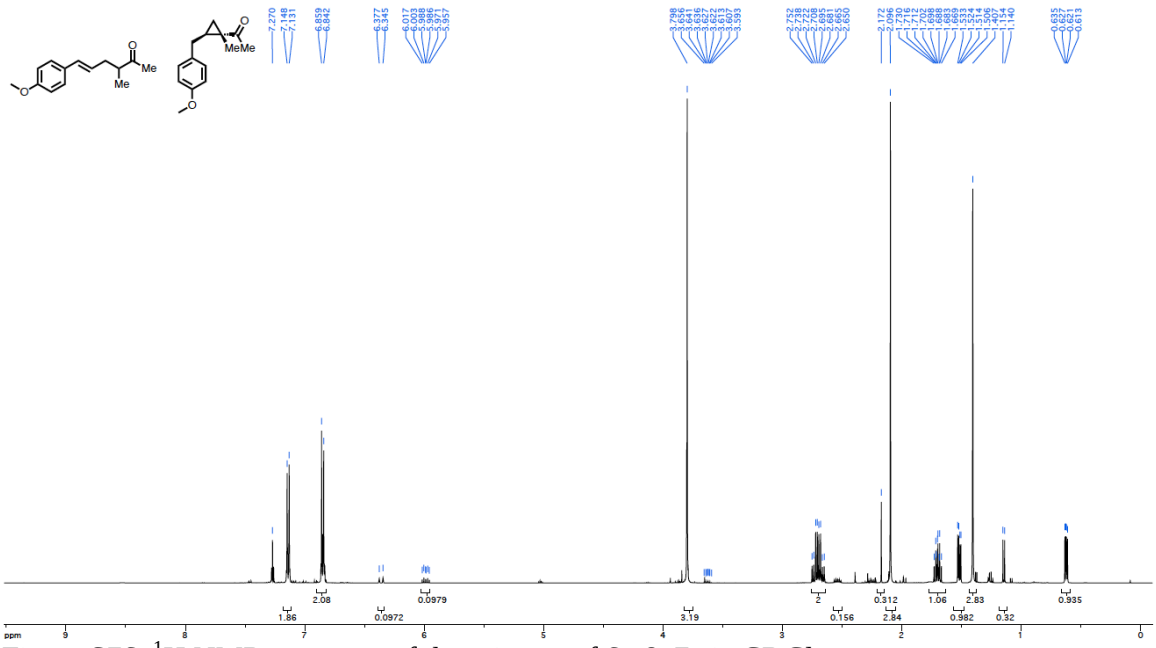


Figure S76: ^{1}H NMR spectrum of the mixture of **6c** & **7c** in $CDCl_3$.

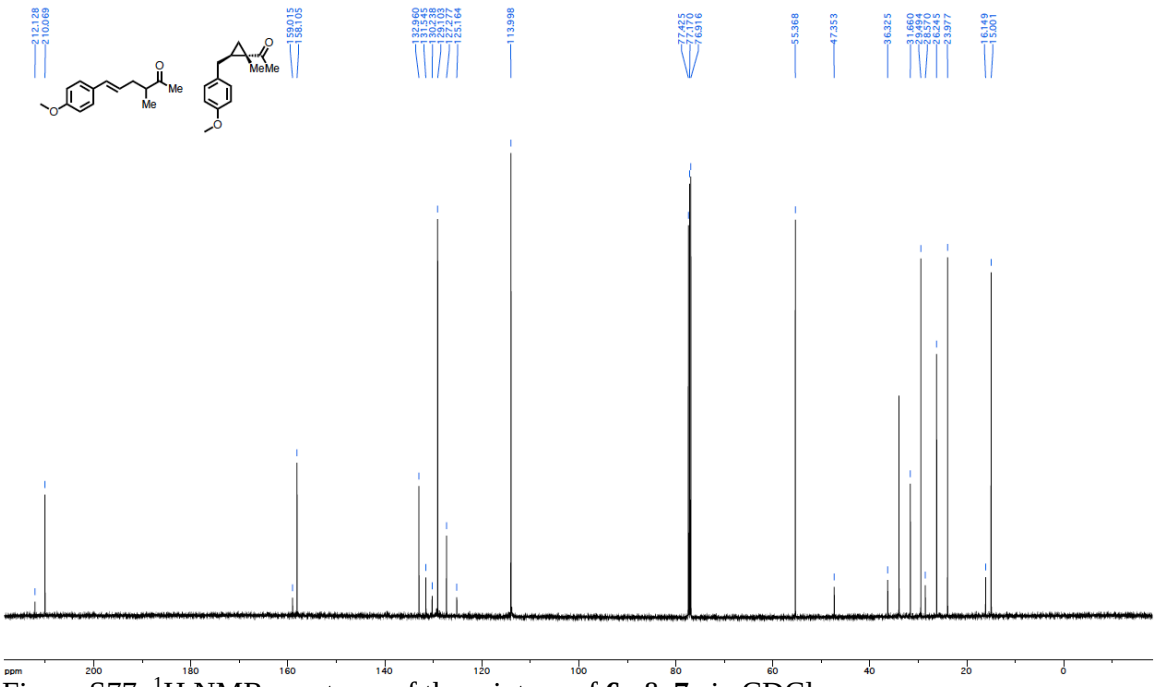


Figure S77: ^{1}H NMR spectrum of the mixture of **6c** & **7c** in $CDCl_3$.

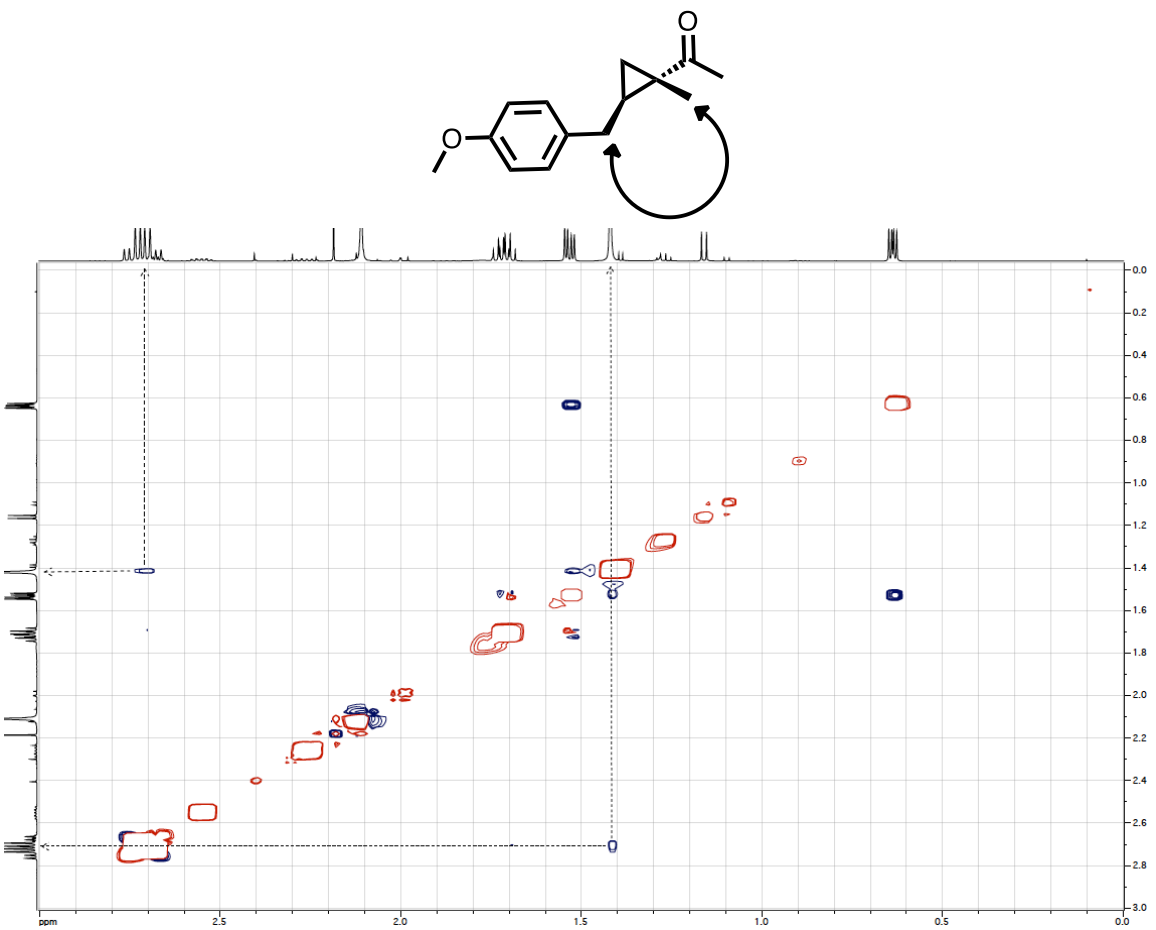


Figure S78: NOESY of the mixture of **6c** & **7c** in $CDCl_3$ from 0.0 to 3.0 ppm and 0.0 to 3.0 ppm.

NMR Reaction of 5c

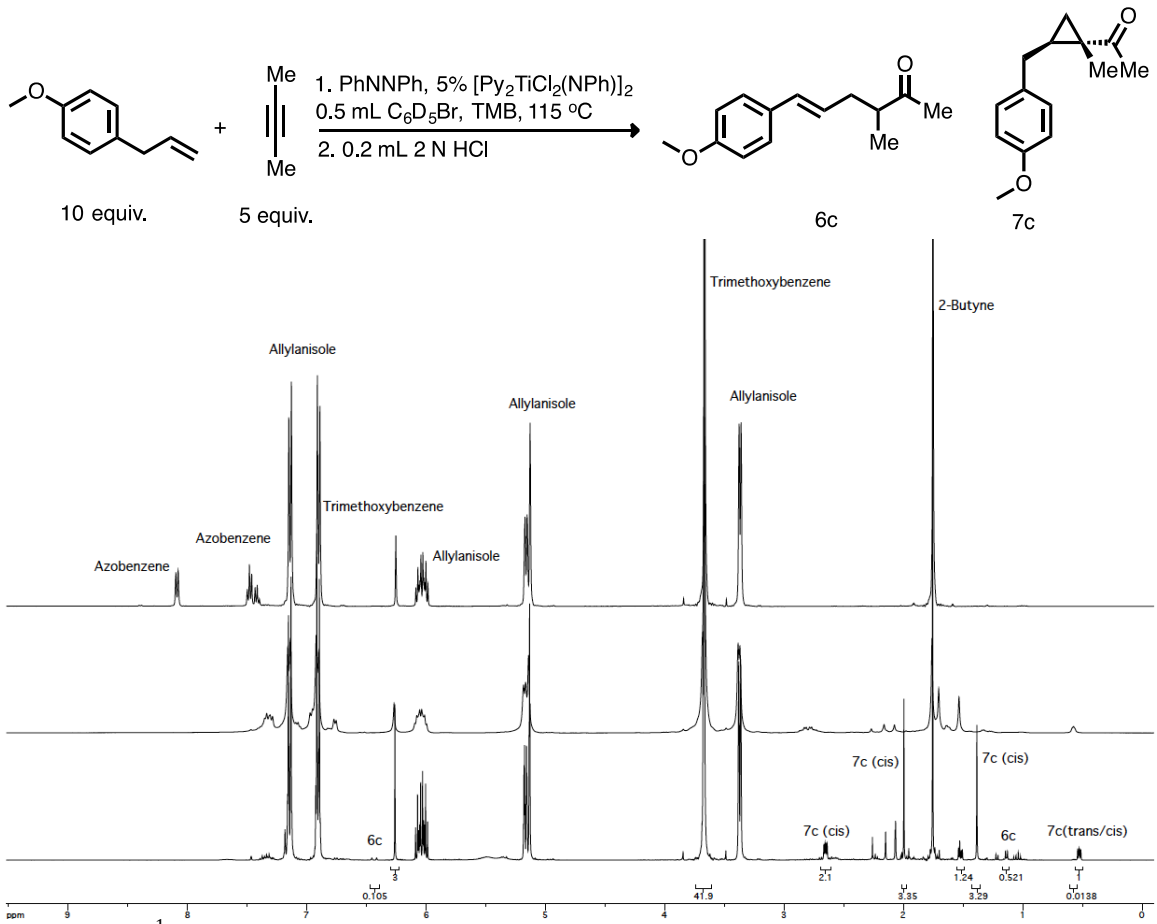
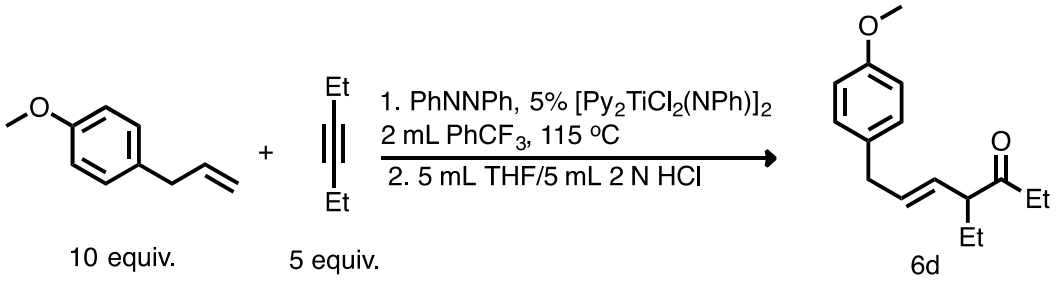


Figure S79: ^{1}H NMR spectra at Time = 0 h (Top), Time = 16 h (Middle), and Time = 16 h (2 N HCl quench, Bottom) of **6c** and **7c**.

Synthesis of (*E*)-4-ethyl-7-(4-methoxyphenyl)hept-5-en-3-one (6d)



10 equiv. 5 equiv. 6d

In a glovebox, to a 20 mL scintillation vial with a stir bar were added 108.2 mg azobenzene (1 equiv, 0.593 mmol), 22.0 mg $[Py_2TiCl_2(NPh)]_2$ (0.05 equiv, 0.03 mmol), 227.5 mg 3-hexyne (5 equiv, 0.318 mL, 2.77 mmol), and 813.0 mg 4-allylanisole (10 equiv, 0.842 mL, 5.45 mmol). The mixture was then diluted with 2 mL α,α,α-trifluorotoluene, and the vial was sealed with a Teflon screw cap and removed from the glovebox. The reaction mixture was heated to 115 °C overnight for 16 h in a preheated oil bath, cooled to room temperature and quenched with 1 mL DI H_2O. The reaction mixture was further diluted with a mixture of 5 mL THF/5 mL 2 N HCl and stirred overnight. The mixture was poured into 20 mL saturated Na_2CO_3 and extracted 3x with 20 mL Et_2O. The organic layers were collected, washed with 20 mL brine, dried over $MgSO_4$, and concentrated in vacuo. The crude oil was purified by column chromatography using a 0-5% gradient of EtOAc/hexanes to give **6d** as a yellow oil (151.1 mg, 51.4% yield).

^{1}H NMR (400 MHz, $CDCl_3$; δ, ppm): 0.87 (t, *J* = 7.4 Hz, 3H, -CHCH$_2$C*H*$_3$), 1.04 (t, *J* = 7.3 Hz, 3H, -CH$_2$C*H*$_3$), 1.55-1.44 (m, 1H -CHCH*H*CH$_3$), 1.81-1.70 (m, 1H, -CHCH*H*CH$_3$), 2.41 (dq, *J* = 17.8, 7.3 Hz, 1H, -C(O)CH*H*CH$_3$), 2.53 (dq, *J* = 17.8, 7.3 Hz, 1H, -C(O)CH*H*CH$_3$), 3.00 (dt, *J* = 8.5, 7.5 Hz, 1H, -C*H*CH$_2$CH$_3$), 3.32 (d, *J* = 6.7 Hz, 2H, -CHC*H*$_2$-C$_6$H$_5$OCH$_3$), 3.80 (s, 3H, -OC*H*$_3$), 5.39 (ddt, *J* = 15.2, 9.1, 1.4 Hz, 1H, -CH$_2$C*H*=CHCH-), 5.70 (dtd, *J* = 15.2, 6.8, 0.7 Hz, 1H, -CH$_2$CH=C*H*CH-), 6.84 (d, *J* = 8.7 Hz, 2H, CH$_2$-(*o*-*H*$_2$C$_6$H$_2$-OCH$_3$)), 7.08 (d, *J* = 8.8 Hz, 2H, CH$_2$-(*m*-*H*$_2$C$_6$H$_2$-OCH$_3$)).

^{13}C NMR (126 MHz, $CDCl_3$; δ, ppm): 7.9, 11.9, 24.6, 34.8, 38.3, 55.4, 58.1, 114.0, 129.4, 129.5, 132.3, 133.1, 158.1, 212.5.

GC-HRMS: Calc for $C_{16}H_{22}O$ [M^+] 246.1620; found 246.1622.

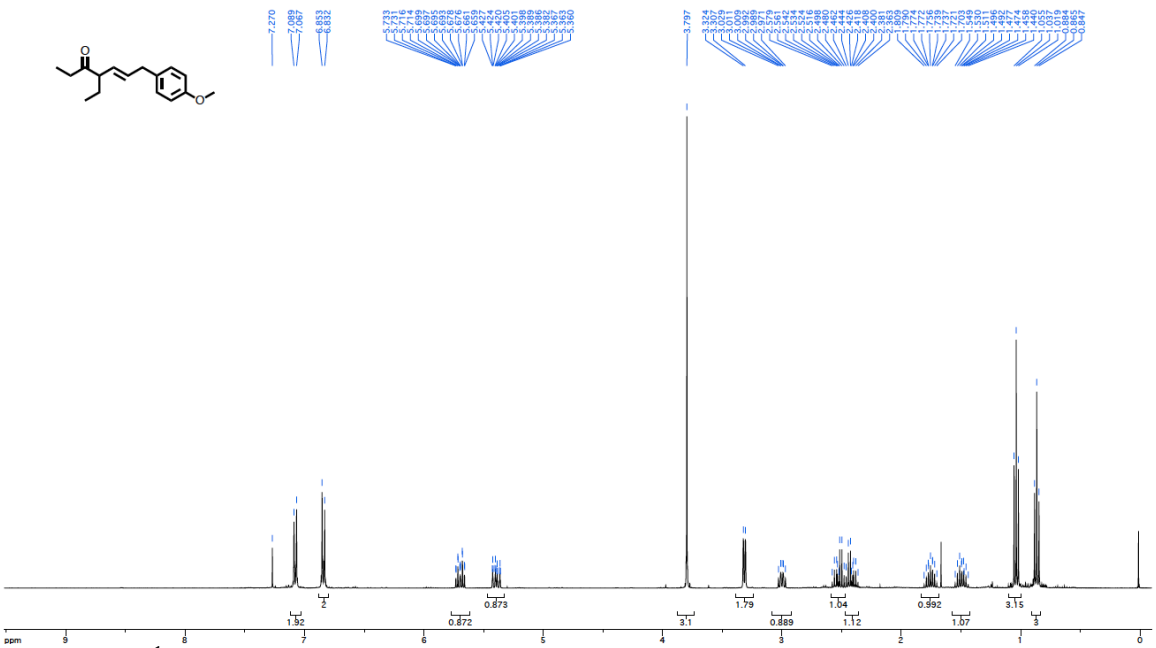


Figure S80: ^{1}H NMR spectrum of **6d** in $CDCl_3$.

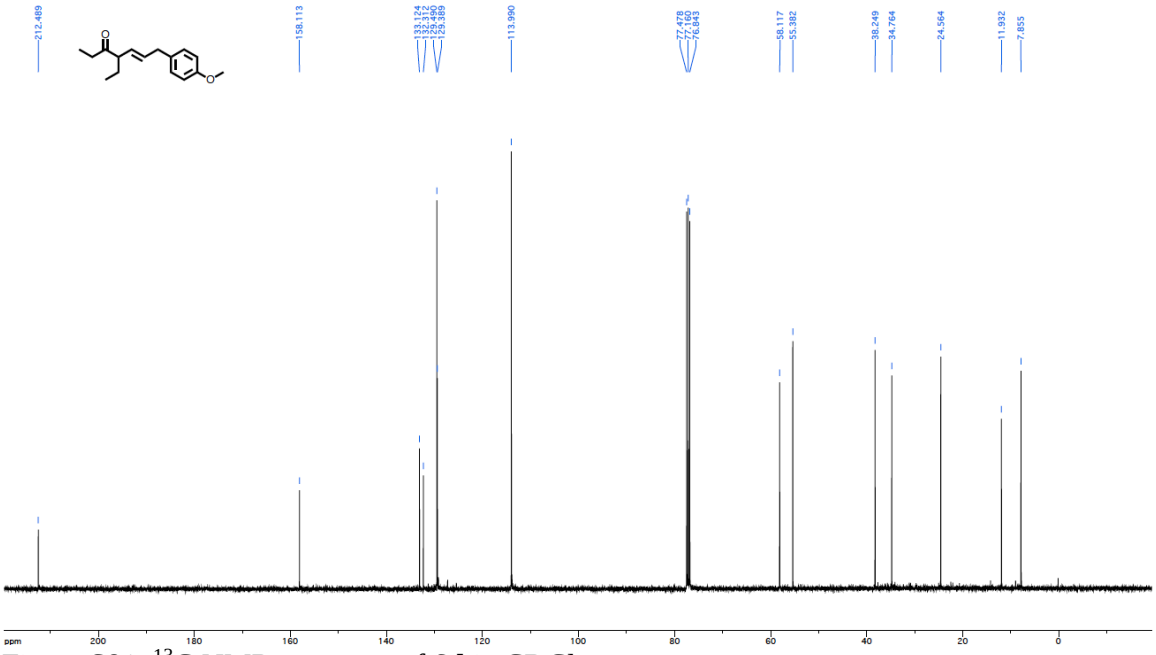


Figure S81: ^{13}C NMR spectrum of **6d** in $CDCl_3$.

NMR Reaction of 5d

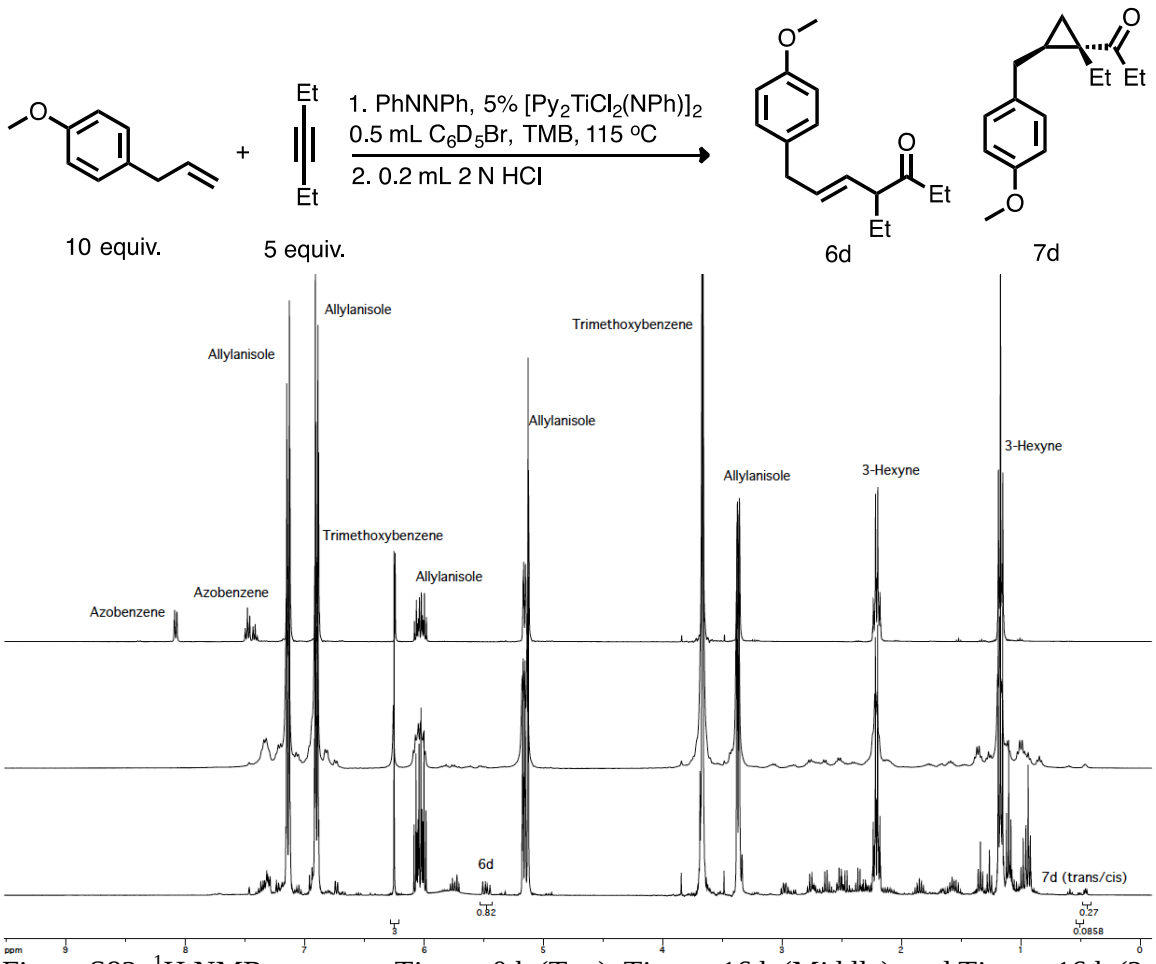
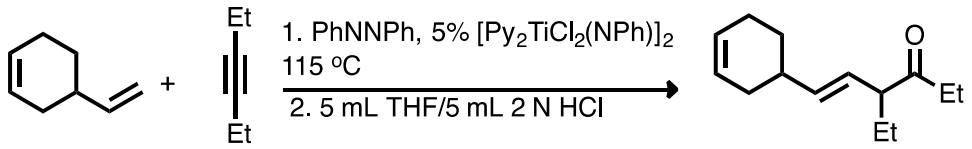


Figure S82: ^{1}H NMR spectra at Time = 0 h (Top), Time = 16 h (Middle), and Time = 16 h (2 N HCl quench, Bottom) of **6d** and **7d**.

Synthesis of (*E*)-6-(cyclohex-3-en-1-yl)-4-ethylhex-5-en-3-one (6e)



Neat 5 equiv.

In a glovebox, to a 20 mL scintillation vial with a stir bar were added 100.0 mg azobenzene (1 equiv, 0.549 mmol), 19.3 mg $[Py_2TiCl_2(NPh)]_2$ (0.05 equiv, 0.0262 mmol), 235.8 mg 3-hexyne (5 equiv, 0.341 mL, 4.36 mmol), and 2 mL 4-vinylcyclohexene. The vial was sealed with a Teflon screw cap and removed from the glovebox. The reaction mixture was then heated to 115 ℃ overnight for 16 h in a preheated oil bath, cooled to room temperature and quenched with 1 mL DI H_2O. The reaction mixture was further diluted with a mixture of 5 mL THF/5 mL 2 N HCl and stirred overnight. The mixture was poured into 20 mL saturated Na_2CO_3 and extracted 3x with 20 mL Et_2O. The organic layers were collected, washed with 20 mL brine, dried over $MgSO_4$, and concentrated in vacuo. The crude oil was purified by column chromatography using a 0-5% gradient of EtOAc/hexanes to give **6e** as a yellow oil (122 mg, 39.7% yield).

^{1}H NMR (400 MHz, $CDCl_3$; δ, ppm): 0.84 (td, *J* = 7.4, 2.1 Hz, 3H, -$CHCH_2CH_3$), 1.03 (td, *J* = 7.3, 1.0 Hz, 3H, -$C(O)CH_2CH_3$), 1.51-1.33 (m, 2H), 1.85-1.72 (m, 4H), 2.08-2.05 (m, 3H), 2.32-2.24 (m, 2H), 2.40 (dqd, *J* = 17.7, 7.3 Hz, 1H, -$C(O)CHHCH_3$), 2.52 (dqd, *J* = 17.6, 7.4 Hz, 1H, -$C(O)CHHCH_3$), 2.98-2.92 (m, 1H, -$CH=CHCH(CH_2CH_3)C(O)$-), 5.31 (ddt, *J* = 15.4, 9.0, 1.3 Hz, 1H, -$CHCH=CHCH$-), 5.57 (dd, *J* = 15.4, 7.0 Hz, 1H, -$CHCH=CHCH$-), 5.69-5.63 (m, 2H, cyclohexyl -$CH_2HC=CHCH_2$-).

^{13}C NMR (101 MHz, $CDCl_3$; δ, ppm): 7.9, 11.9, 24.6, 24.9, 28.8, 31.5, 34.6, 36.7, 58.3, 126.1, 126.5, 127.1, 139.2, 212.8.

GC-HRMS: Calc for $C_{14}H_{22}O$ [M^+] 206.1671; found 206.1663.

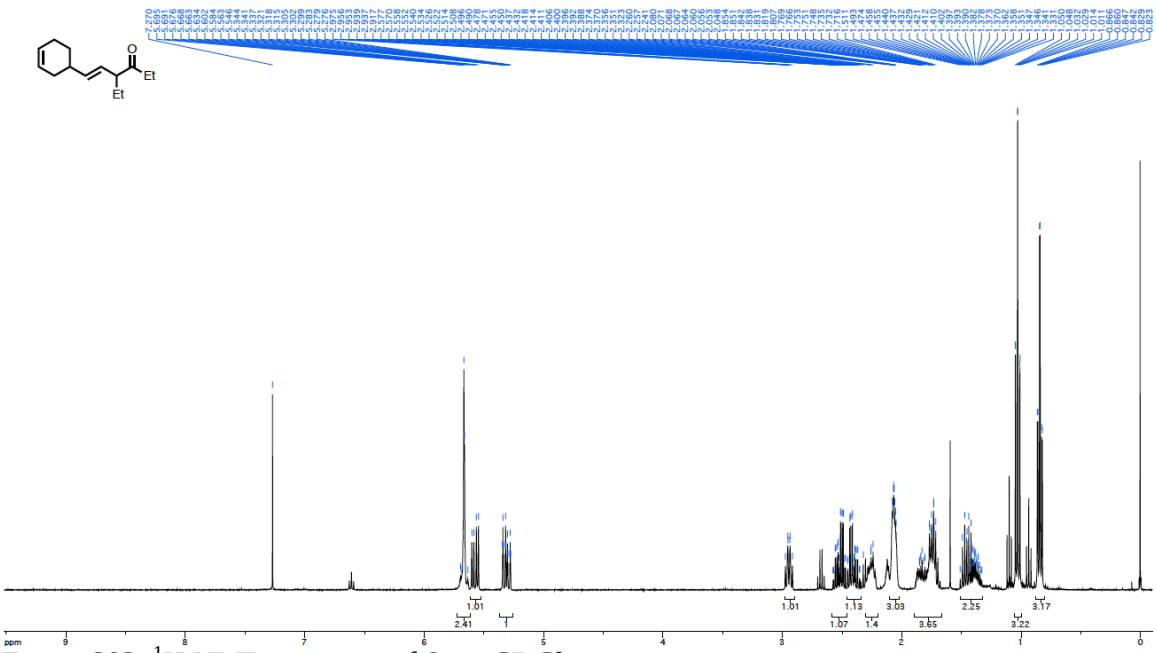


Figure S83: ^{1}H NMR spectrum of **6e** in $CDCl_3$.

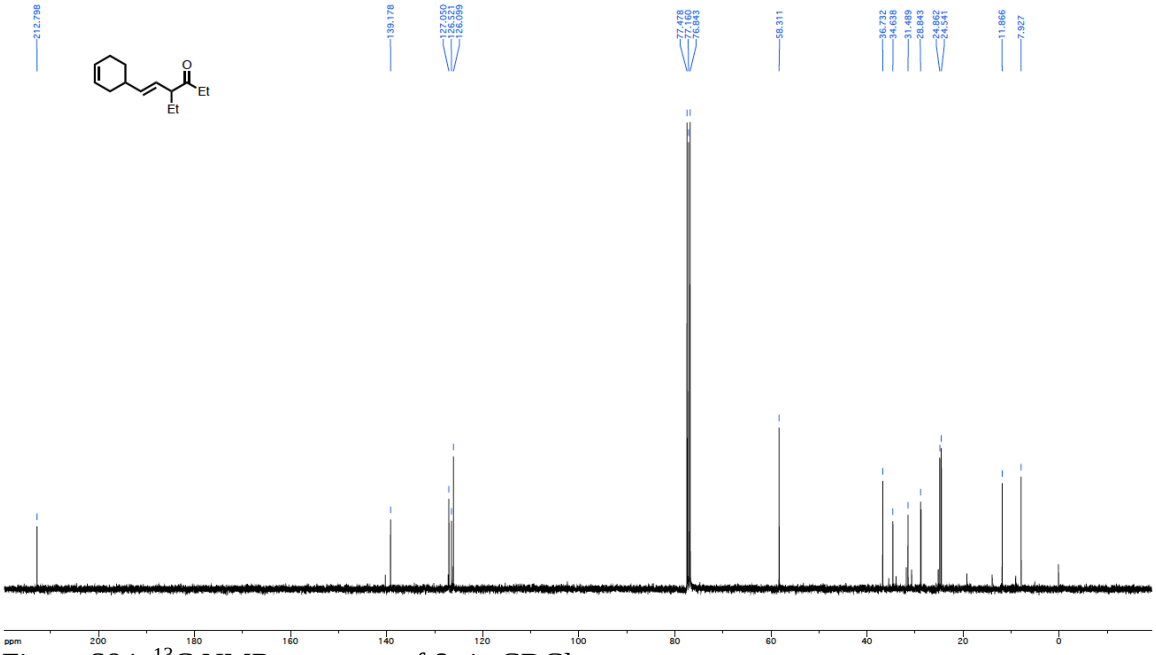


Figure S84: ^{13}C NMR spectrum of **6e** in $CDCl_3$.

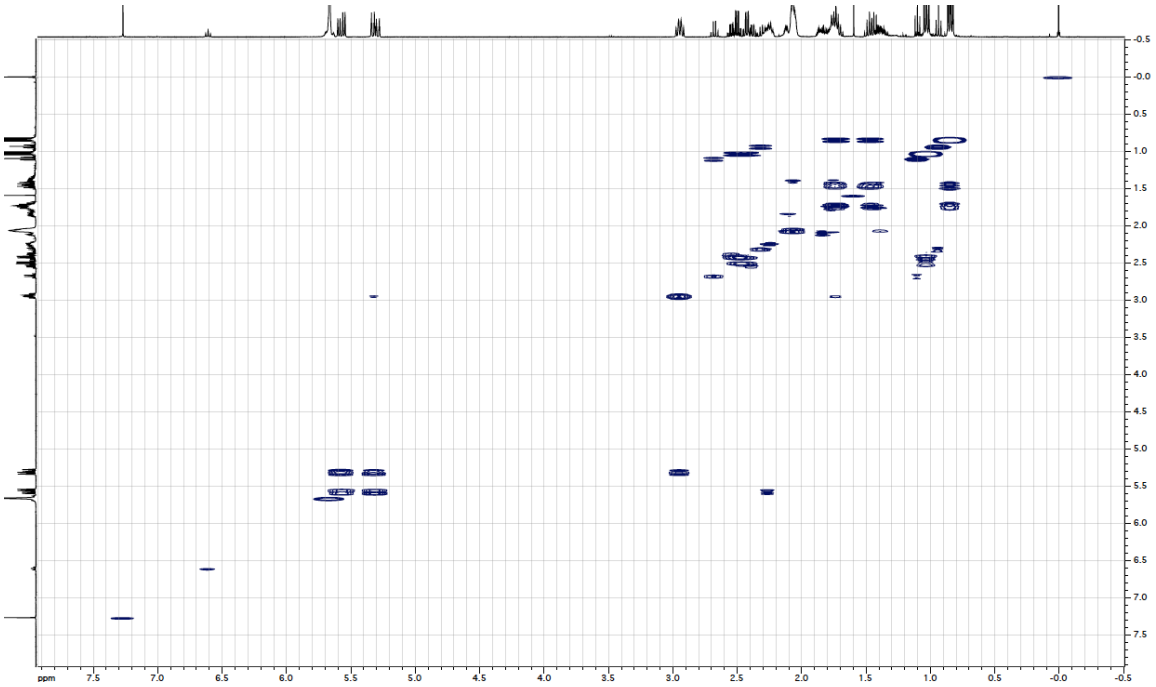


Figure S85: COSY of **6e** in $CDCl_3$ from -0.5 to 8.0 ppm and -0.5 to 8.0 ppm.

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