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Transition Metal-Catalyzed Redox-Triggered C-C Couplings of Alcohols via Transfer Hydrogenation

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Michael J. Krische

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Eric V. Anslyn

Transition Metal-Catalyzed Redox-Triggered C-C Couplings of Alcohols via Transfer Hydrogenation

by

Hongde Xiao

Thesis

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Master of Arts

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Dedication

I dedicate this thesis to my parents and my grandparents for their love and support.

Acknowledgements

First of all, I must thank my supervisor, Professor Michael J. Krische for providing me the opportunity to study at UT, it is a very valuable experience. Your mentorship and instruction open the door of this new world of chemistry to me. Your passion and dedication to chemistry will always remind me what a scientist should be like.

I would also like to thank the wonderful members of the Krische group and chemistry department staff. Acknowledgment is much deserved to Gang Wang for his mentorship and instruction when I joined the group. Thank you for all the guidance and help you offered. I am also grateful that I got the chance to work with Yian, Tao, Louis. I also need to thank all the other group members and for the help you provided.

Abstract

Transition Metal-Catalyzed Redox-Triggered C-C Couplings of Alcohols via Transfer Hydrogenation

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The University of Texas at Austin, 2017

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In the first chapter, the first example of transfer hydrogenative cross-couplings of styrene with primary alcohols is reported. Using $RuHCl(CO)(PCy_3)_2$ as the precatalyst, AgOTf or HBF_4 as additives, branched or linear adducts with styrene would be generated from benzylic or aliphatic alcohols respectively. In the second chapter, a strategy for asymmetric construction of cyclopropanes is developed. In the presence of phosphine ligand, the nickel(0) catalyst react with enantiomerically enriched 3-aryl-4-vinyl-1,3-dioxanones to form (cyclopropylcarbinyl)nickel(II) species, which then couples with organoboron reagents to generate the cyclopropane in a stereospecific way. In this way, the enantioselective synthesis of tetra-substituted cyclopropanes bearing all-carbon quaternary stereocenters is achieved.

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Chapter 1: Regioselective Hydrohydroxyalkylation of Styrene with Primary Alcohols or Aldehydes via Ruthenium Catalyzed C-C Bond Forming Transfer Hydrogenation*

1.1 INTRODUCTION

C-C bond formation via carbonyl addition mediated by premetalated reagents has great significance in synthetic chemistry since the work by Butlerov and Grignard.[1] However, the traditional carbonyl addition reactions always require stoichiometric organometallic reagents, which may cause the issues of safety, selectivity and waste. As an alternative, the metal-catalyzed reductive coupling of π-unsaturated reactants with carbonyl compounds has been developed.[2] However, in many cases, the requisite terminal reductants are just as problematic as the organometallic reagents. For instance, the reductants like Et_2Zn or Et_3B are highly pyrophoric and another common reductant, silane, is very expansive.[3,4] Transfer hydrogenation mediated C-C coupling is a more ideal strategy for byproduct-free carbonyl addition as relatively safe, inexpensive reductants with low molecular weights may be used (H_2 or 2-propanol).[5] Besides the carbonyl addition from aldehyde, reactions from alcohol oxidation level are also ideal.[6]

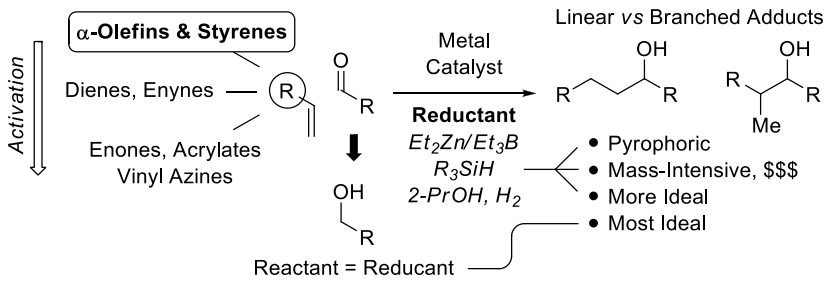


Figure 1.1 The catalytic reductive coupling of π-unsaturated reactants with carbonyl compounds.

*This chapter is partially based on the previously published work:
Xiao, H.; Wang, G.; Krische, M. J. *Angew. Chem. Int. Ed.* **2016**, *55*, 16119–16122. Hongde accomplished the Scheme 1.2, four substrates in Table 1.1, five substrates in Table 1.2, and Scheme 1.4.

Based on this, the Krische group has developed many transfer hydrogenative coupling of primary alcohols with diverse olefin pronucleophiles, such as1,3-dienes,[7] and 1,3-enynes,[8] to generate the new C-C bonds.

Styrene ranks among the most abundant π-unsaturated feedstocks (>25 x 10^6 tons/2010),[9] but the examples of catalytic reductive coupling of styrene with carbonyl compounds are still very limited (Figure 1.2). Following the initial work of Miura,[10] a rhodium catalyzed reductive coupling of carboxylic anhydrides with styrene mediated by elemental hydrogen was developed.[11] Recently, Buchwald developed an enantioselective version of this reaction catalyzed by copper.[12] These processes display branch-regioselectivity. In contrast, Ye reported a 2-propanol mediated reductive Prins reaction of vinyl arenes with aldehydes to form linear adducts.[13]

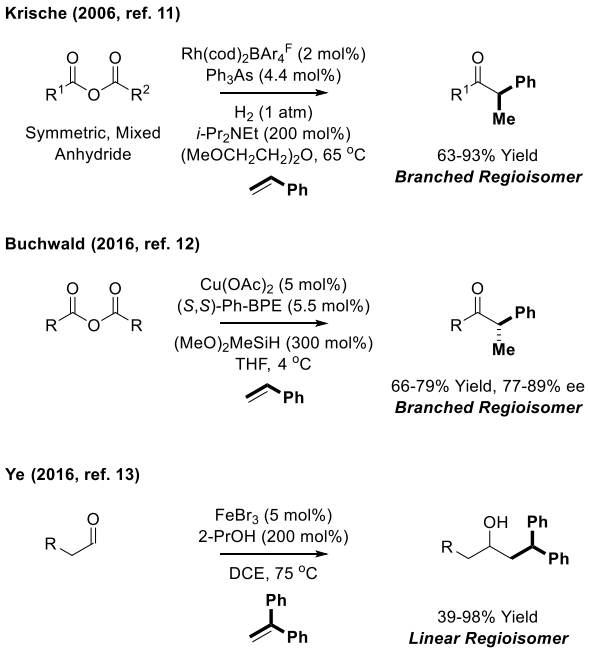


Figure 1.2 Metal catalyzed reductive coupling of styrene with carbonyl compounds.

As for the reductive cross-coupling reactions of styrene with alcohols, efficient transformations are restricted to the use of α-hydroxy-carbonyl compounds,[14] that is, precursors to highly activated vicinal dicarbonyl compounds (Figure 1.3).

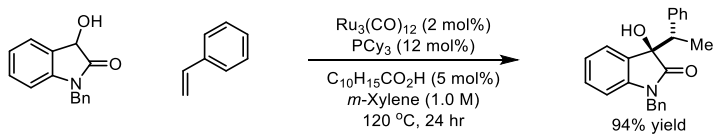
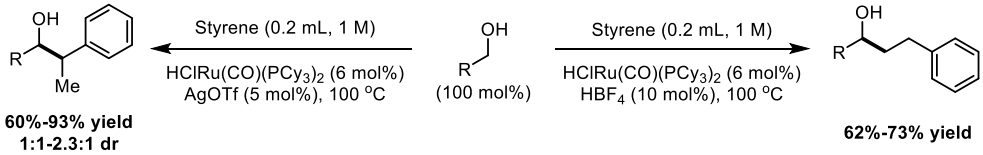


Figure 1.3 Ruthenium catalyzed reductive coupling of styrene withα-hydroxy-carbonyl compounds.

1.2 Reaction Development and Scope

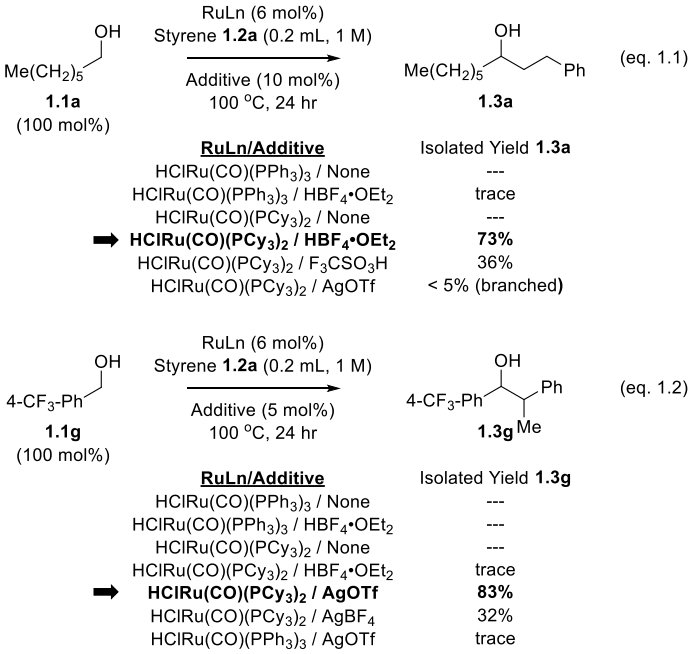
Herein, we developed the first example of transfer hydrogenative couplings of styrene with primary alcohols (Scheme 1.1).[15] Using the $RuHCl(CO)(PCy_3)_2$ as the precatalyst, AgOTf or HBF_4 as additives, branched or linear adducts with styrene would be generated from benzylic or aliphatic alcohols respectively.



Scheme 1.1 Ruthenium catalyzed cross coupling of Styrene with Primary Alcohols.

Our initial results were inspired by Yi's catalytic system for alkene hydrogenation and hydrovinylation.[8a] They found that treatment by HBF_4•OEt_2 will dramatically increase the catalytic activity of the ruthenium-hydride complex $RuHCl(CO)(PCy_3)_2$. According to their mechanistic studies, HBF_4•OEt_2 has the ability to open a coordination site at ruthenium by protonating a tricyclohexylphosphine ligand. As for the reported transformations based on transfer hydrogenation, closely related ruthenium(II) carbonyl complexes catalyze the coupling of primary alcohols with diverse olefin pronucleophiles, including 1,3-dienes[9] and 1,3-enynes.[10] Nevertheless, employing the styrene as pronucleophiles in C-C bond forming transfer hydrogenation is still a great challenge. Hoping that this type of catalyst with a vacant coordination site could enable the cross-coupling reaction between the primary alcohol and styrene, a series of conditions was assayed. We started from the coupling reactions of heptanol **1.1a** with styrene **1.2a**. Even though the commercially available $RuHCl(CO)(PPh_3)_3$ did not give us any desired product in the absence or presence of HBF_4•OEt_2,

$RuHCl(CO)(PCy_3)_2/HBF_4{\bullet}OEt_2$ catalyst system gives the linear single regioisomer **1.3a** in 73% yield as finial coupling product. The other Brønsted acids were proven to be able to mediate the reaction together with $RuHCl(CO)(PCy_3)_2$, but less effective.

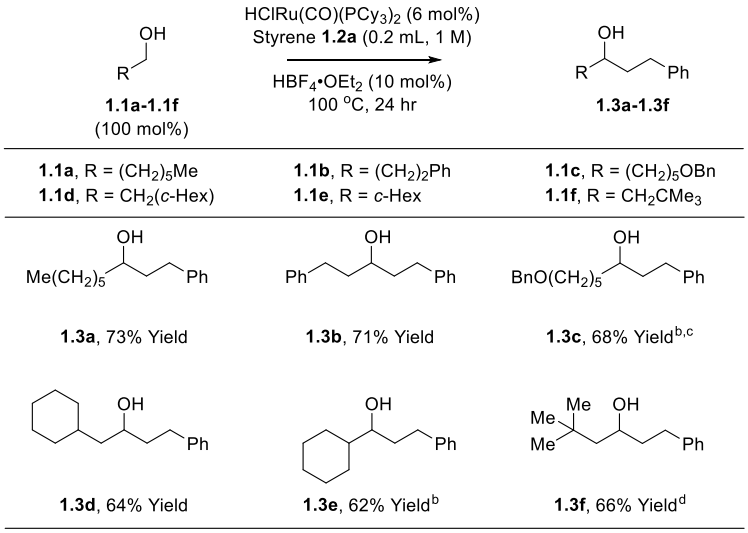


[a]Yields are of material isolated by silica gel chromatography.

Scheme 1.2 Selected optimization experiments for the ruthenium catalyzed C-C coupling of 1-heptanol **1.1a** and bicenzyl alcohol **1.1g** with styrene **1.2a**.[a]

According to Connell's study,[16] cationic ruthenium(II) complexes obtained from $RuHCl(CO)(PCy_3)_2$ and AgOTf might also display enhanced catalytic activity due to coordinative unsaturation. Therefore, coupling reactions between **1.1a** and **1.2a** was conducted using $RuHCl(CO)(PCy_3)_2$ as catalyst in the presence of AgOTf. However, in this condition, the linear regioisomer **1.3a** was not generated, but a small quantity of the corresponding branched regioisomer was obtained. These results indicate that the cationic ruthenium complexes do not catalyze reactions that form linear regioisomers but support the feasibility of optimizing a catalytic pathway to branched adducts. Even though the branch-selective coupling reactions between aliphatic alcohols with styrene **1.2a** were not efficient, the coupling of benzylic alcohol **1.1g** with styrene **1.2a** could form the branched adduct **1.3g** in 83% yield using $RuHCl(CO)(PCy_3)_2$/AgOTf catalyst system.

We then explored the alcohol scope of this regioselective transfer hydrogenative coupling reaction. As shown in **Table 1.1**, coupling of styrene **1.2a** with aliphatic alcohols **1.1a-1.1f** delivered linear adducts **1.3a-1.3f** in good yield, with no branched product generated. Even cyclohexyl methanol **1.1e**, namely alcohols with branching at the β-position, worked well in the C-C coupling reaction.

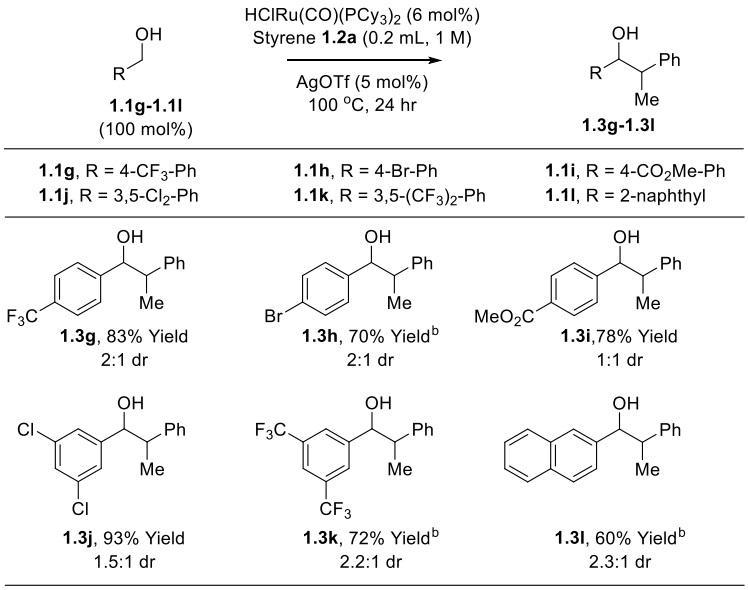


[a]Yields are of material isolated by silica gel chromatography. See Supporting Information for further details. [b]$HClRu(CO)(PCy_3)_2$ (10 mol%), HBF_4 (15 mol%). [c]styrene **1.2a** (0.4 mL), 120 °C. [d]2-PrOH (100 mol%).

Table 1.1 Ruthenium catalyzed C-C coupling of aliphatic alcohols **1.1a-1.1f** with styrene **1.2a** to form secondary alcohols **1.3a-1.3f**.[a]

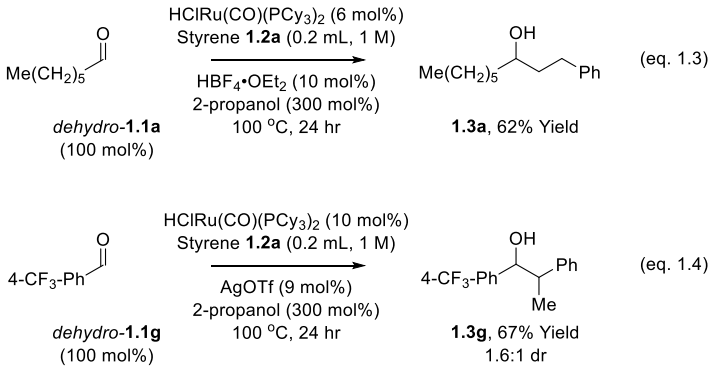
For the coupling of benzylic alcohols **1.1g-1.1l**, the catalyst system $RuHCl(CO)(PCy_3)_2$/AgOTf gives the single branched regioisomer **1.3g-1.3l** in good to excellent yields (**Table 1.2**). It was found that electron withdrawing substitutes in benzylic alcohols enables the C-C coupling reactions more efficient.

Beyond the redox-neutral couplings from the alcohol oxidation level, reactions from the aldehyde oxidation level were also efficient employing 2-propanol as the reductant, as illustrated by the conversion of heptanal (*dehydro*-**1.1a**) to the linear secondary alcohol **1.3a** (eq. 1.3) and the conversion of benzyl alcohol **1.1g** to the branched adduct **1.3g** (eq. 1.4).



[a]Yields are of material isolated by silica gel chromatography. [b]$HClRu(CO)(PCy_3)_2$ (10 mol%), AgOTf (9 mol%).

Table 1.2 Ruthenium catalyzed C-C coupling of benzylic alcohols **1.1g-1.1l** with styrene **1.2a** to form secondary alcohols **1.3g-1.3l**.[a]

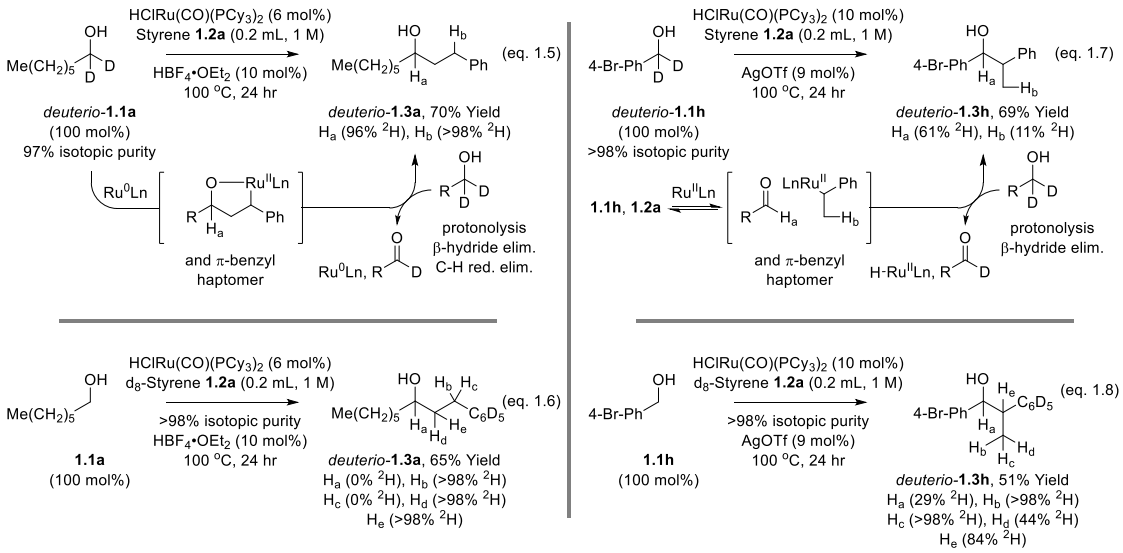


[a]Yields are of material isolated by silica gel chromatography.

Scheme 1.3 Ruthenium catalyzed C-C coupling of aldehyde with styrene **1.2a** to form secondary alcohols.[a]

1.3 MECHANISM AND DISCUSSION

Deuterium labelling experiments were conducted to investigate the mechanism, especially the difference between linear and branched regioselectivity (Scheme 1.4). Coupling of *deuterio*-**1.1a**, which is deuterated at the carbinol position (97% ^{2}H), with styrene **1.2a** under standard conditions gives *deuterio*-**1.3a** (eq. 1.5). Deuterium at the carbinol methine is completely retained (96% ^{2}H), along with the complete transfer of deuterium to the benzylic methylene (>98% ^{2}H). These results suggests a catalytic mechanism including carbonyl-styrene oxidative coupling to form an oxaruthenacycle, which undergoes hydrogenolysis mediated by *deuterio*-**1.1a** to deliver *deuterio*-**1.3a**. In this case, formation of a benzylic carbon-ruthenium bond defines the regioselectivity of oxaruthenacycle formation and, hence, the linear regioselectivity of C-C coupling. A related deuterium labeling assay in which alcohol **1.1a** couples with d_8-styrene **1.2a** further confirm this mechanism (eq. 1.6).



[a]Yields are of material isolated by silica gel chromatography. Isotopic composition determined by HRMS, ^{1}H and ^{2}H NMR.

Scheme 1.4 General catalytic pathways accounting for linear *vs* branched regioselectivity as corroborated by deuterium labelling studies.[a]

Then we studied the mechanism of generating the branched product. Coupling of *deuterio*-**1.1h** with styrene **1.2a** generates *deuterio*-**1.3h** under standard conditions (eq. 7). In this case, significant loss of deuterium is observed at the carbinol methine (61% ^{2}H) is accompanied by the incomplete transfer of deuterium to the methyl hydrogen (11% ^{2}H). This loss of deuterium is because of the rapid, reversible hydrogen transfer between *deuterio*-**1.1h** and styrene **1.2a** to form aldehyde-benzylruthenium pairs in advance of turn-over limiting carbonyl addition. In this way, the branched regioselectivity origins from the hydrometalation to give a benzylic carbon-ruthenium bond. Also, coupling of the non-deuterated alcohol 1h with d_8-styrene **1.2a** corroborates reversible transfer of hydrogen between alcohol and styrene (Scheme 1.4, eq. 1.8).

1.4 CONCLUSION

The first example of first transfer hydrogenative couplings of styrene with primary alcohols was developed. Employing the ruthenium precatalyst $RuHCl(CO)(PCy_3)_2$, branched or linear adducts from benzylic or aliphatic alcohols could be obtained when AgOTf or HBF_4•OEt_2 was added to the reaction system. Deuterium labelling experiments were conducted to investigate the mechanism. The formation of a benzylic carbon-ruthenium bond defines the regioselectivity of oxaruthenacycle formation and, hence, the linear regioselectivity of C-C coupling. Whereas branched regioselectivity is a consequence of pathways involving styrene hydrometalation.

1.5 EXPERIMENT DETAILS

General Information:

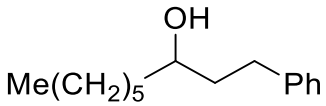
All reactions were run under an atmosphere of argon. Sealed tubes (13x100 mm) were purchased from Fischer Scientific (catalog number 14-959-35C) and were flame dried followed by cooling in a desiccator. Anhydrous solvents were transferred by oven-dried syringes. Analytical thin-layer chromatography (TLC) was carried out using 0.25 mm commercial silica gel plates (Dynanmic Absorbents F254). Visualization was accomplished with UV light followed by dipping in $KMnO_4$ stain solution then heating. Purification of reactions was carried out by flash chromatography using Silacycle silica gel (40-63 μm, unless indicated specifically). All silver salts were purchased from Alfa Aesar, and stored in a desiccator. All alcohol substrates were purchased from commercially available sources and purified prior to use. Styrene was purchased from Sigma Aldrich and used without further purification. All aldehydes were used from commercially available sources, and purified via distillation in a Hickman still or column chromatography prior to use.

Spectroscopy, Spectrometry, and Data Collection:

Infrared spectra were recorded on a Perkin-Elmer 1600 spectrometer. High-resolution mass spectra (HRMS) were obtained on an Agilent Technologies 6530 Accurate Mass Q-TOF LC/MS instrument and are reported as m/z (relative intensity). Accurate masses are reported for the molecular ion (M, M+H, or M-H), or a suitable fragment ion. ^{1}H nuclear magnetic resonance spectra were recorded using a 400 MHz spectrometer. Coupling constants are reported in Hertz (Hz) for $CDCl_3$ solutions, and chemical shifts are reported as parts per million (ppm) relative to residual $CHCl_3$ δ_H (7.26 ppm). ^{13}C nuclear magnetic resonance spectra were recorded using a 100 MHz spectrometer for $CDCl_3$ solutions, and chemical shifts are reported as parts per million (ppm) relative to residual $CDCl_3$ δ_C (77.0 ppm). The products formed through C-C coupling from the alcohol and aldehyde oxidation levels are identical in all respects outside of diastereomeric ratios.

Detailed Procedures and Spectral Data for the Coupling Products 1.3a-1.3l:

1-phenylnonan-3-ol (1.3a)



From alcohol oxidation level: An oven-dried pressure tube equipped with a magnetic stir bar was charged with 1-heptanol (23.2 mg, 0.2 mmol, 100 mol%) and $RuHCl(CO)(PCy_3)_2$ (8.7 mg, 0.012 mmol, 6 mol%). The reaction vessel was placed under an atmosphere of argon. Styrene (0.2 mL, 1 M, 870 mol%) was added by syringe followed by $HBF_4{\cdot}Et_2O$ (5.5 µL, 0.02 mmol, 10 mol%). The reaction vessel was sealed and the reaction mixture was allowed to stir at 100 ˚C for 24 h. The reaction was allowed to reach ambient temperature. The reaction mixture was concentrated *in vacuo*. The residue was subjected to column chromatography (SiO_2: hexanes:ethyl acetate, 40:1) to furnish the title compound (32.2 mg, 0.146 mmol) as a colorless oil in 73% yield.

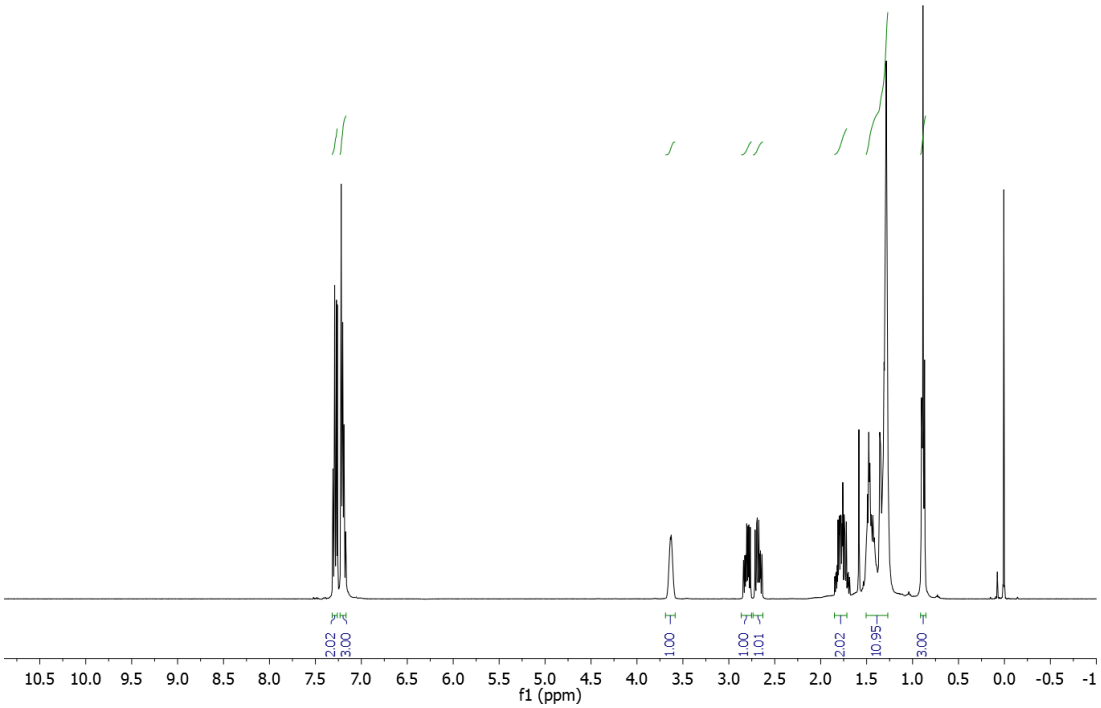
From aldehyde oxidation level: An oven-dried pressure tube equipped with a magnetic stir bar was charged with heptanal (22.8 mg, 0.2 mmol, 100 mol%) and $RuHCl(CO)(PCy_3)_2$ (8.7 mg, 0.012 mmol, 6 mol%). The reaction vessel was placed under an atmosphere of argon. Styrene (0.2 mL, 1 M, 870 mol%) and 2-propanol (36 mg, 0.6 mmol, 300 mol%) were added by syringe followed by $HBF_4{\cdot}Et_2O$ (5.5 µL, 0.02 mmol, 10 mol%). The reaction vessel was sealed and the reaction mixture was allowed to stir at 100 ˚C for 24 h. The reaction was allowed to reach ambient temperature. The reaction mixture was concentrated *in vacuo*. The residue was subjected to column chromatography (SiO_2: hexanes:ethyl acetate, 40:1) to furnish the title compound (27.3 mg, 0.124 mmol) as a colorless oil in 62% yield.

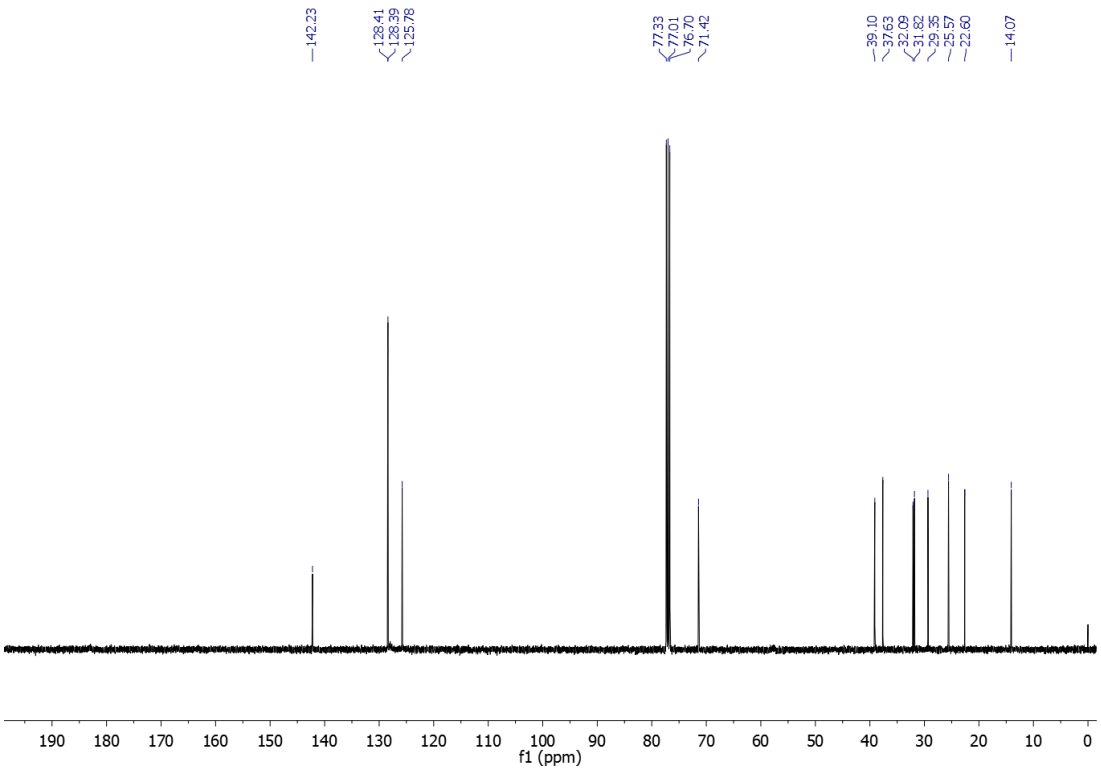
^{1}H NMR (400 MHz, $CDCl_3$) δ7.32–7.26 (m, 2H), 7.24–7.16 (m, 3H), 3.63 (dq, J = 8.2, 3.9 Hz, 1H), 2.80 (ddd, J = 13.9, 9.7, 5.8 Hz, 1H), 2.68 (ddd, J = 13.8, 9.6, 6.6 Hz, 1H), 1.87–1.67 (m, 2H), 1.55–1.24 (m, 11H), 0.96–0.83 (m, 3H).

^{13}C NMR (100 MHz, $CDCl_3$) δ 142.2, 128.4, 128.4, 125.8, 71.4, 39.1, 37.6, 32.1, 31.8, 29.4, 25.6, 22.6, 14.1.

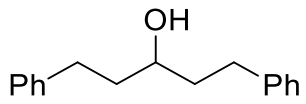
HRMS (CI) Calcd. For $C_{15}H_{23}O$ $[M-H]^-$ 219.1749, Found 219.1750.

FTIR (neat): 3345, 2927, 2855, 1494, 1453, 1029, 746, 698 cm^{-1}.


2.02
3.00
1.00
1.00
1.01
2.02
10.95
3.00
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1
f1 (ppm)


142.23
128.41
128.39
125.78
77.33
77.01
76.70
71.42
39.10
37.63
32.09
31.82
29.35
25.57
22.60
14.07
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

1,5-diphenylpentan-3-ol (1.3b)



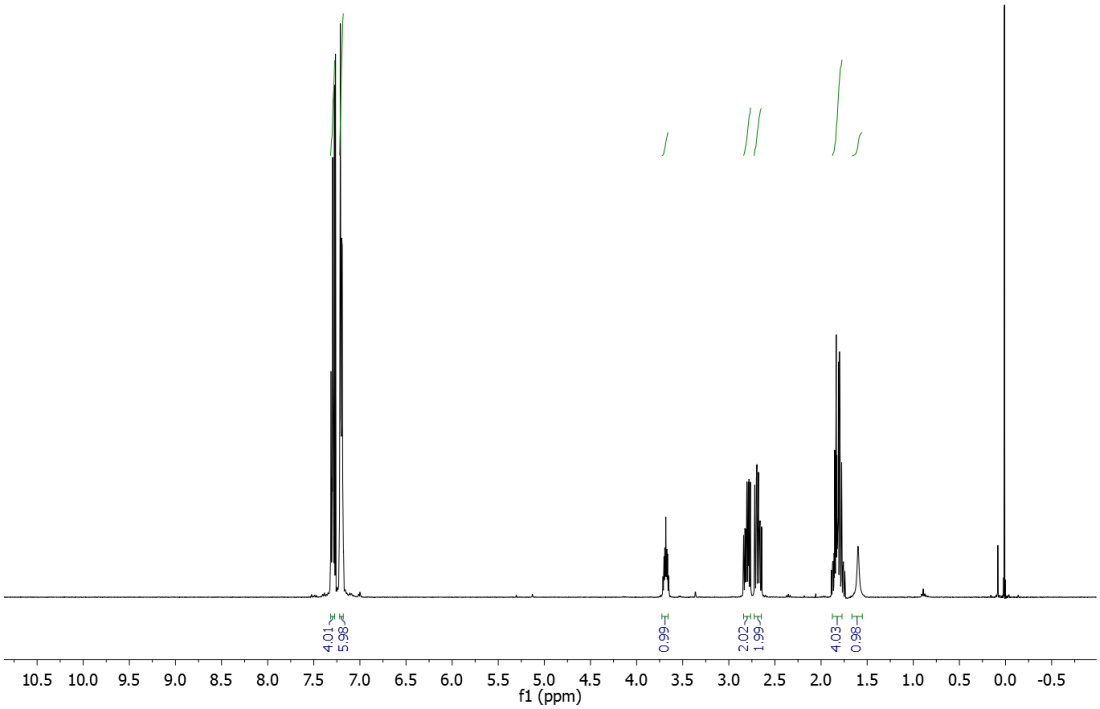
An oven-dried pressure tube equipped with a magnetic stir bar was charged with 3-phenylpropan-1-ol (27.2 mg, 0.2 mmol, 100 mol%) and $RuHCl(CO)(PCy_3)_2$ (8.7 mg, 0.012 mmol, 6 mol%). The reaction vessel was placed under an atmosphere of argon. Styrene (0.2 mL, 1 M, 870 mol%) was added by syringe followed by $HBF_4{\cdot}Et_2O$ (5.5 μL, 0.02 mmol, 10 mol%). The reaction vessel was sealed and the reaction mixture was allowed to stir at 100 ˚C for 24 h. The reaction was allowed to reach ambient temperature. The reaction mixture was concentrated *in vacuo*. The residue was subjected to column chromatography (SiO_2: hexanes:ethyl acetate, 20:1) to furnish the title compound (34.1 mg, 0.142 mmol) as a colorless oil in 71% yield.

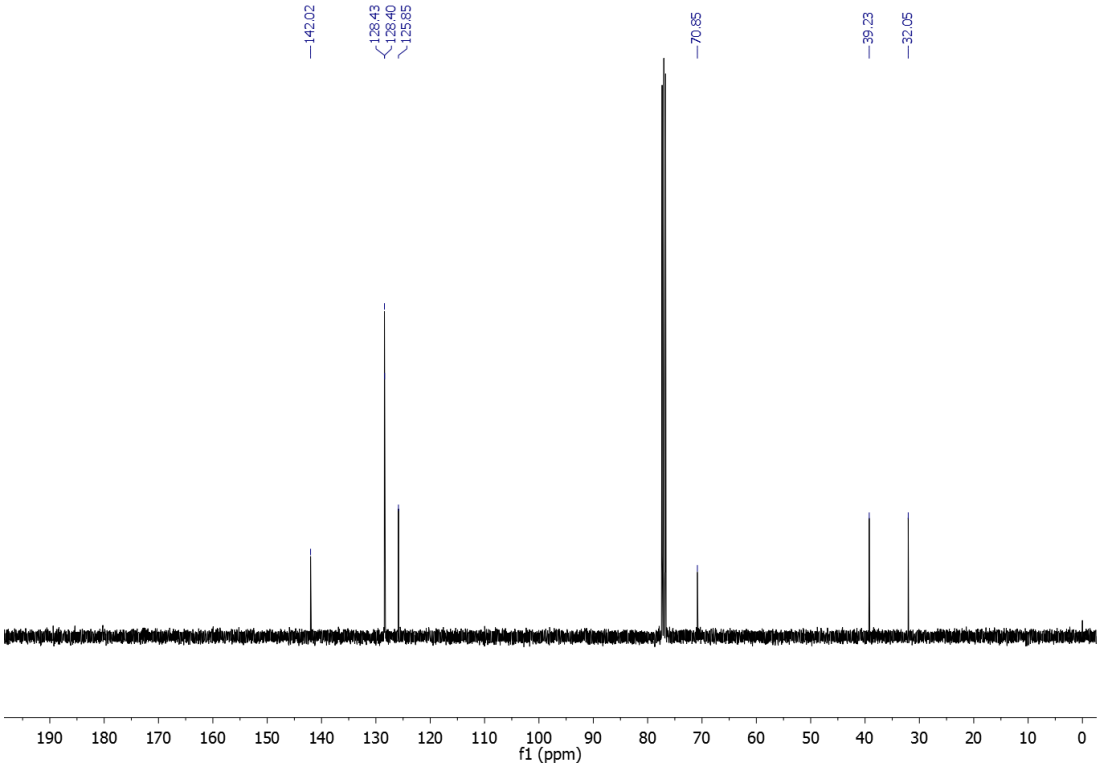
^{1}H NMR (400 MHz, $CDCl_3$) δ7.32–7.27 (m, 4H), 7.23–7.18 (m, 6H), 3.68 (tt, *J* = 7.8, 4.5 Hz, 1H), 2.80 (ddd, *J* = 13.6, 9.5, 6.1 Hz, 2H), 2.68 (ddd, *J* = 13.7, 9.5, 6.8 Hz, 2H), 1.90–1.72 (m, 4H), 1.60 (s, 1H).

^{13}C NMR (100 MHz, $CDCl_3$) δ 142.0, 128.4, 128.4, 125.9, 70.9, 39.2, 32.1.

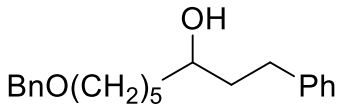
HRMS (CI) Calcd. For $C_{17}H_{21}O$ $[M+H]^+$ 241.1592, Found 241.1591.

FTIR (neat): 3382, 3025, 2930, 2856, 1602, 1495, 1453, 1261, 1091, 1030, 800, 747, 698 cm^{-1}.


4.01
5.98
0.99
2.02
1.99
4.03
0.98
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)


142.02
128.43
128.40
125.85
70.85
39.23
32.05
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

8-(benzyloxy)-1-phenyloctan-3-ol (1.3c)



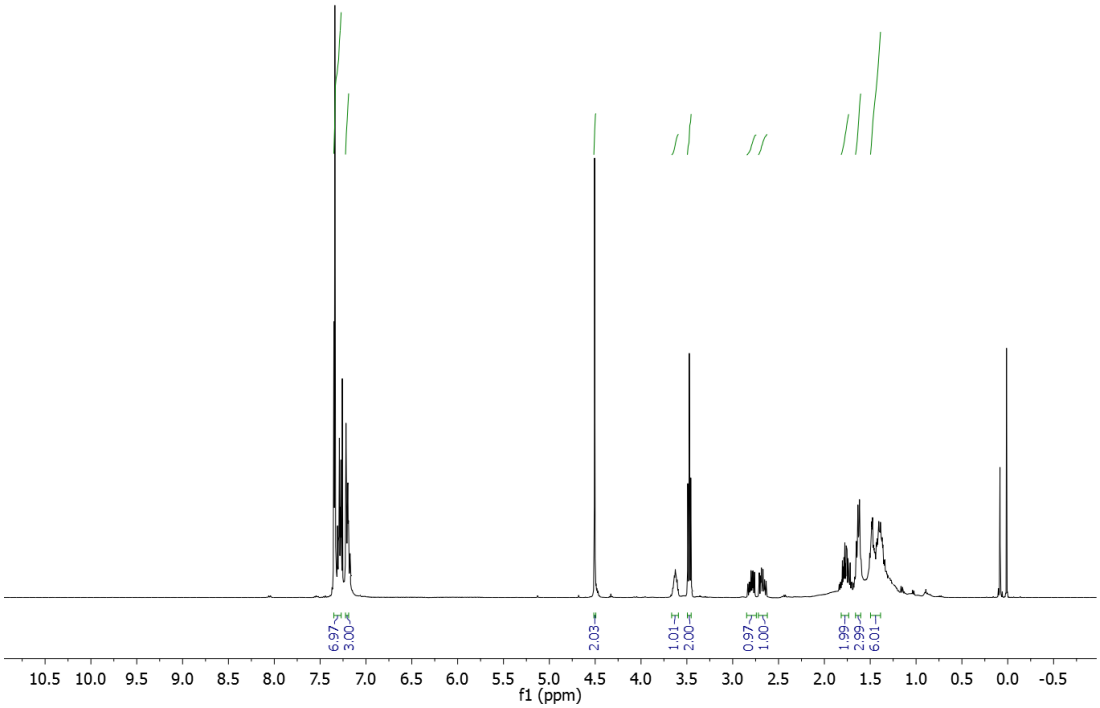
An oven-dried pressure tube equipped with a magnetic stir bar was charged with 6-(benzyloxy)hexan-1-ol (41.7 mg, 0.2 mmol, 100 mol%) and $RuHCl(CO)(PCy_3)_2$ (14.5 mg, 0.02 mmol, 10 mol%). The reaction vessel was placed under an atmosphere of argon. Styrene (0.4 mL, 0.5 M) was added by syringe followed by $HBF_4{\cdot}Et_2O$ (8.3 µL, 0.03 mmol, 15 mol%). The reaction vessel was sealed and the reaction mixture was allowed to stir at 120 ˚C for 24 h. The reaction was allowed to reach ambient temperature. The reaction mixture was concentrated *in vacuo*. The residue was subjected to column chromatography (SiO_2: hexanes:ethyl acetate, 20:1) to furnish the title compound (42.5 mg, 0.136 mmol) as a colorless oil in 68% yield

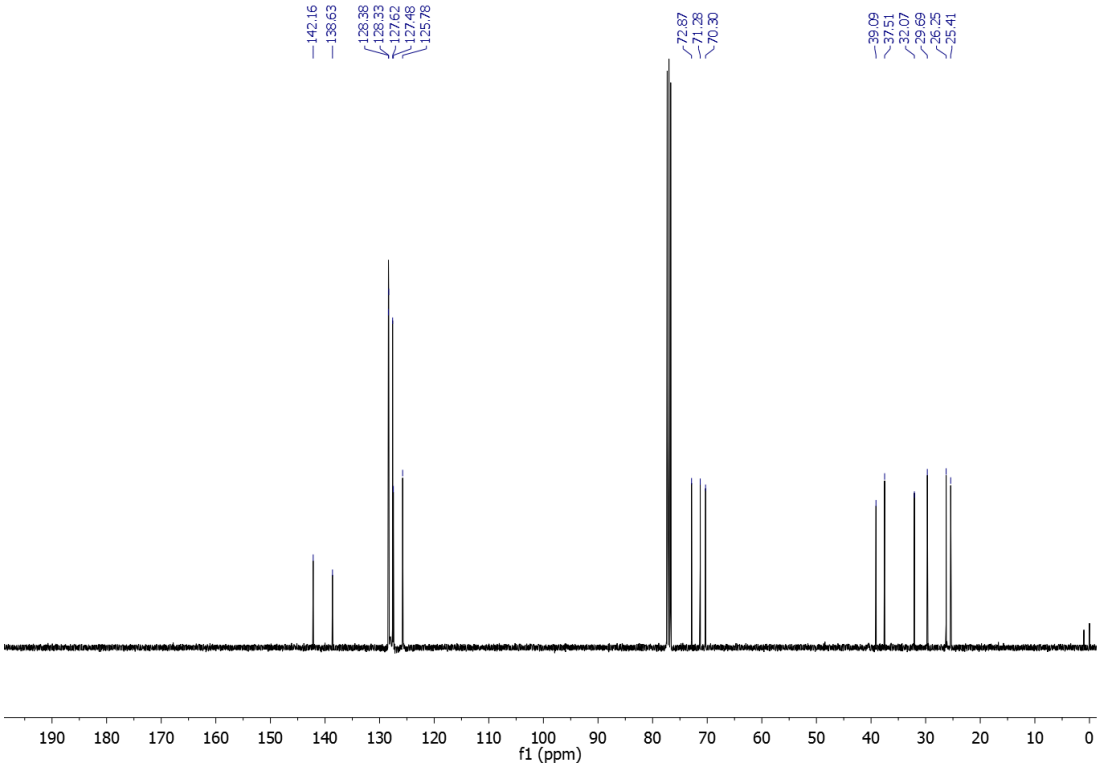
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.36–7.27 (m, 7H), 7.21 (dt, *J* = 8.1, 2.0 Hz, 3H), 4.51 (s, 2H), 3.63 (tt, *J* = 8.5, 4.2 Hz, 1H), 3.47 (t, *J* = 6.6 Hz, 2H), 2.80 (ddd, *J* = 13.8, 9.6, 5.9 Hz, 1H), 2.67 (ddd, *J* = 13.7, 9.6, 6.7 Hz, 1H), 1.81–1.73 (m, 2H), 1.63 (dd, *J* = 8.7, 5.0 Hz, 3H), 1.50–1.38 (m, 6H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 142.2, 138.6, 128.4, 128.3, 127.6, 127.5, 125.8, 72.9, 71.3, 70.3, 39.1, 37.5, 32.1, 29.7, 26.3, 25.4.

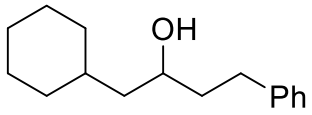
HRMS (CI) Calcd. For $C_{21}H_{29}O_2$ $[M+H]^+$ 313.2168, Found 313.2174.

FTIR (neat): 3406, 3060, 3025, 2929, 2855, 1567, 1493, 1452, 1364, 1098, 1028, 857, 797, 745, 698 cm^{-1}.


6.97
3.00
2.03
1.01
2.00
0.97
1.00
1.99
2.99
6.01
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)


142.16
138.63
128.38
128.33
127.62
127.48
125.78
72.87
71.28
70.30
39.09
37.51
32.07
29.69
26.25
25.41
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

1-cyclohexyl-4-phenylbutan-2-ol (1.3d)



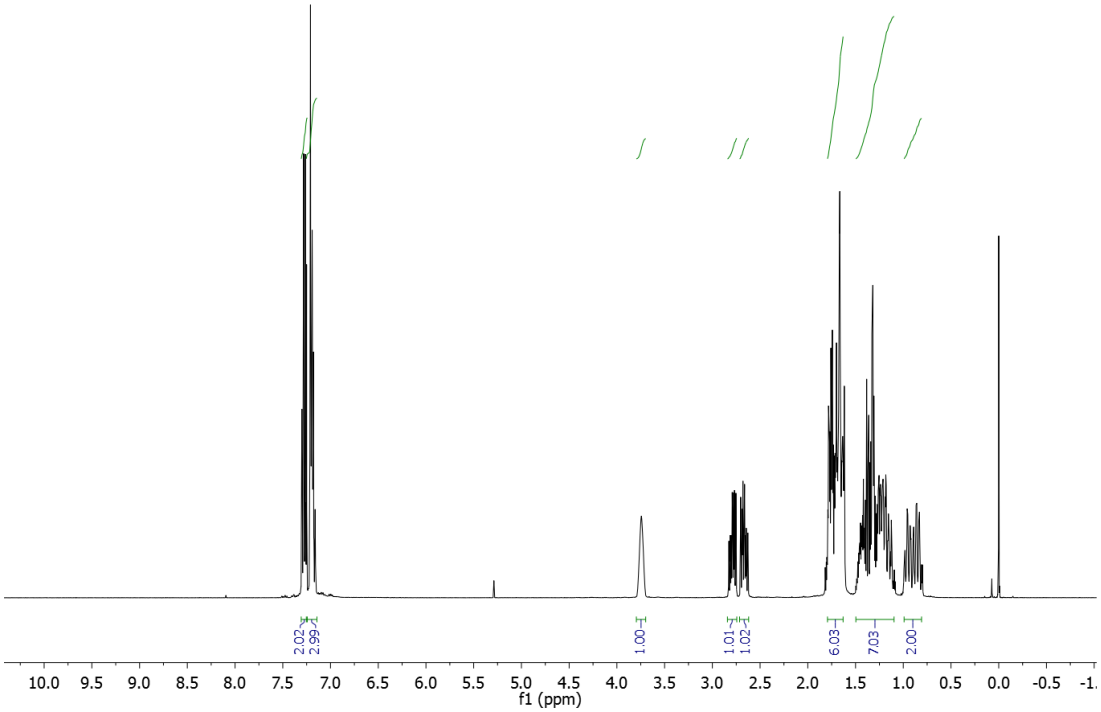
An oven-dried pressure tube equipped with a magnetic stir bar was charged with 2-cyclohexylethan-1-ol (25.6 mg, 0.2 mmol, 100 mol%) and $RuHCl(CO)(PCy_3)_2$ (8.7 mg, 0.012 mmol, 6 mol%). The reaction vessel was placed under an atmosphere of argon. Styrene (0.2 mL, 1 M, 870 mol%) was added by syringe followed by $HBF_4{\cdot}Et_2O$ (5.5 μL, 0.02 mmol, 10 mol%). The reaction vessel was sealed and the reaction mixture was allowed to stir at 100 ˚C for 24 h. The reaction was allowed to reach ambient temperature. The reaction mixture was concentrated *in vacuo*. The residue was subjected to column chromatography (SiO_2: hexanes:ethyl acetate, 40:1) to furnish the title compound (29.8 mg, 0.128 mmol) as a colorless oil in 64% yield.

^{1}H NMR (400 MHz, Chloroform-*d*) δ 3.74 (t, *J* = 6.5 Hz, 1H), 2.79 (ddd, *J* = 13.7, 9.7, 6.0 Hz, 1H), 2.67 (ddd, *J* = 13.8, 9.7, 6.6 Hz, 1H), 1.81–1.63 (m, 5H), 1.50–1.09 (m, 6H), 1.01–0.77 (m, 2H).

^{13}C NMR (100 MHz, $CDCl_3$) δ 142.2, 128.4, 125.8, 68.9, 45.5, 39.7, 34.2, 34.2, 33.0, 32.1, 26.6, 26.4, 26.2.

HRMS (CI) Calcd. For $C_{16}H_{23}O$ $[M-H]^+$ 231.1749, Found 231.1746.

FTIR (neat): 3336, 2919, 2850, 1494, 1448, 1068, 1046, 1000, 931, 745, 697 cm^{-1}.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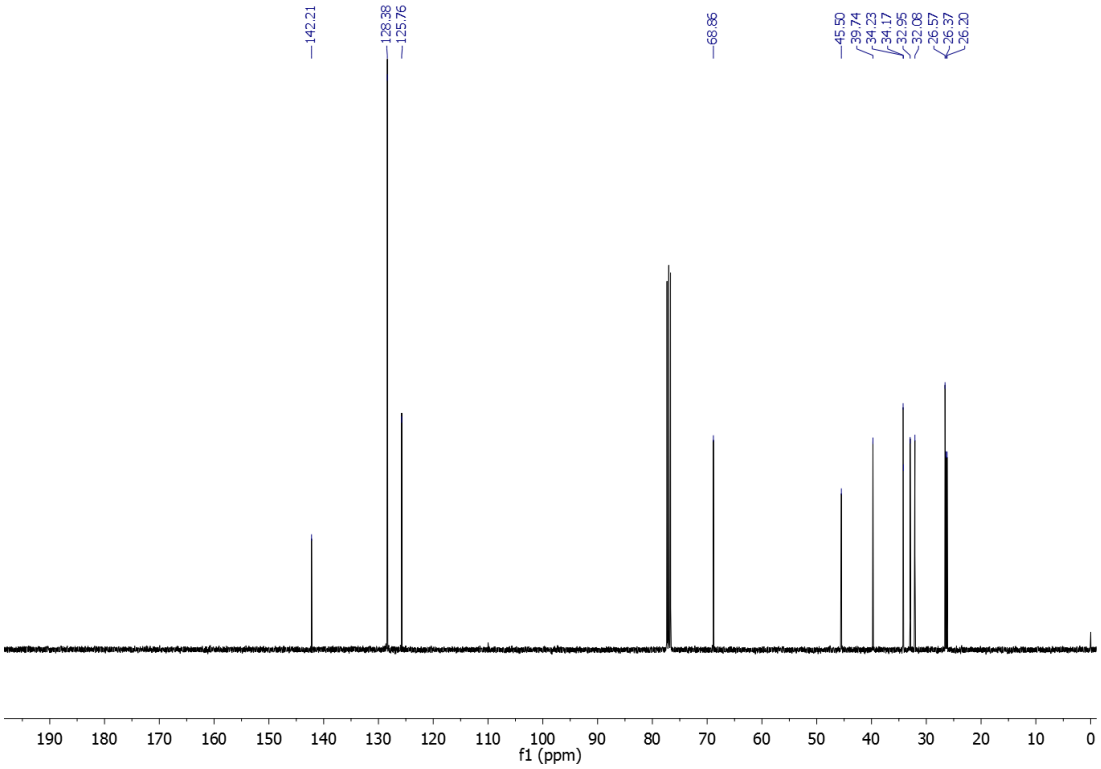
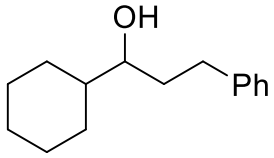
2.99
1.00
1.01
1.02
6.03
7.03
2.00
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)


142.21
128.38
125.76
68.86
45.50
39.74
34.23
34.17
32.95
32.08
26.57
26.37
26.20
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

1-cyclohexyl-3-phenylpropan-1-ol (1.3e)



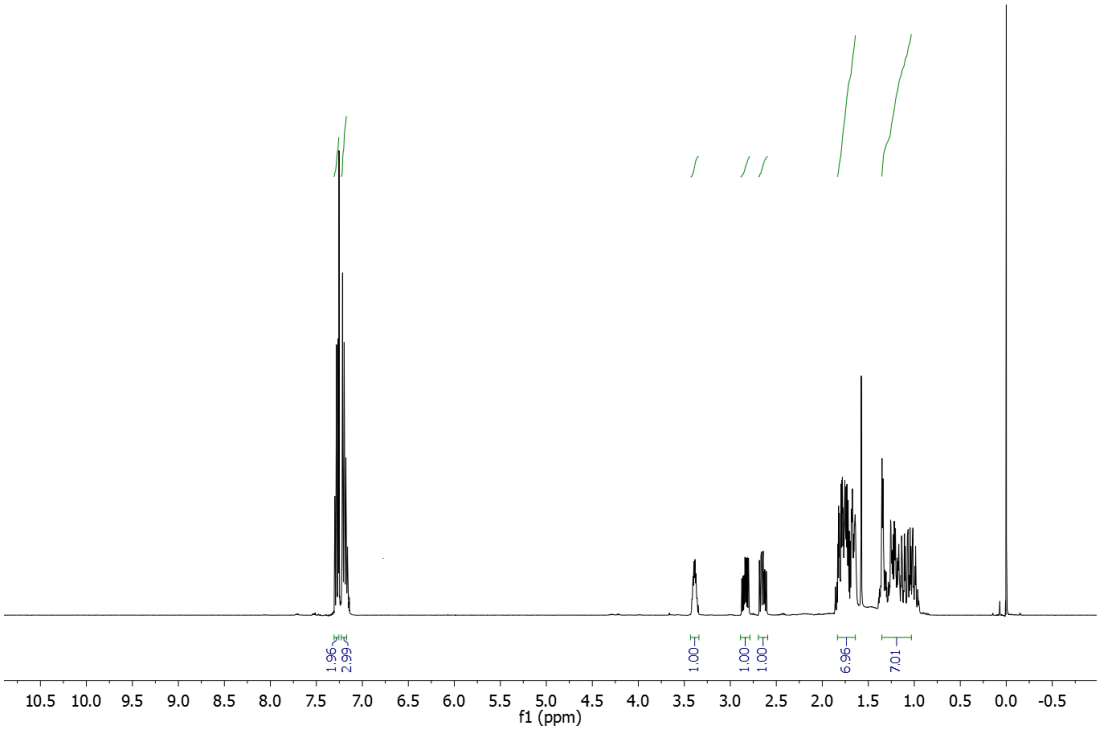
An oven-dried pressure tube equipped with a magnetic stir bar was charged with cyclohexylmethanol (22.8 mg, 0.2 mmol, 100 mol%) and $RuHCl(CO)(PCy_3)_2$ (14.5 mg, 0.02 mmol, 10 mol%). The reaction vessel was placed under an atmosphere of argon. Styrene (0.2 mL, 1 M, 870 mol%) was added by syringe followed by $HBF_4{\cdot}Et_2O$ (8.3 μL, 0.03 mmol, 15 mol%). The reaction vessel was sealed and the reaction mixture was allowed to stir at 100 ˚C for 24 h. The reaction was allowed to reach ambient temperature. The reaction mixture was concentrated *in vacuo*. The residue was subjected to column chromatography (SiO_2: hexanes:ethyl acetate, 40:1) to furnish the title compound (27.1 mg, 0.124 mmol) as a colorless oil in 62% yield.

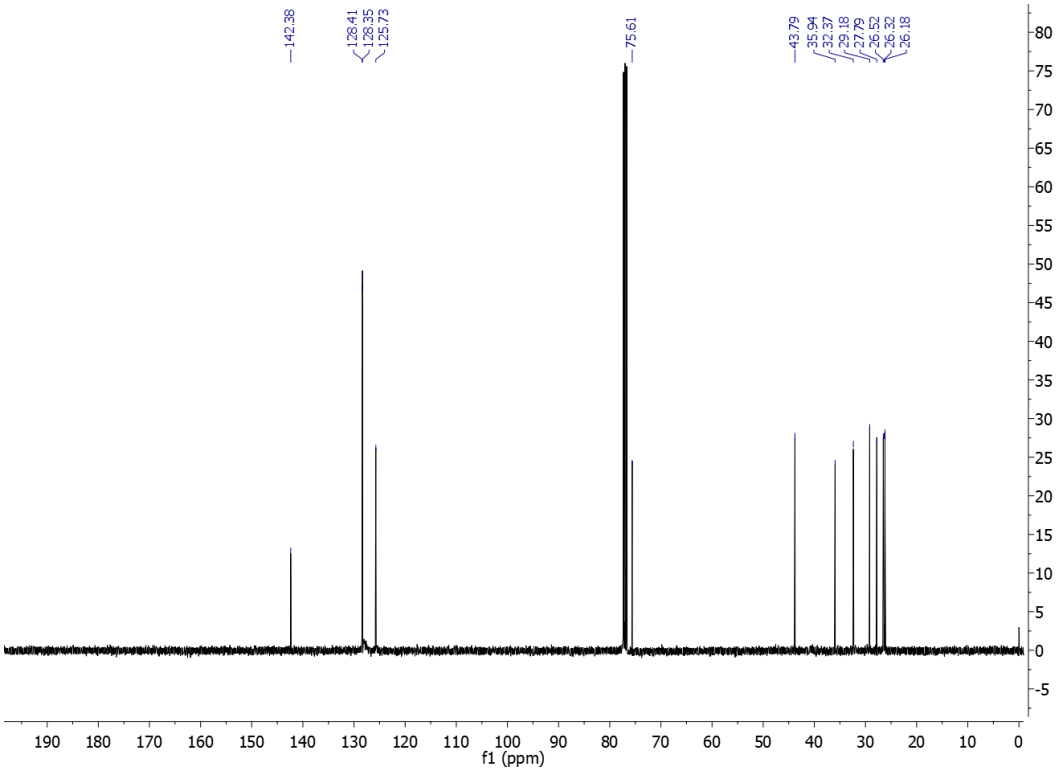
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.32–7.27 (m, 2H), 7.24–7.16 (m, 3H), 3.44–3.36 (m, 1H), 2.85 (ddd, J = 13.7, 10.1, 5.3 Hz, 1H), 2.66 (ddd, J = 13.7, 9.8, 6.6 Hz, 1H), 1.92–1.62 (m, 7H), 1.39–0.98 (m, 7H).

^{13}C NMR (100 MHz, CDCl3) δ 142.4, 128.4, 128.4, 125.7, 75.6, 43.8, 35.9, 32.4, 29.2, 27.8, 26.5, 26.3, 26.2.

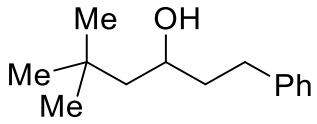
HRMS (CI) Calcd. For $C_{15}H_{21}O$ $[M-H]^-$ 217.1592, Found 217.1601.

FTIR (neat): 3365, 3026, 2923, 2851, 1602, 1494, 1451, 1064, 1030, 748, 698 cm^{-1}.


1.96
2.99
1.00
1.00
1.00
6.96
7.01
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)


142.38
128.41
128.35
125.73
75.61
43.79
35.94
32.37
29.18
27.79
26.52
26.32
26.18
80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5 0 -5
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

5,5-dimethyl-1-phenylhexan-3-ol (1.3f)



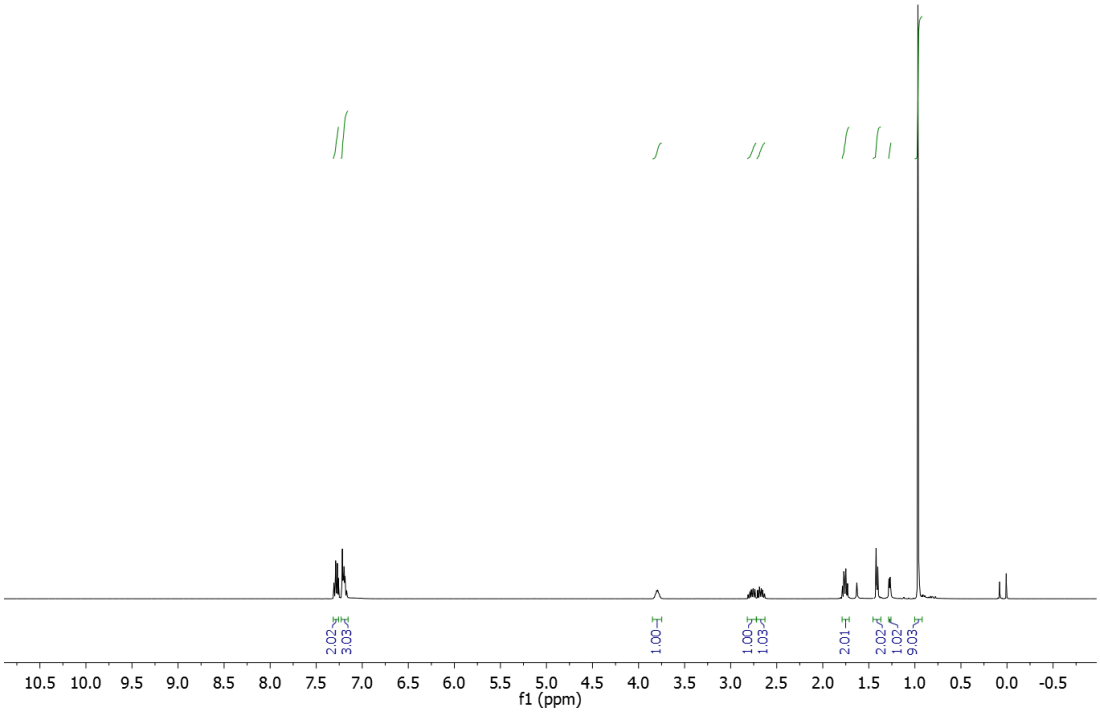
An oven-dried pressure tube equipped with a magnetic stir bar was charged with 3,3-dimethylbutan-1-ol (20.4 mg, 0.2 mmol, 100 mol%) and $RuHCl(CO)(PCy_3)_2$ (8.7 mg, 0.012 mmol, 6 mol%). The reaction vessel was placed under an atmosphere of argon, isopropyl alcohol (12 mg, 15µL, 0.2 mmol, 100 mol%) was added by syringe. Styrene (0.2 mL, 1 M, 870 mol%) was added by syringe followed by $HBF_4{\cdot}Et_2O$ (5.5 µL, 0.02 mmol, 10 mol%). The reaction vessel was sealed and the reaction mixture was allowed to stir at 100 ˚C for 24 h. The reaction was allowed to reach ambient temperature. The reaction mixture was concentrated *in vacuo*. The residue was subjected to column chromatography (SiO_2: hexanes:ethyl acetate, 40:1) to furnish the title compound (27.2 mg, 0.132 mmol) as a colorless oil in 66% yield.

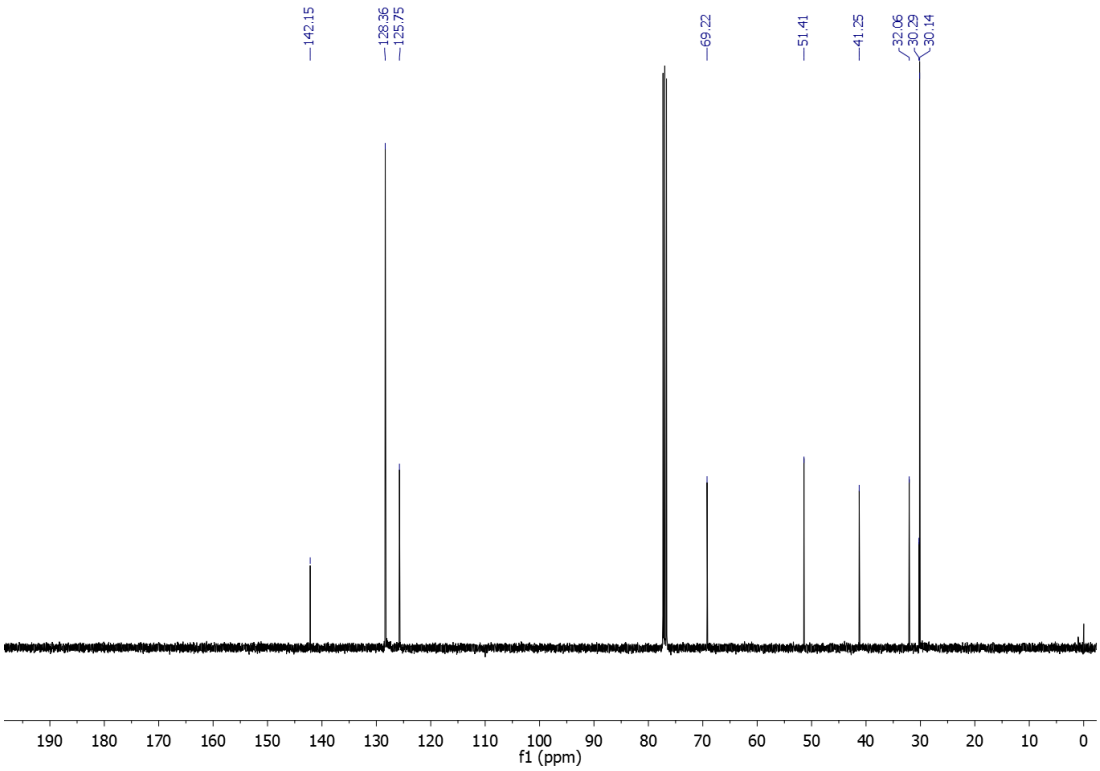
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.33–7.26 (m, 2H), 7.24–7.16 (m, 3H), 3.80 (h, J = 5.8 Hz, 1H), 2.82–2.73 (m, 1H), 2.72–2.63 (m, 1H), 1.80–1.72 (m, 2H), 1.45–1.38 (m, 2H), 0.97 (d, J = 0.9 Hz, 9H).

^{13}C NMR (101 MHz, $CDCl_3$) δ 142.2, 128.4, 125.8, 69.2, 51.4, 41.3, 32.1, 30.3, 30.1.

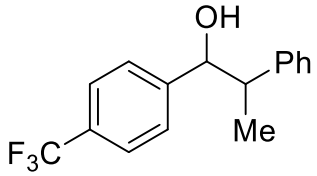
HRMS (CI) Calcd. For $C_{14}H_{22}O$ $[M-H]^-$ 206.1671, Found 206.1679.

FTIR (neat): 3394, 3026, 2950, 2865, 1495, 1474, 1454, 1364, 1249, 1060, 1029, 743, 698 cm^{-1}.


2.02
3.03
1.00
1.00
1.03
2.01
2.02
1.02
9.03
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)


142.15
128.36
125.75
69.22
51.41
41.25
32.06
30.29
30.14
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

2-phenyl-1-(4-(trifluoromethyl)phenyl)propan-1-ol (1.3g)



<u>*From alcohol oxidation level:*</u> An oven-dried pressure tube equipped with a magnetic stir bar was charged with 4-(trifluoromethyl)benzyl alcohol (35.2 mg, 0.2 mmol, 100 mol%), $RuHCl(CO)(PCy_3)_2$ (8.7 mg, 0.012 mmol, 6 mol%), and AgOTf (2.6 mg, 0.01 mmol, 5 mol%). The reaction vessel was placed under an atmosphere of argon. Styrene (0.2 mL, 1 M, 870 mol%) was added by syringe. The reaction vessel was sealed and the reaction mixture was allowed to stir at 100 ˚C for 24 h. The reaction was allowed to reach ambient temperature. The reaction was concentrated *in vacuo*. The residue was subjected to column chromatography (SiO_2: hexanes:ethyl acetate, 30:1) to furnish the title compound (46.5 mg, 0.166 mmol, *dr*: 2:1) as a colorless oil in 83% yield.

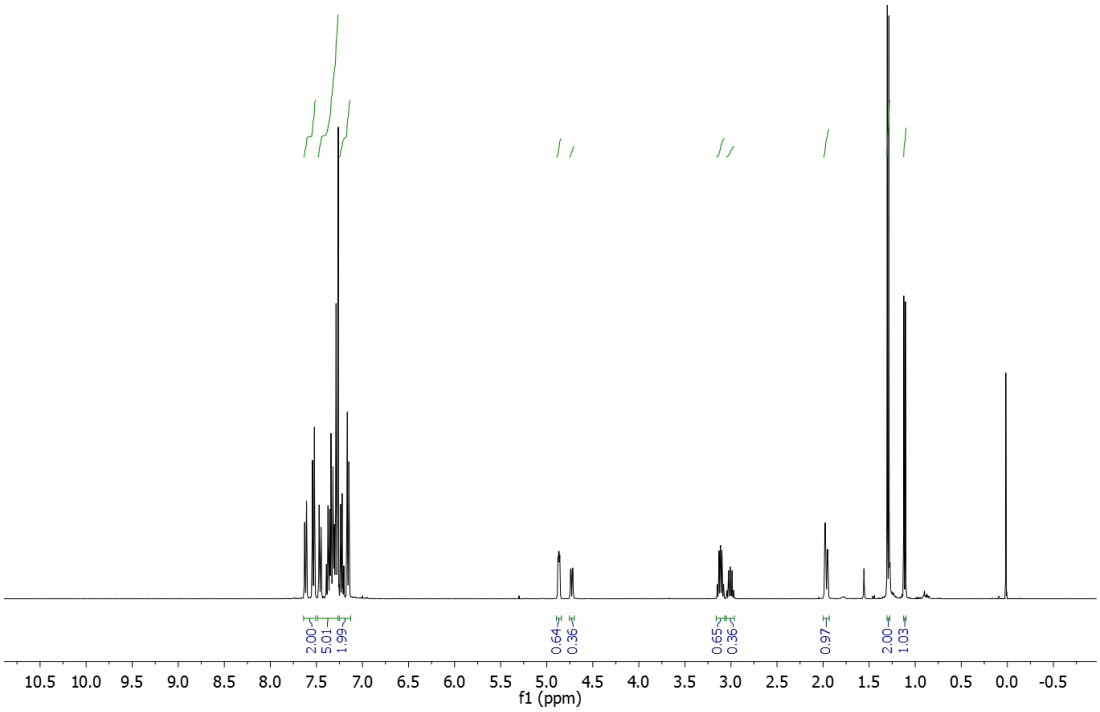
<u>*From aldehyde oxidation level:*</u> An oven-dried pressure tube equipped with a magnetic stir bar was charged with 4-(trifluoromethyl)benzyl aldehyde (34.8 mg, 0.2 mmol, 100 mol%), $RuHCl(CO)(PCy_3)_2$ (14.5 mg, 0.02 mmol, 10 mol%), and AgOTf (4.7 mg, 0.018 mmol, 9 mol%). The reaction vessel was placed under an atmosphere of argon. Styrene (0.2 mL, 1 M, 870 mol%) and isopropyl alcohol (24 mg, 0.4 mmol, 200 mol%) were added by syringe. The reaction vessel was sealed and the reaction mixture was allowed to stir at 100 ˚C for 24 h. The reaction was allowed to reach ambient temperature. The reaction mixture was concentrated *in vacuo*. The residue was subjected to column chromatography (SiO_2: hexanes:ethyl acetate, 30:1) to furnish the title compound (37.5 mg, 0.134 mmol, *dr*: 1.6:1) as a colorless oil (37.5 mg, *dr*: 1.6:1) in 67 % yield.

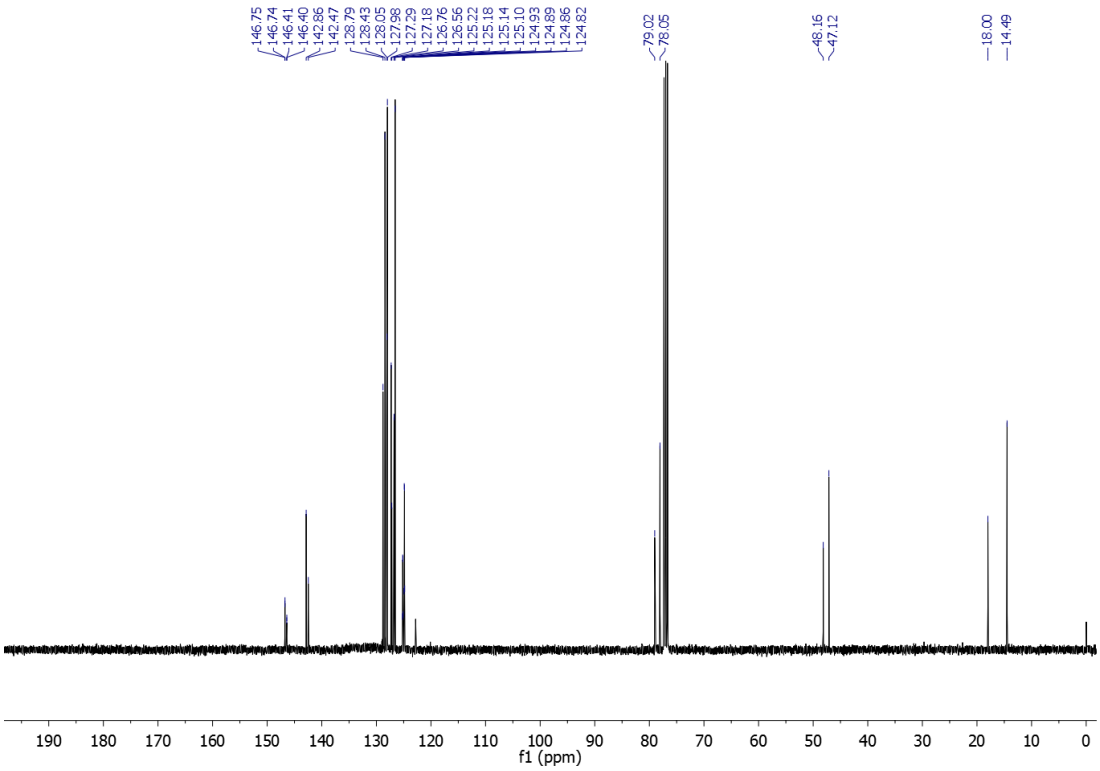
^{1}H NMR (400 MHz, $CDCl_3$) for the 2:1 mixture of diastereomers: δ 7.57 (ddt, J = 34.2, 7.9, 0.8 Hz, 2H), 7.49–7.27 (m, 5H), 7.25–7.13 (m, 2H), 4.87 (dd, J = 5.6, 3.0 Hz, 0.64H), 4.73 (dd, J = 8.5, 2.2 Hz, 0.36H), 3.11 (qd, J = 7.0, 5.5 Hz, 0.65H), 3.01 (dq, J = 8.5, 7.1 Hz, 0.36H), 1.96 (ddd, J = 9.7, 3.0, 1.8 Hz, 1H), 1.29 (d, J = 7.1 Hz, 2H), 1.12 (d, J = 7.1 Hz, 1H).

^{13}C NMR (100 MHz, $CDCl_3$) δ 146.7 (d, *J* = 1.5 Hz), 146.4 (d, *J* = 1.5 Hz), 142.9, 142.5, 128.8, 128.4, 128.1, 128.0, 127.3, 127.2, 126.8, 126.6, 125.2 (q, *J* = 3.8 Hz), 124.9 (q, *J* = 3.7 Hz), 79.0, 78.1, 48.2, 47.1, 18.0, 14.5.

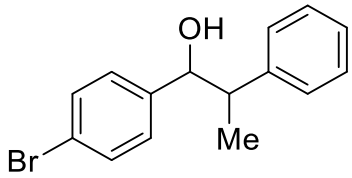
HRMS (CI) Calcd. For $C_{16}H_{15}F_3O$ $[M+H]^+$ 281.1153, Found 281.1160.

FTIR (neat): 3425, 2970, 1619, 1494, 1453, 1324, 1122, 1067, 1016, 841, 760, 700 cm^{-1}.


2.00
5.01
1.99
0.64
0.36
0.65
0.36
0.97
2.00
1.03
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)


146.75
146.74
146.41
146.40
142.86
142.47
128.79
128.43
128.05
127.98
127.29
127.18
126.76
126.56
125.22
125.18
125.14
125.10
124.93
124.89
124.86
124.82
79.02
78.05
48.16
47.12
18.00
14.49
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

1-(4-bromophenyl)-2-phenylpropan-1-ol (1.3h)



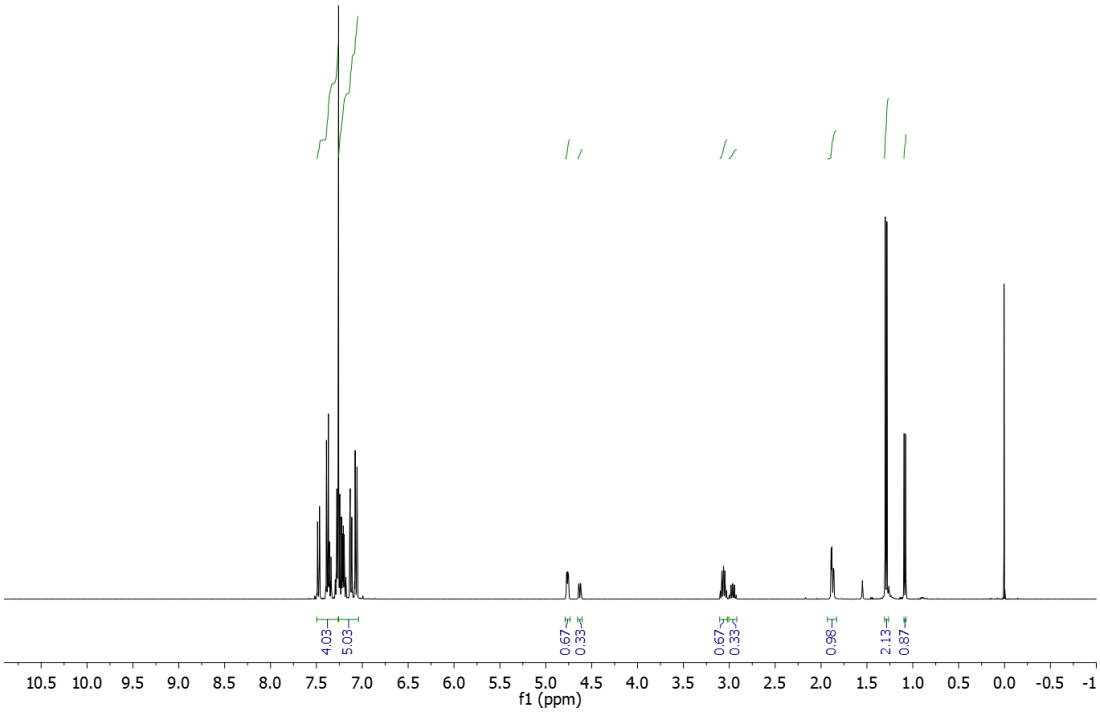
An oven-dried pressure tube equipped with a magnetic stir bar was charged with 4-bromobenzyl alcohol (37.4 mg, 0.2 mmol, 100 mol%), $RuHCl(CO)(PCy_3)_2$ (14.5 mg, 0.02 mmol, 10 mol%), and AgOTf (4.6 mg, 0.018 mmol, 9 mol%). The reaction vessel was placed under an atmosphere of argon. Styrene (0.2 mL, 1 M, 870 mol%) was added by syringe. The reaction vessel was sealed and the reaction mixture was allowed to stir at 100 ˚C for 24 h. The reaction was allowed to reach ambient temperature. The reaction mixture was concentrated *in vacuo*. The residue was subjected to column chromatography (SiO_2: hexanes:ethyl acetate, 30:1) to furnish the title compound (40.5 mg, 0.140 mmol, *dr*: 2:1) as a colorless oil in 70% yield.

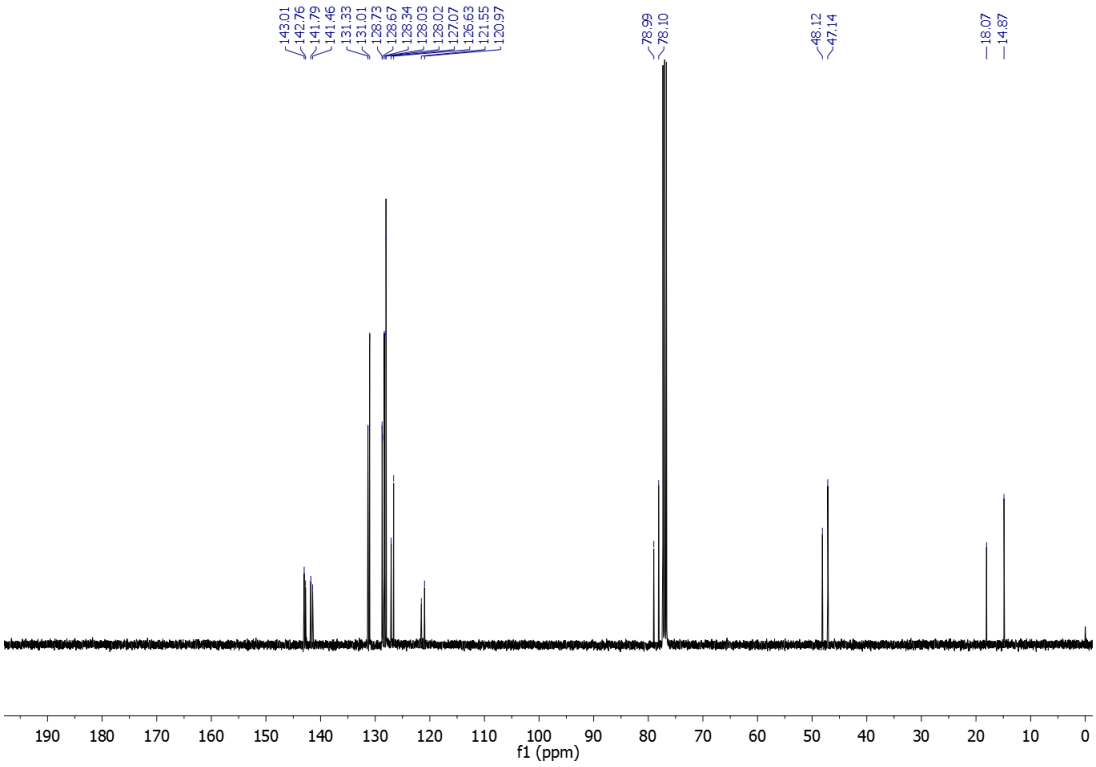
^{1}H NMR (400 MHz, $CDCl_3$) for the 3:2 mixture of diastereomers: δ7.51–7.26 (m, 4H), 7.26–7.03 (m, 5H), 4.76 (dd, *J* = 5.9, 2.7 Hz, 0.67H), 4.63 (dd, *J* = 8.5, 2.1 Hz, 0.33H), 3.11–3.02 (m, 0.67H), 2.96 (dq, *J* = 8.5, 7.1 Hz, 0.33H), 1.87 (dd, *J* = 9.4, 2.8 Hz, 1H), 1.29 (d, *J* = 7.1 Hz, 2.13H), 1.09 (d, *J* = 7.1 Hz, 0.87H).

^{13}C NMR (100 MHz, $CDCl_3$) δ 143.0, 142.8, 141.8, 141.5, 131.3, 131.0, 128.7, 128.7, 128.3, 128.0 (d, *J* = 1.4 Hz), 127.1, 126.6, 79.0, 78.1, 48.1, 47.1, 18.1, 14.9.

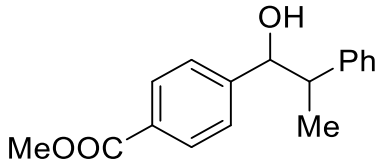
HRMS (CI) Calcd. For $C_{15}H_{16}OBr$ $[M+H]^+$ 291.0385, Found 291.0369.

FTIR (neat): 3411, 3026, 2964, 2927, 1592, 1486, 1452, 1403, 1183, 1070, 1024, 1008, 909, 820, 759, 699 cm^{-1}.


4.03
5.03
0.67
0.33
0.67
0.33
0.98
2.13
0.87
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1
f1 (ppm)


143.01
142.76
141.79
141.46
131.33
131.01
128.73
128.67
128.34
128.03
128.02
127.07
126.63
121.55
120.97
78.99
78.10
48.12
47.14
18.07
14.87
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

Methyl 4-(1-hydroxy-2-phenylpropyl)benzoate (1.3i)



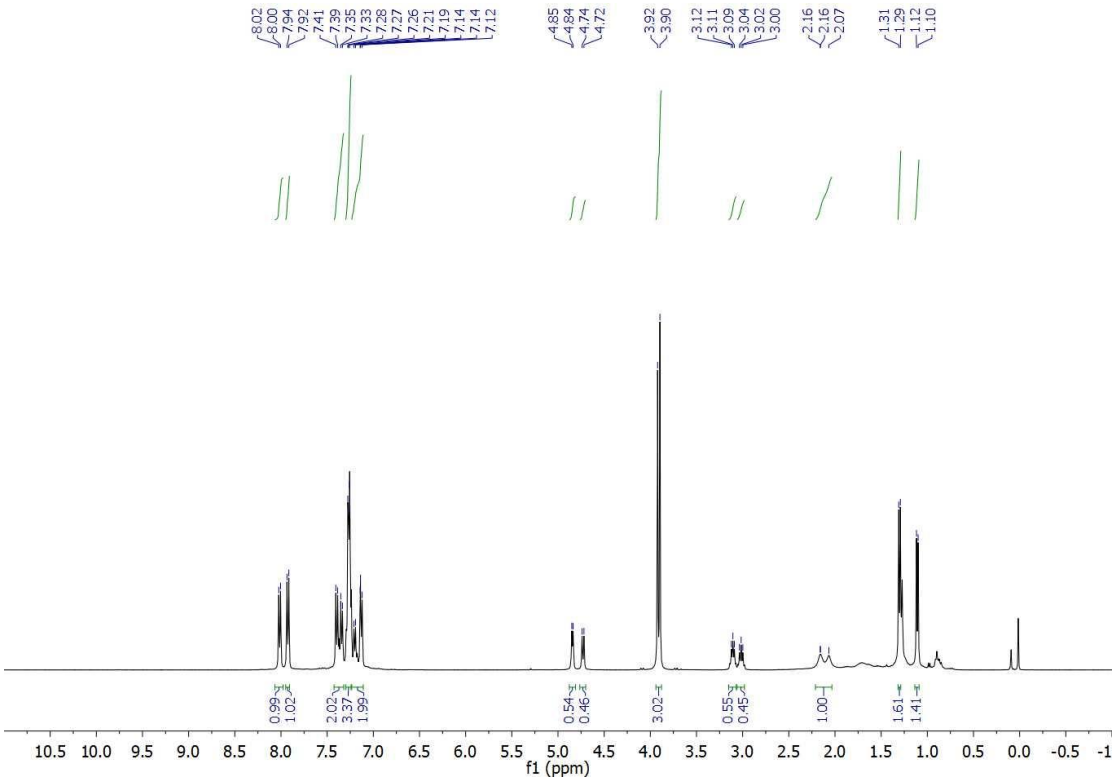
An oven-dried pressure tube equipped with a magnetic stir bar was charged with methyl 4-(hydroxymethyl)benzoate (33.2 mg, 0.2 mmol, 100 mol%), $RuHCl(CO)(PCy_3)_2$ (8.7 mg, 0.02 mmol, 6 mol%), and AgOTf (2.6 mg, 0.01 mmol, 5 mol%). The reaction vessel was placed under an atmosphere of argon. Styrene (0.2 mL, 1 M, 870 mol%) was added by syringe. The reaction vessel was sealed and the reaction mixture was allowed to stir at 100 ˚C for 24 h. The reaction was allowed to reach ambient temperature. The reaction mixture was concentrated *in vacuo*. The residue was subjected to column chromatography (SiO_2: hexanes:ethyl acetate, 30:1) to furnish the title compound (42.2 mg, 0.156 mmol, *dr*: 1:1) as a colorless oil in 78% yield.

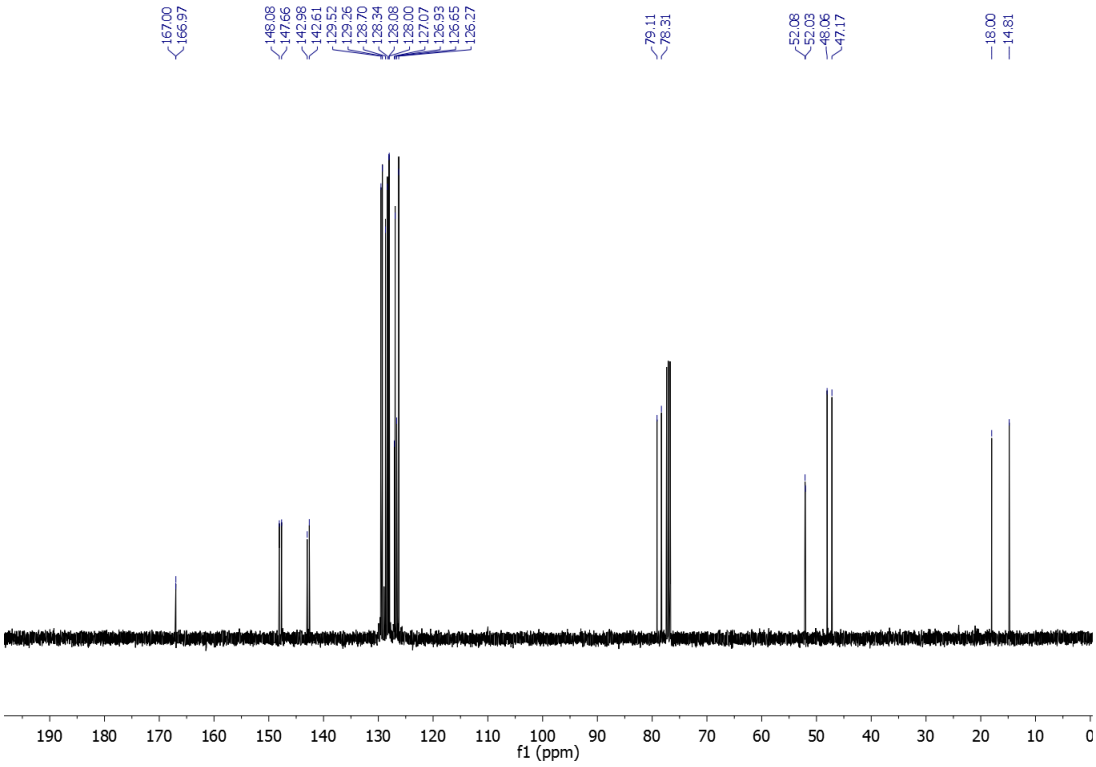
^{1}H NMR (400 MHz, $CDCl_3$) δ 8.01 (d, *J* = 7.9 Hz, 1H), 7.93 (d, *J* = 8.0 Hz, 1H), 7.37 (dd, *J* = 21.1, 7.6 Hz, 2H), 7.24–7.30 (m, 3H), 7.23–7.10 (m, 2H), 4.84 (d, *J* = 5.7 Hz, 0.54H), 4.73 (d, *J* = 8.2 Hz, 0.46H), 3.91 (d, *J* = 10.1 Hz, 3H), 3.21 – 3.04 (m, 0.55H), 3.02 (t, *J* = 7.4 Hz, 0.45H), 2.24–2.03 (m, 1H), 1.30 (d, *J* = 7.0 Hz, 1.6H), 1.11 (d, *J* = 7.0 Hz, 1.4H).

^{13}C NMR (100 MHz, $CDCl_3$) δ 167.0 (d, *J*=2.9 Hz), 148.1, 147.7, 143.0, 142.6, 129.5, 129.3, 128.7, 128.3, 128.1, 128.0, 127.1, 126.9, 126.7, 126.3, 79.1, 78.3, 52.1 (d, *J*=5.7 Hz), 48.1, 47.2, 18.0, 14.8.

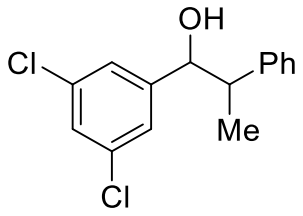
HRMS (CI) Calcd. For $C_{17}H_{19}O_3$ $[M-H]^-$ 271.1334, Found 219.1750.

FTIR (neat): 3468, 2926, 1717, 1610, 1494, 1435, 1277, 1177, 1109, 1018, 967, 910, 859, 771, 733, 699 cm^{-1}.


8.02
8.00
7.94
7.92
7.41
7.39
7.35
7.33
7.28
7.27
7.26
7.21
7.19
7.14
7.14
7.12
4.85
4.84
4.74
4.72
3.92
3.90
3.12
3.11
3.09
3.04
3.02
3.00
2.16
2.16
2.07
1.31
1.29
1.12
1.10
0.99
1.02
2.02
3.37
1.99
0.54
0.46
3.02
0.55
0.45
1.00
1.61
1.41
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1
f1 (ppm)


167.00
166.97
148.08
147.66
142.98
142.61
129.52
129.26
128.70
128.34
128.08
128.00
127.07
126.93
126.65
126.27
79.11
78.31
52.08
52.03
48.06
47.17
18.00
14.81
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

1-(3,5-dichlorophenyl)-2-phenylpropan-1-ol (1.3j)



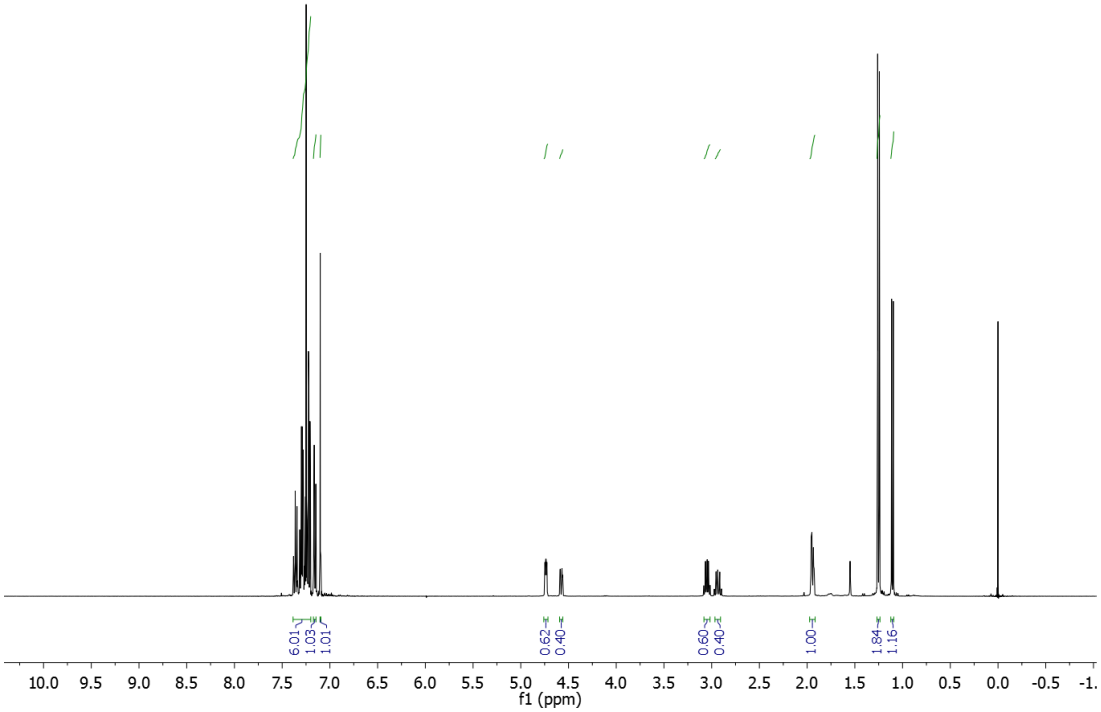
An oven-dried pressure tube equipped with a magnetic stir bar was charged with 3,5-dichlorobenzyl alcohol (35.4 mg, 0.2 mmol, 100 mol%), $RuHCl(CO)(PCy_3)_2$ (8.7 mg, 0.01 mmol, 6 mol%), and AgOTf (2.6 mg, 0.01 mmol, 5 mol%). The reaction vessel was placed under an atmosphere of argon. Styrene (0.2 mL, 1 M, 870 mol%) was added by syringe. The reaction vessel was sealed and the reaction mixture was allowed to stir at 100 ˚C for 24 h. The reaction was allowed to reach ambient temperature. The reaction mixture was concentrated *in vacuo*. The residue was subjected to column chromatography (SiO_2: hexanes:ethyl acetate, 30:1) to furnish the title compound (52.1 mg, 0.186 mmol, *dr*: 1.5:1) as a colorless oil in 93% yield.

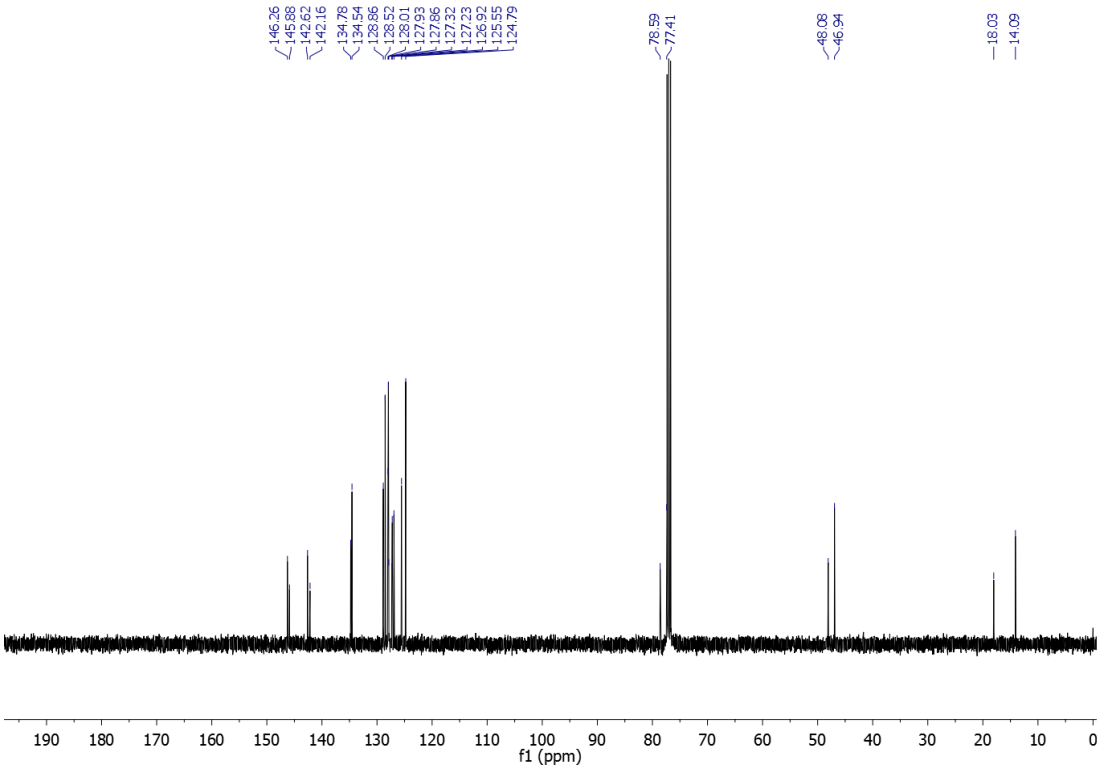
^{1}H NMR (400 MHz, $CDCl_3$) for the 3:2 mixture of diastereomers: δ 7.40–7.21 (m, 6H), 7.19–7.15 (m, 1H), 7.11 (dd, *J* = 1.9, 0.7 Hz, 1H), 4.75 (dd, *J* = 5.3, 3.0 Hz, 0.6H), 4.59 (dd, *J* = 8.5, 2.2 Hz, 0.4H), 3.06 (qd, *J* = 7.1, 5.1 Hz, 0.6H), 2.94 (dq, *J* = 8.6, 7.1 Hz, 0.4H), 1.95 (dd, *J* = 8.9, 2.9 Hz, 2H), 1.26 (d, *J* = 7.1 Hz, 1.8H), 1.12 (d, *J* = 7.1 Hz, 1.2H).

^{13}C NMR (100 MHz, $CDCl_3$) δ 146.3, 145.9, 142.6, 142.2, 134.8, 134.6, 128.9, 128.6, 128.0, 127.9, 127.9, 127.3, 127.2, 126.9, 125.6, 124.8, 78.6, 77.4, 48.1, 46.9, 18.0, 14.1.

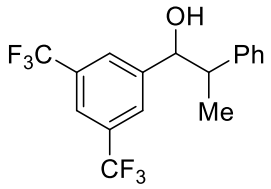
HRMS (ESI) Calcd. For $C_{15}H_{14}Cl_2OAg$ $[M+Ag]^+$: 386.9467, Found, 386.9467.

FTIR (neat): 3424, 3082, 3028, 2974, 1588, 1567, 1494, 1452, 1432, 1380, 1200, 1063, 1008, 857, 797, 699 cm^{-1}.


6.01
1.03
1.01
0.62
0.40
0.60
0.40
1.00
1.84
1.16
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.
f1 (ppm)


146.26
145.88
142.62
142.16
134.78
134.54
128.86
128.52
128.01
127.93
127.86
127.32
127.23
126.92
125.55
124.79
78.59
77.41
48.08
46.94
18.03
14.09
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

1-(3,5-bis(trifluoromethyl)phenyl)-2-phenylpropan-1-ol (1.3k)



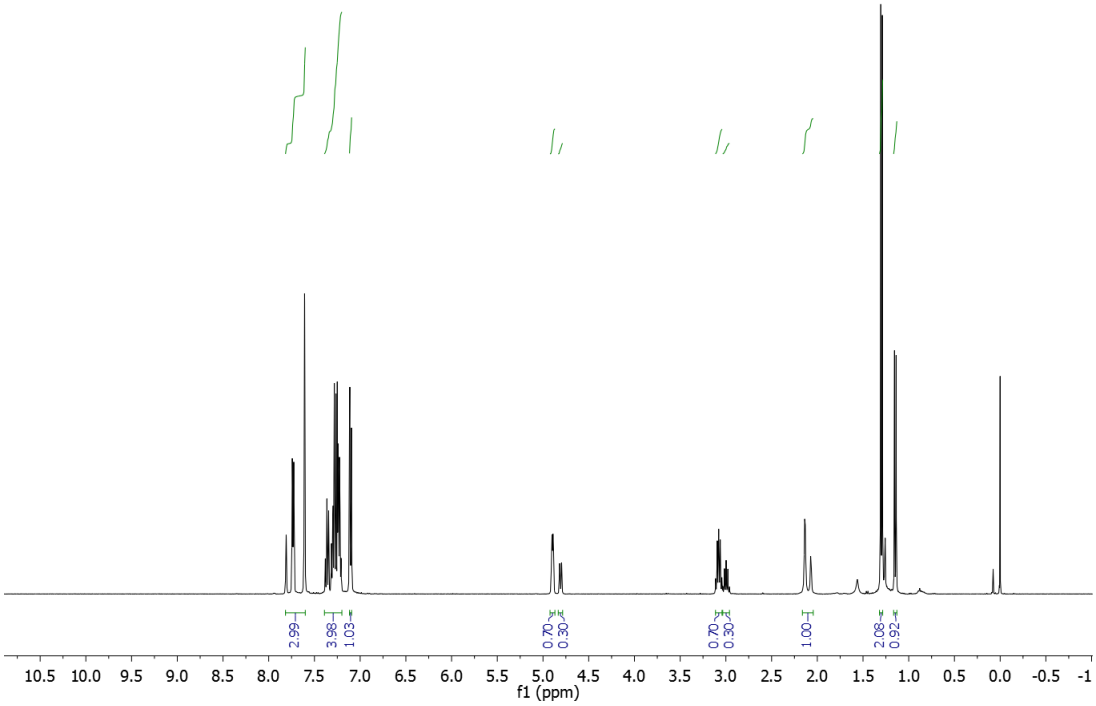
An oven-dried pressure tube equipped with a magnetic stir bar was charged with (3,5-bis(trifluoromethyl)phenyl)methanol (48.8 mg, 0.2 mmol, 100 mol%), $RuHCl(CO)(PCy_3)_2$ (8.7 mg, 0.01 mmol, 6 mol%), and AgOTf (2.6 mg, 0.01 mmol, 5 mol%). The reaction vessel was placed under an atmosphere of argon. Styrene (0.2 mL, 1 M, 870 mol%) was added by syringe. The reaction vessel was sealed and the reaction mixture was allowed to stir at 100 ˚C for 24 h. The reaction was allowed to reach ambient temperature. The reaction mixture was concentrated *in vacuo*. The residue was subjected to column chromatography (SiO_2: hexanes:ethyl acetate, 30:1) to furnish the title compound (50.2 mg, 0.144 mmol, *dr*: 2.2:1) as a colorless oil in 72% yield.

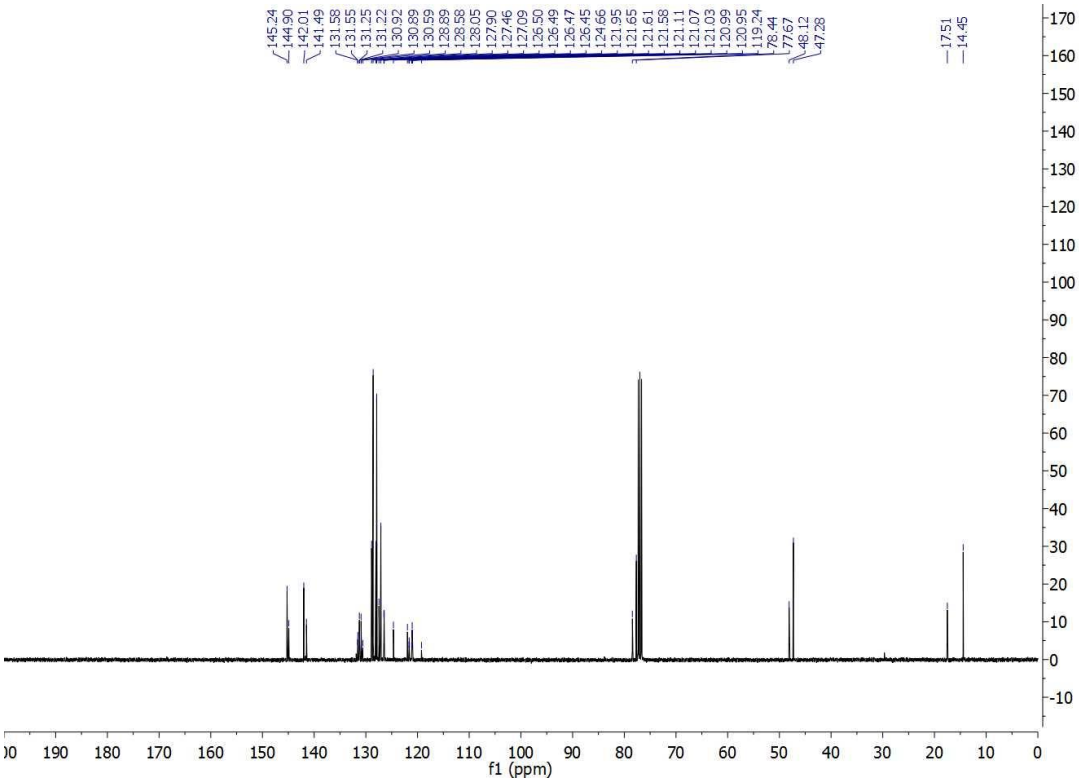
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.85–7.55 (m, 3H), 7.41–7.19 (m, 4H), 7.12–7.09 (m, 1H), 4.90 (dd, *J* = 5.8, 2.2 Hz, 0.7H), 4.83–4.79 (m, 0.3H), 3.13–3.04 (m, 0.7H), 3.00 (p, *J* = 7.2 Hz, 0.3H), 2.10 (dd, *J* = 25.7, 2.9 Hz, 1H), 1.30 (d, *J* = 7.0 Hz, 2.08H), 1.15 (d, *J* = 7.1 Hz, 0.92H).

^{13}C NMR (100 MHz, $CDCl_3$) δ 145.2, 144.9, 142.0, 141.5, 131.6 (d, *J* = 3.5 Hz), 131.2 (d, *J* = 3.5 Hz), 130.9 (d, *J* = 3.7 Hz), 130.6, 128.89, 128.6, 128.1, 127.9, 127.5, 127.1, 126.5, 126.5, 126.4, 126.4, 124.7, 121.6 (t, *J* = 3.8 Hz), 121.0 (p, *J* = 3.9 Hz), 119.2, 78.4, 77.7, 48.1, 47.3, 17.5, 14.5.

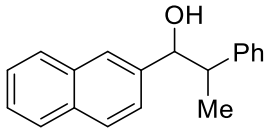
HRMS (CI) Calcd. For $C_{17}H_{13}F_6O$ $[M-H]^+$: 347.0871, Found, 347.0868.

FTIR (neat): 3458, 2967, 1624, 1495, 1453, 1365, 1275, 1168, 1126, 1024, 1009, 899, 874, 842, 761, 700, 681 cm^{-1}.


2.99
3.98
1.03
0.70
0.30
0.70
0.30
1.00
2.08
0.92
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1
f1 (ppm)


145.24
144.90
142.01
141.49
131.58
131.55
131.25
131.22
130.92
130.89
130.59
128.89
128.58
128.05
127.90
127.46
127.09
126.50
126.49
126.47
126.45
124.66
121.95
121.65
121.61
121.58
121.11
121.07
121.03
120.99
120.95
119.24
78.44
77.67
48.12
47.28
17.51
14.45
170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

1-(naphthalen-2-yl)-2-phenylethan-1-ol (1.3l)



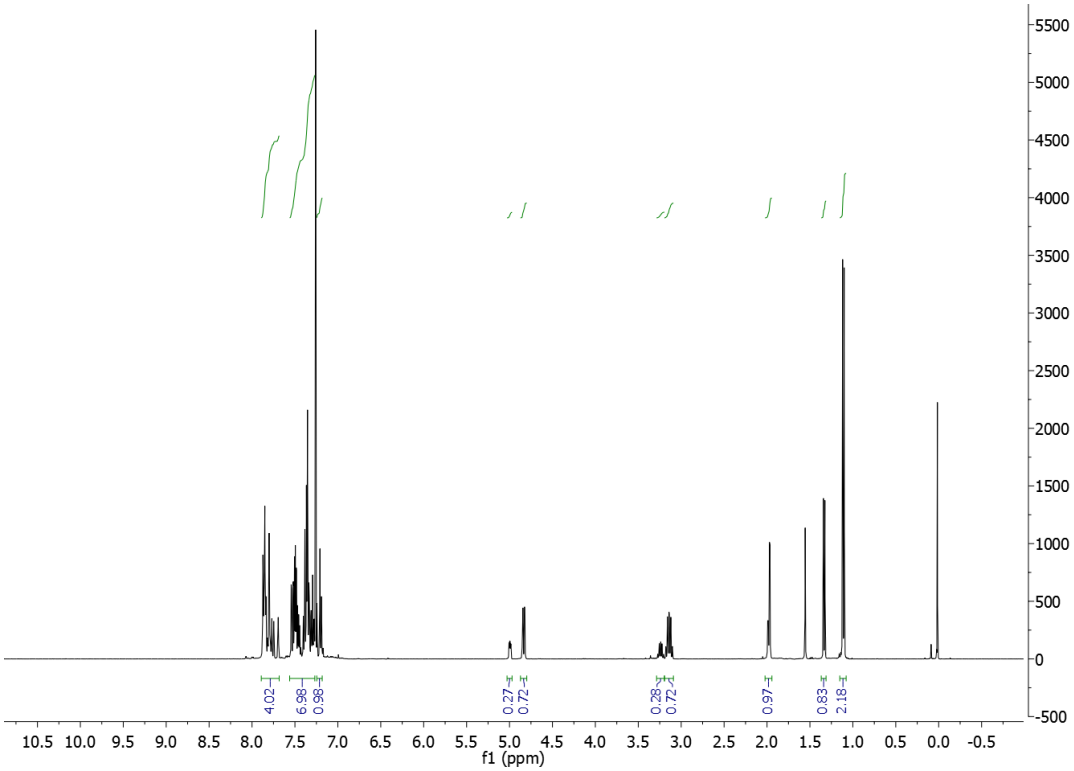
An oven-dried pressure tube equipped with a magnetic stir bar was charged with naphthalen-2-ylmethanol (31.6 mg, 0.2 mmol, 100 mol%), $RuHCl(CO)(PCy_3)_2$ (14.5 mg, 0.02 mmol, 10 mol%), and AgOTf (4.6 mg, 0.018 mmol, 9 mol%). The reaction vessel was placed under an atmosphere of argon. Styrene (0.2 mL, 1 M, 870 mol%) was added by syringe. The reaction vessel was sealed and the reaction mixture was allowed to stir at 100 ˚C for 24 h. The reaction was allowed to reach ambient temperature. The reaction mixture was concentrated *in vacuo*. The residue was subjected to column chromatography (SiO_2: hexanes:ethyl acetate, 30:1) to furnish the title compound (31.5 mg, 0.120 mmol, *dr*: 2.3:1) as a colorless oil in 60% yield.

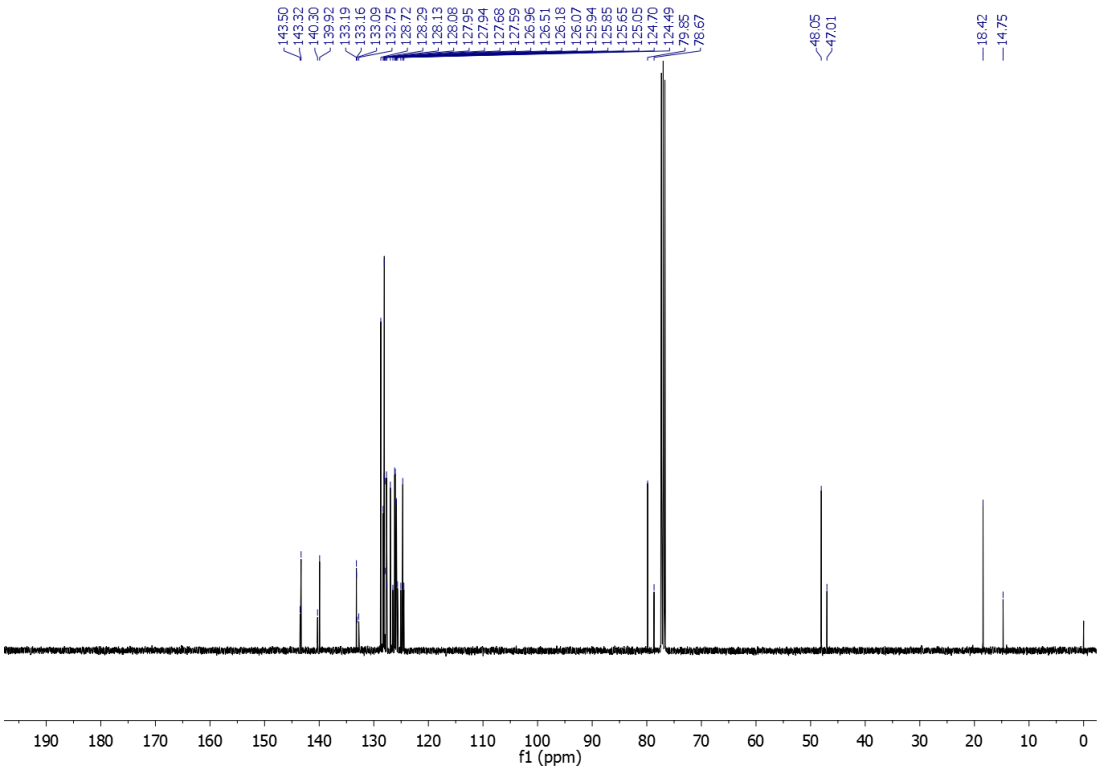
^{1}H NMR (400 MHz, $CDCl_3$) for the 2.6:1 mixture of diastereomers: δ 7.90–7.68 (m, 4H), 7.57–7.27 (m, 7H), 7.25–7.18 (m, 1H), 5.00 (dd, *J* = 5.6, 3.1 Hz, 0.27H), 4.84 (dd, *J* = 8.8, 2.2 Hz, 0.72H), 3.24 (qd, *J* = 7.0, 5.4 Hz, 0.28H), 3.14 (dq, *J* = 8.8, 7.1 Hz, 0.72H), 1.98 (dd, *J* = 7.8, 2.9 Hz, 1H), 1.33 (d, *J* = 7.0 Hz, 0.83H), 1.11 (d, *J* = 7.1 Hz, 2.18H).

^{13}C NMR (100 MHz, $CDCl_3$) δ 143.5, 143.3, 140.3, 139.9, 133.2 (d, *J* = 2.3 Hz), 133.1, 132.8, 128.7, 128.3, 128.1, 128.1, 128.0 (d, *J* = 1.5 Hz), 127.7, 127.6, 127.0, 126.5, 126.2, 126.1, 125.9, 125.9, 125.7, 125.1, 124.7, 124.5, 79.9, 78.7, 48.1, 47.0, 18.4, 14.8.

HRMS (CI) Calcd. For $C_{19}H_{18}O$ $[M]^+$ 262.1358, Found 262.1354.

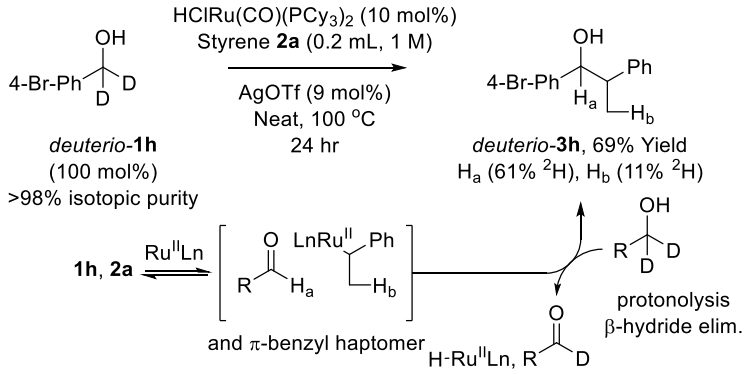
FTIR (neat): 3414, 3056, 3026, 2964, 2925, 1601, 1493, 1451, 1374, 1269, 1164, 1091, 1022, 1008, 891, 856, 799, 747, 699, 666 cm^{-1}.


4.02
6.98
0.98
0.27
0.72
0.28
0.72
0.97
0.83
2.18
f1 (ppm)


143.50
143.32
140.30
139.92
133.19
133.16
133.09
132.75
128.72
128.29
128.13
128.08
127.95
127.94
127.68
127.59
126.96
126.51
126.18
126.07
125.94
125.85
125.65
125.05
124.70
124.49
79.85
78.67
48.05
47.01
18.42
14.75
f1 (ppm)

Isotopic Labelling Studies:

1. Deuterium labelling studies of 1.1h:



^{1}H NMR (400 MHz, $CDCl_3$) for the 1.5:1 mixture of diastereomers: δ 7.51–7.26 (m, 4H), 7.25–7.02 (m, 5H), 4.75 (dd, *J*=5.8, 3.3 Hz, 0.22H), 4.62 (dd, *J*=8.5, 2.4 Hz, 0.17H), 3.05 (q, *J*=7.0 Hz, 0.59H), 3.00–2.90 (m, 0.40H), 1.99–1.80 (m, 1H), 1.28 (d, *J*=7.1 Hz, 1.72H), 1.08 (d, *J*=7.0 Hz, 1.17H).

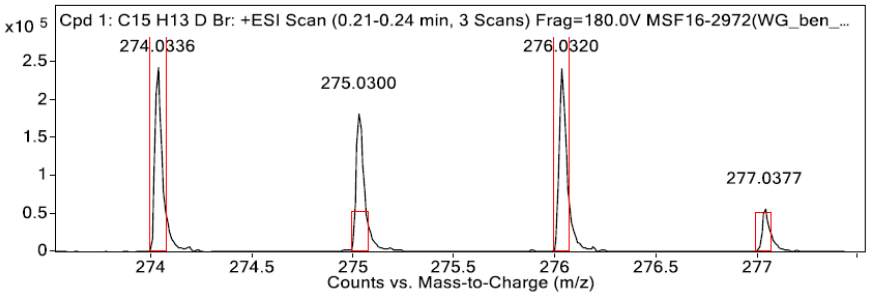
^{2}H NMR (77 MHz, $CDCl_3$) for the 1.5:1 mixture of diastereomers: δ 4.69 (d, *J*=9.5 Hz, 0.61H), 1.20 (d, *J*=15.8 Hz, 0.11H).

HRMS (ESI): Calcd. For $C_{15}H_{12}DBr$ $[M\text{-}OH]^+$ 274.0336, Found 274.0336.

Target Compound Screening Report

Data File	MSF16-2972(WG_ben_Ha_and_Hb)_hrESIpos1.d	**Sample Name**	2972(WG_ben_Ha_and_Hb)	**Comment**	2972(WG_ben_Ha_and_Hb)
Position	P1-B2	**Instrument Name**	Instrument 1	**User Name**	
Acq Method	pos.m	**Acquired Time**	8/16/2016 10:42:26 AM	**DA Method**	KS.m

MS Zoomed Spectrum



MS Spectrum Peak List

Obs. m/z	Calc. m/z	Charge	Abund	Formula	Ion/Isotope	Tgt Mass Error (ppm)
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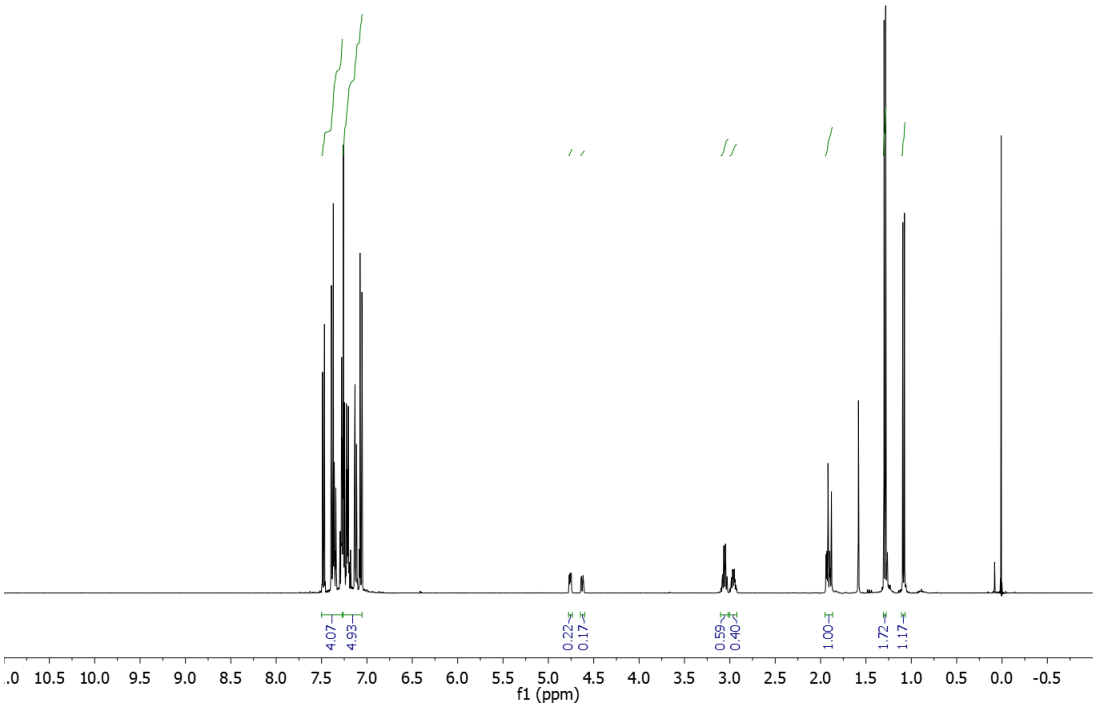
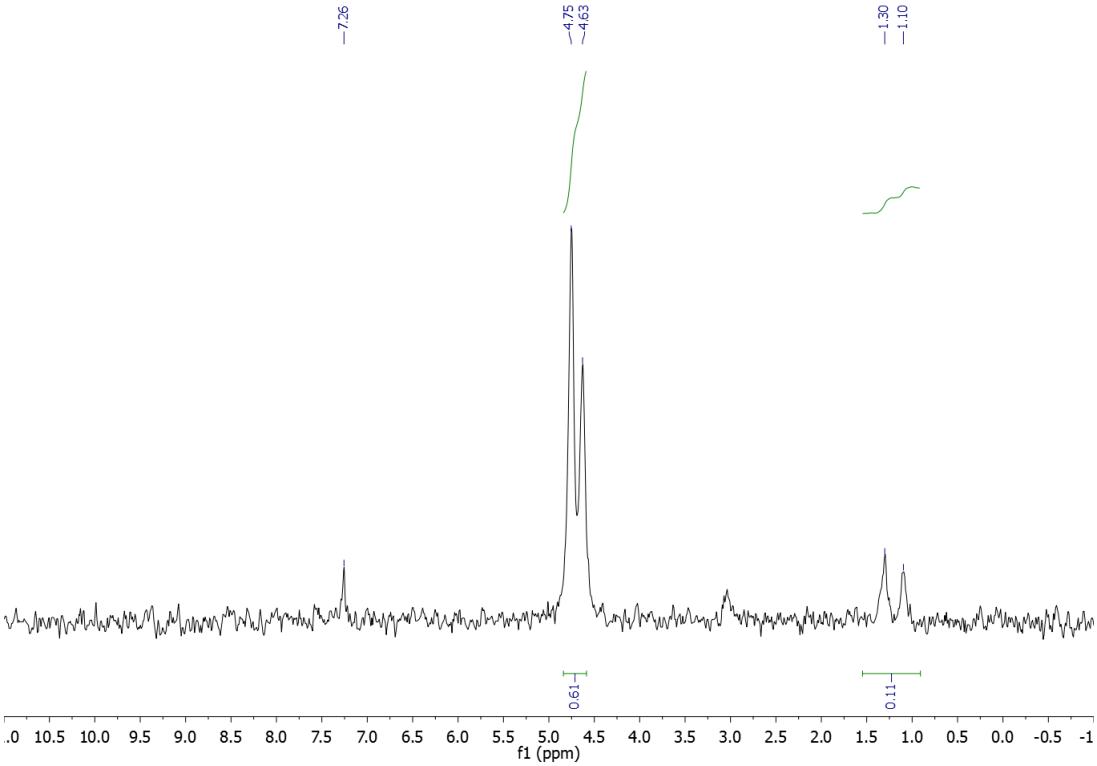
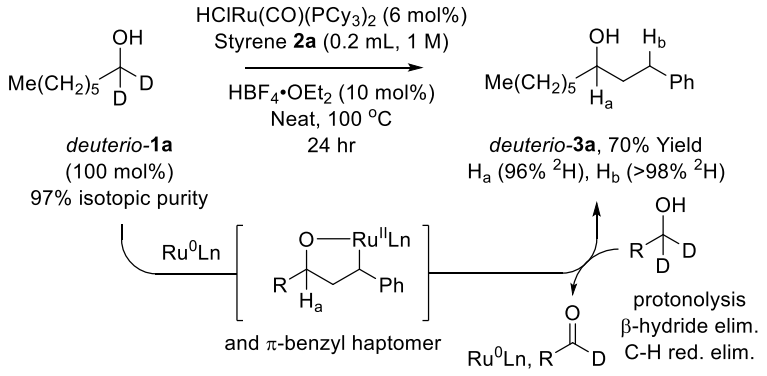
275.03000	275.03700	1	182693.41	C15H13DBr	M+	25.45
276.03200	276.03170	1	242491.56	C15H13DBr	M+	-1.12
277.03770	277.03500	1	56898.75	C15H13DBr	M+	-9.7
278.04280	278.03840	1	8108.76	C15H13DBr	M+	-16.15
279.04870	279.04170	1	3618.56	C15H13DBr	M+	-24.94
297.23500			458616.28			

--- End Of Report ---


4.07
4.93
0.22
0.17
0.59
0.40
1.00
1.72
1.17
.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)


7.26
4.75
4.63
1.30
1.10
0.61
0.11
.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1
f1 (ppm)

2. Deuterium labelling studies of 1.1a:



^{1}H NMR (400 MHz, $CDCl_3$) δ 7.33–7.25 (m, 2H), 7.23–7.15 (m, 3H), 3.63 (s, 0.03H), 2.82–2.73 (m, 0.2H), 2.73–2.57 (m, 0.8H), 1.75 (qd, J = 13.8, 8.1 Hz, 2H), 1.51–1.22 (m, 11H), 0.92–0.83 (m, 3H).

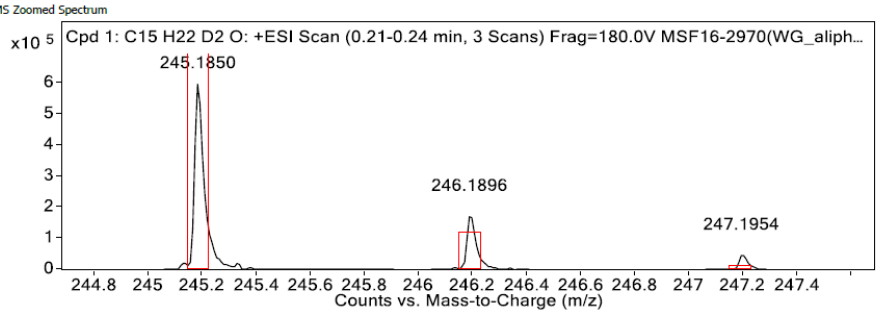
^{2}H NMR (77 MHz, $CDCl_3$) δ 3.62 (s, 1H), 2.79 (s, 1H).

HRMS (ESI): Calcd. For $C_{15}H_{22}D_2O$ $[M+Na]^+$ 245.1845, Found 245.1850.

Target Compound Screening Report

Data File	MSF16-2970(WG_aliph_Ha_and_Hb)_hrESIpos1.d	**Sample Name**	2970(WG_aliph_Ha_and_Hb)	**Comment**	2970(WG_aliph_Ha_and_Hb)
Position	P1-B1	**Instrument Name**	Instrument 1	**User Name**	
Acq Method	pos.m	**Acquired Time**	8/16/2016 10:41:32 AM	**DA Method**	KS.m

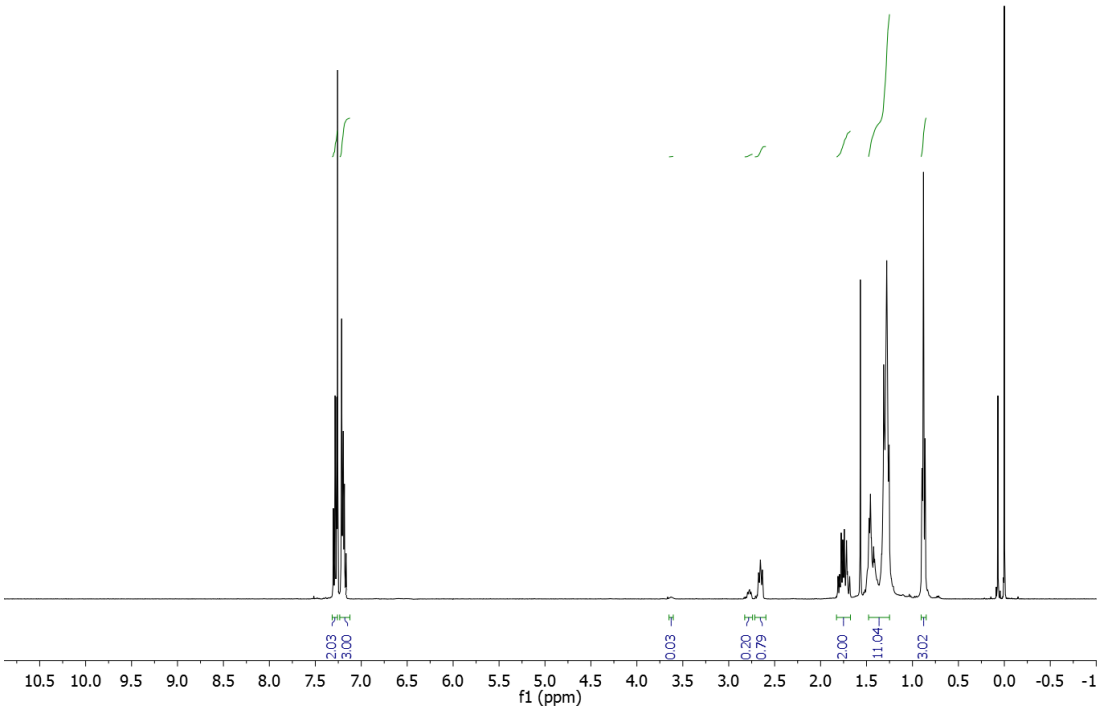
MS Zoomed Spectrum

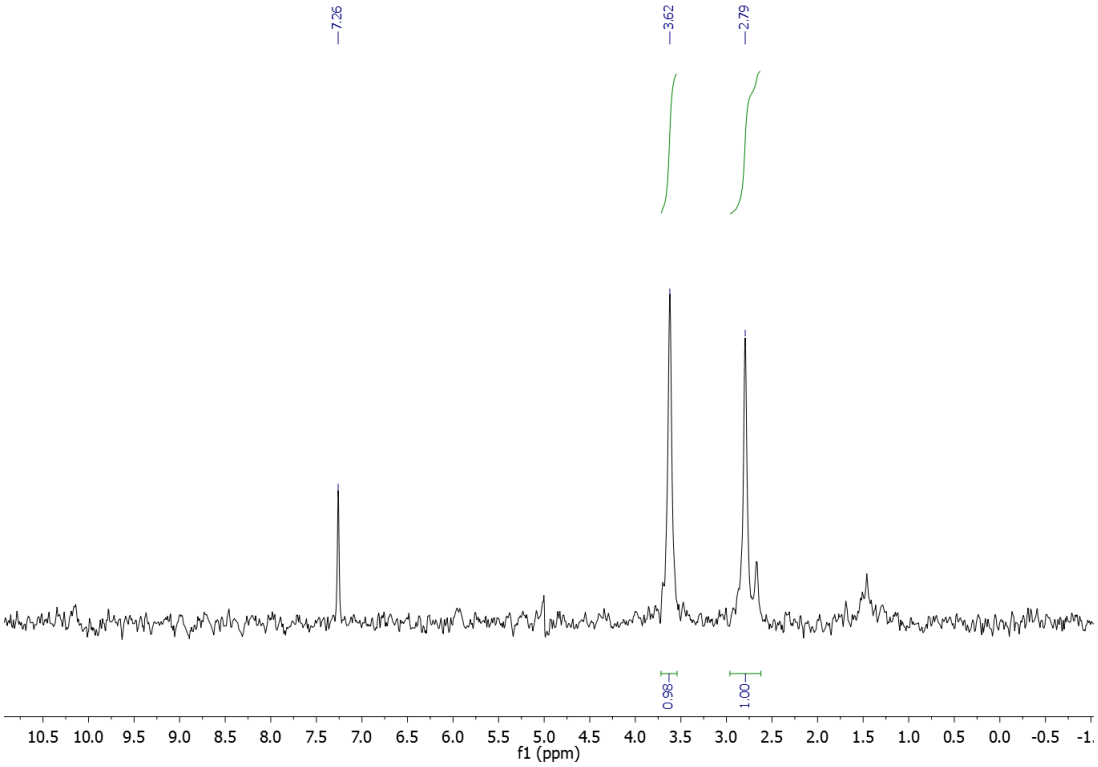


MS Spectrum Peak List

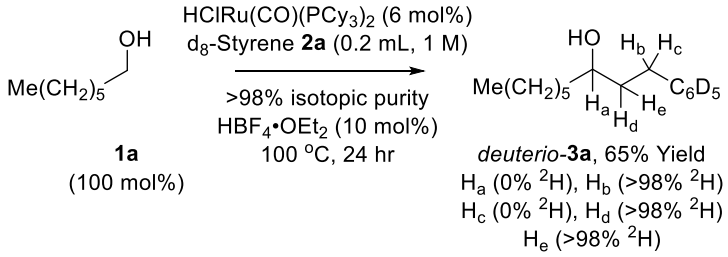
Obs. m/z	Calc. m/z	Charge	Abund	Formula	Ion/Isotope	Tgt Mass Error (ppm)
245.18500	245.18450	1	604815.1	C15H22D2O	(M+Na)+	2.07
246.18960	246.18790	1	180698.37	C15H22D2O	(M+Na)+	6.89
261.14950		1	116558.7			
307.15560		1	415395.29			
308.16010		1	127644.09			
323.12850		1	89002.26			
419.31590		1	98135.17			
441.29830		1	482678.6			
442.30110		1	126728.54			
457.27570		1	139965.61			

--- End Of Report ---


2.03
3.00
0.03
0.20
0.79
2.00
11.04
3.02
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1
f1 (ppm)


7.26
3.62
2.79
0.98
1.00
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.
f1 (ppm)

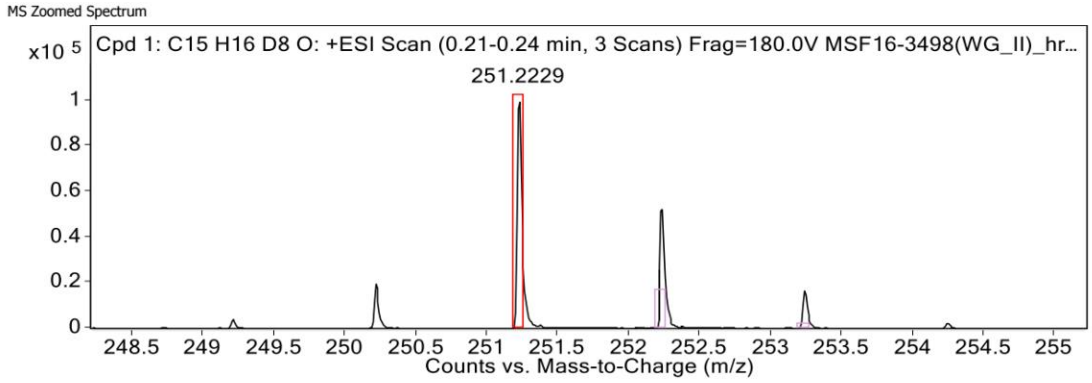
3. Deuterium labelling studies of 1a with d8-Styrene:



^{1}H NMR (400 MHz, $CDCl_3$): δ 3.61 (s, 1H), 2.76 (s, 0.79H), 2.65 (d, *J*=13.4 Hz, 0.21H), 1.52–1.17 (m, 11H), 0.95–0.82 (m, 3H).

^{2}H NMR (92 MHz, CH_2Cl_2): δ 7.30 (d, *J*=7.3 Hz, 5H), 2.73 (d, *J*=11.0 Hz, 1H), 1.75 (d, *J*=5.1 Hz, 2H).

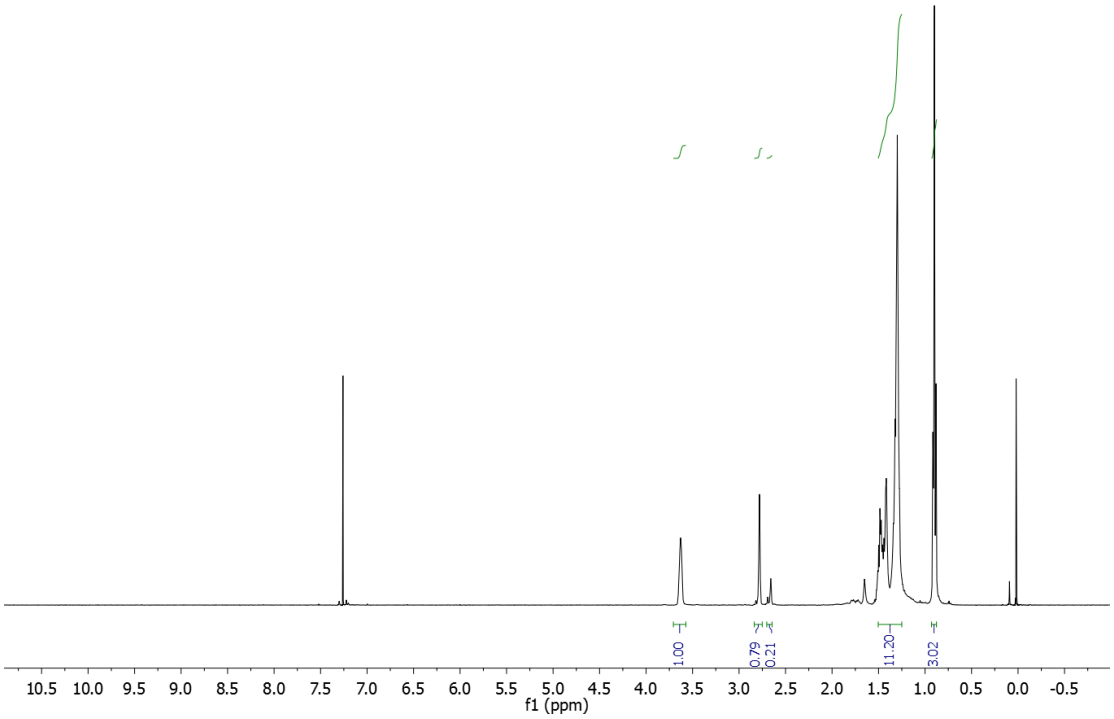
HRMS (ESI): Calcd. For $C_{15}H_{16}D_8NaO$ $[M+Na]^+$ 251.2222, Found 251.2229.

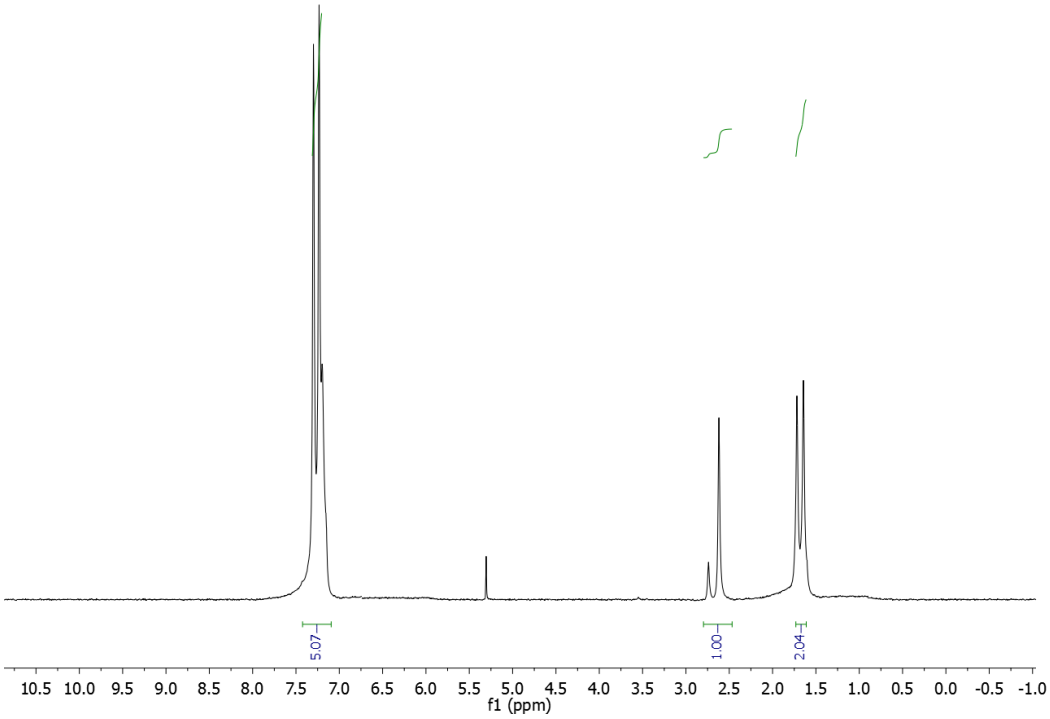


MS Spectrum Peak List

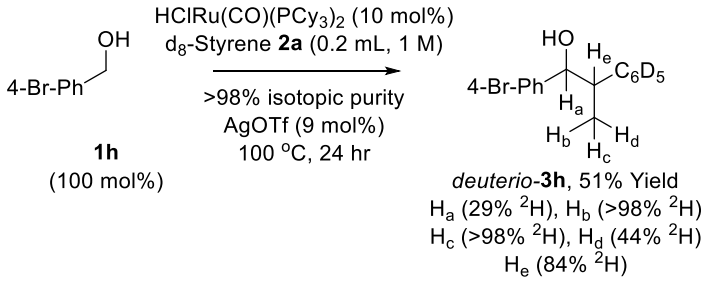
Obs. m/z	Calc. m/z	Charge	Abund	Formula	Ion/Isotope	Tgt Mass Error (ppm)
251.22290	251.22220	1	102132.51	C15H16D8O	(M+Na)+	-3.05
297.23520			163056.72			

--- End Of Report ---


1.00
0.79
0.21
11.20
3.02
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)


5.07
1.00
2.04
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
f1 (ppm)

3. Deuterium labelling studies of 1h with d8-Styrene:

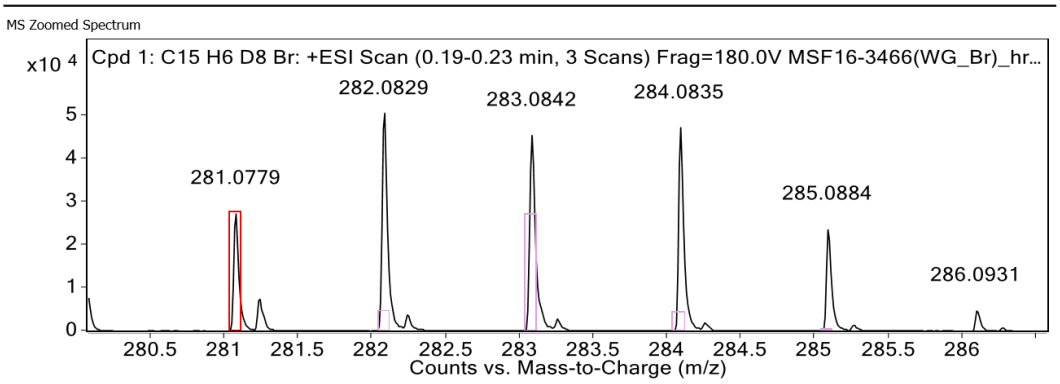


Spectrum of *deuterio*-1.3h

^{1}H NMR (400 MHz, $CDCl_3$) for the 1:1 mixture of diastereomers: δ 7.48–7.43 (m, 1H), 7.39–7.33 (m, 1H), 7.21–7.15 (m, 1H), 7.05–7.01 (m, 1H), 4.65 (dd, *J*=47.5, 2.9 Hz, 0.56H), 2.97 (dd, *J*=34.9, 5.6 Hz, 0.15H), 2.12–1.81 (m, 1H), 1.38–0.96 (m, 0.73H).

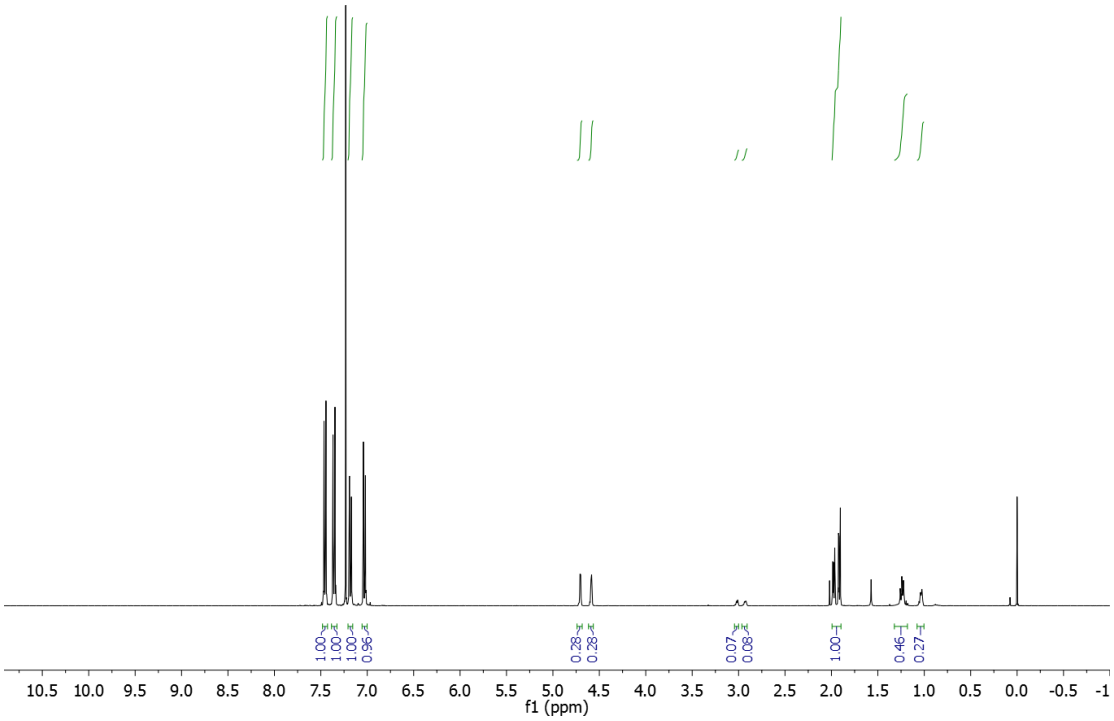
^{2}H NMR (92 MHz, CH_2Cl_2) for the 1:1 mixture of diastereomers: δ 7.27 (dd, *J*=13.1, 6.4 Hz, 5H), 4.68 (d, *J*=9.6 Hz, 0.44H), 2.98 (d, *J*=7.8 Hz, 0.84H), 1.15 (dd, *J*=19.4, 1.7 Hz, 2.29H).

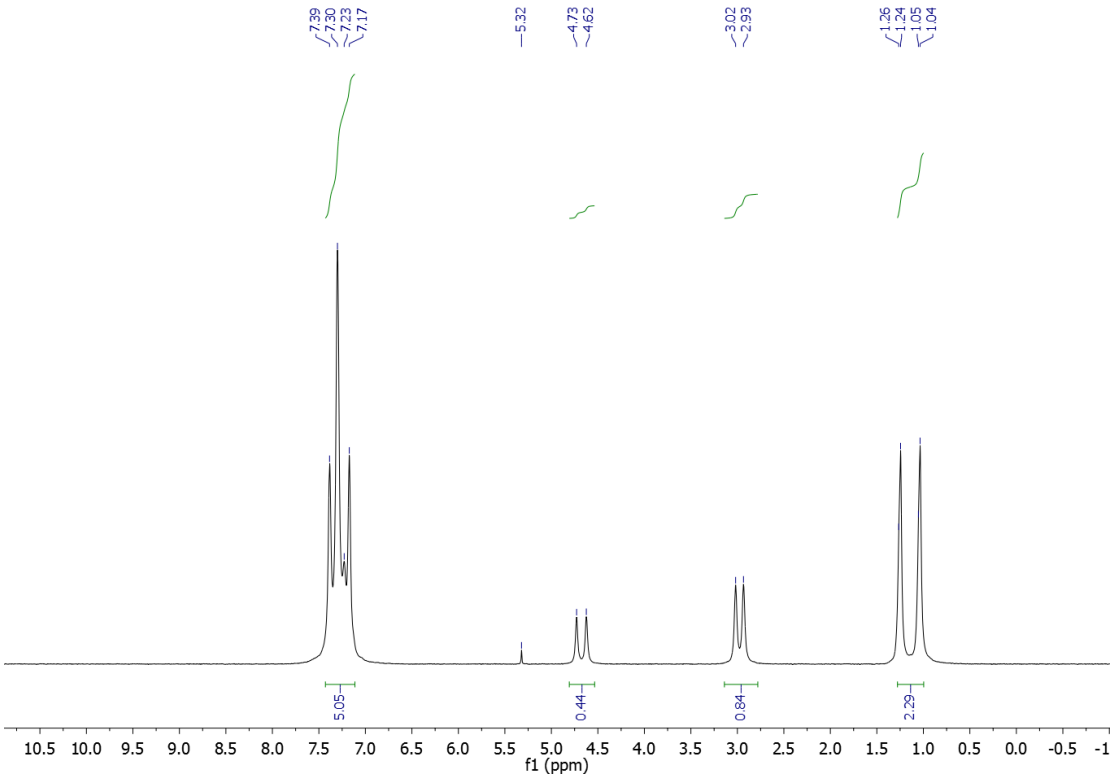
HRMS (ESI): Calcd. For $C_{15}H_6D_8Br$ $[M\text{-}OH]^+$ 281.0776, Found 281.0779.



MS Spectrum Peak List

Obs. m/z	Calc. m/z	Charge	Abund	Formula	Ion/Isotope	Tgt Mass Error (ppm)
281.07790	281.07760		27498.22	C15H6D8Br	M+	1.37
282.08290			51298.98			
283.08420			45451.28			
284.08350			47169.41			
285.08840		1	24156.47			
297.23550		1	21168.97			
322.07550			15316.43			
323.07640			13439.55			
324.07590			14006.07			
441.29900		1	15010.25			

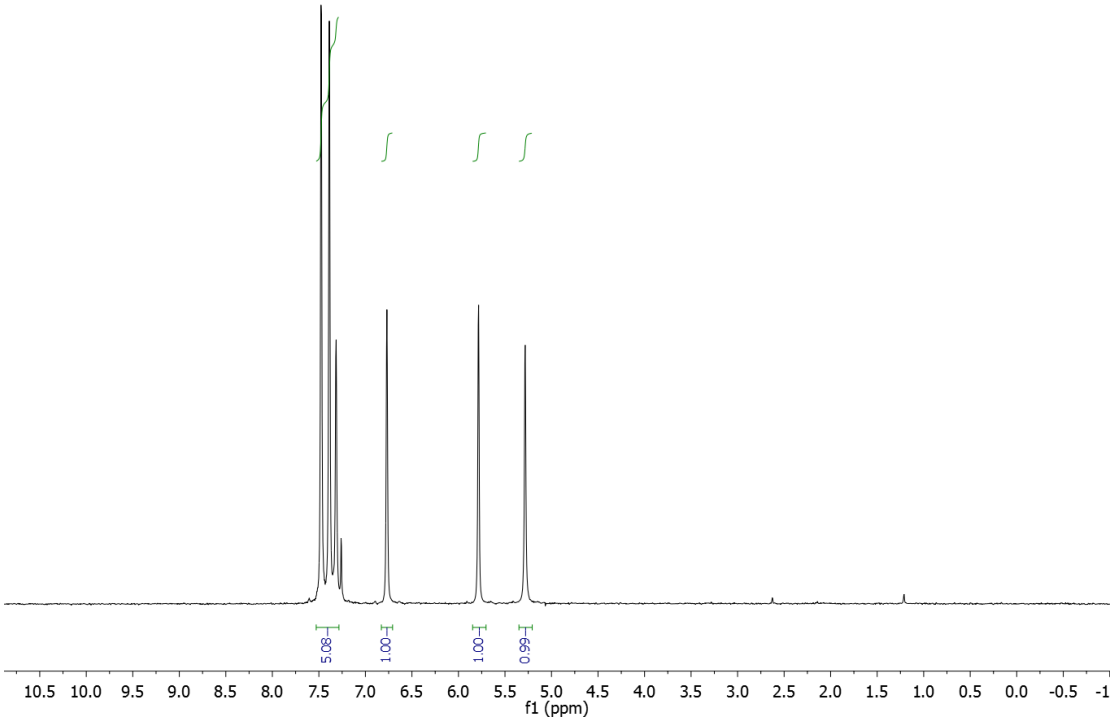

1.00
1.00
1.00
0.96
0.28
0.28
0.07
0.08
1.00
0.46
0.27
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1
f1 (ppm)


7.39
7.30
7.23
7.17
5.32
4.73
4.62
3.02
2.93
1.26
1.24
1.05
1.04
5.05
0.44
0.84
2.29
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1
f1 (ppm)

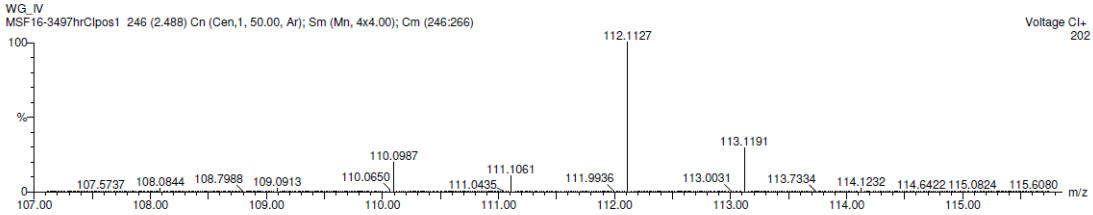
Spectrum of recovered styrene

^{2}H NMR (92 MHz, $CHCl_3$) δ 7.64–7.27 (m, 5H), 6.77 (s, 1H), 5.78 (s, 1H), 5.28 (s, 1H).

HRMS (CI): Calcd. For C_8D_8 M^+ 112.1128, Found 112.1127.



Monoisotopic Mass, Odd and Even Electron Ions
151 formula(e) evaluated with 2 results within limits (all results (up to 1000) for each mass)
Elements Used:
C: 0-100 1H: 0-100 2H: 6-8
WG_IV
MSF16-3497hrClpos1 246 (2.488) Cn (Cen,1, 50.00, Ar); Sm (Mn, 4x4.00); Cm (246:266)

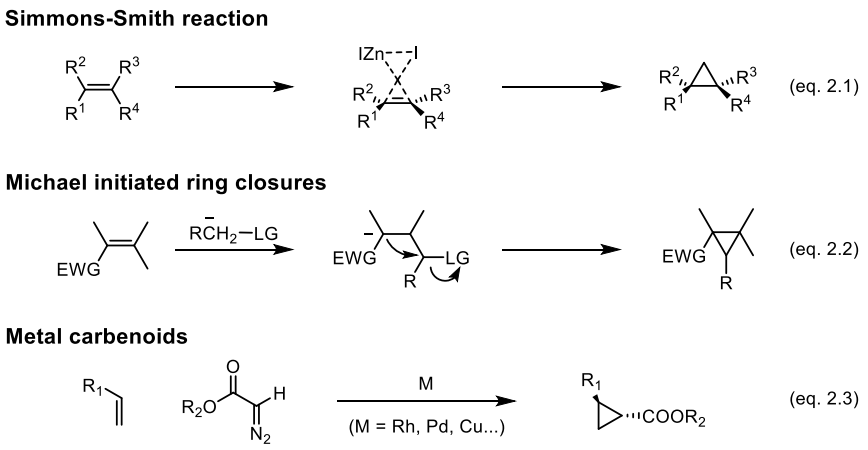


Minimum:	15.00				-1.5		
Maximum:	100.00		5.0	10.0	50.0		
Mass	RA	Calc. Mass	mDa	PPM	DBE	i-FIT	Formula
110.0987	19.25	110.0987	0.0	0.0	5.5	225786.8	C8 2H7
112.1127	100.00	112.1128	-0.1	-0.9	5.0	1628386.4	C8 2H8

Chapter 2: Nickel Catalyzed Cross-Coupling of Vinyl-Dioxanones to Form Enantiomerically Enriched Cyclopropanes*

2.1 INTRODUCTION

Since (+)-*trans*-chrysanthemic acid was discovered by Staudinger and Ruzicka in 1924,[1] a large number of cyclopropane-containing secondary metabolites have been isolated from fungi, plants, marine organisms, and microorganisms.[2] Those compounds, which contain the cyclopropane subunits, usually show diverse biological properties, including antifungal, antibiotic, anticancer, *etc*.[3] To enable synthetic access to these target molecules, chemical research has focused on the development of the efficient methods of generating cyclopropanes from a wide range of intermediates.



Scheme 2.1 General methods to synthesize the cyclopropane ring.

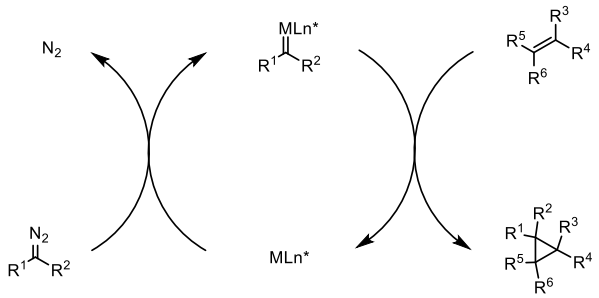
In 1958, H. E. Simmons and R. D. Smith at DuPont discovered that the reaction of alkenes with diiodomethane in the presence of activated zinc afforded cyclopropanes in high yields (eq. 2.1).[5] The synthetic utility of this method derives mainly from the broad substrate generality and the tolerance of various functional groups. However, most of the asymmetric version of this reaction must be conducted employing the chiral

*This chapter is partially based on the previously published work:
Guo, Y.; Liang, T.; Kim, S.; Xiao, H.; Krische, M. J. *J. Am. Chem. Soc.* **2017**, *139*, 6847–6850. Hongde accomplished three substrates in Table 2.1, two substrates in Table 2.2 and one substrate in Table 2.3.

auxiliaries[6] or stochiometric chiral catalysts[7], both of which are undesirable in the synthetic process.

Michael-initiated ring-closing (MIRC) reaction is also a common used method for constructing cyclopropane rings (eq. 2.2).[16] This kind of reactions involves a conjugate addition to an electrophilic alkene to deliver an enolate, which then undergoes an intramolecular ring closure to produce the cyclopropane. For this method, asymmetric induction is usually obtained through chiral auxiliaries linked to the electrophilic moiety.[17]

Since the pioneering work of Nozaki and Noyori in 1966, the transition-metal-catalyzed decomposition of diazoalkenes has emerged as one of the most direct and efficient routes to construct the cyclopropane rings (eq. 2.3).[8] Based on the chiral ligands, numerous enantioselective transformations have been achieved since the 1990s.[9]

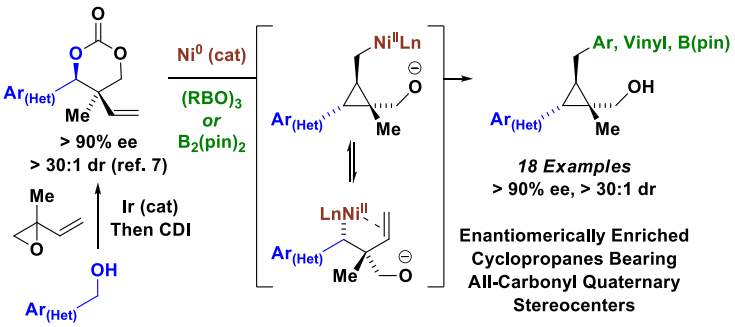


Scheme 2.2 Proposed mechanism for transition-metal-catalyzed cyclopropanation by decomposition of diazoalkanes.

The widely accepted mechanism is shown in Scheme 2.2.[10] Interaction of the catalyst with the diazo precursor to afford a metallocarbene complex was followed by transfer of the carbene species to the alkene. Enantioselectivity could be achieved using chiral ligands. Various metals, such as copper[11], cobalt[12], rhodium[13], ruthenium[14], etc.[15], have been employed as the catalysts to explore the efficient transformations.

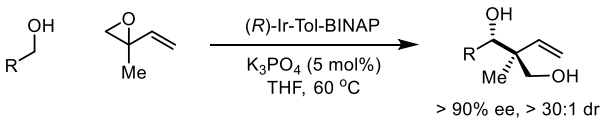
Here, we developed a strategy for asymmetric construction of cyclopropanes (Scheme 2.3). In the presence of phosphine ligand, the nickel(0) catalyst react with enantiomerically enriched 3-aryl-4-vinyl-1,3-dioxanones to form

(cyclopropylcarbinyl)nickel(II) species, which then couples with organoboron reagents to generate the cyclopropane in a stereospecific way.[16] In this way, the enantioselective synthesis of tetra-substituted cyclopropanes bearing all-carbon quaternary stereocenters is achieved.



Scheme 2.3 Nickel Catalyzed Cross-Coupling of Vinyl-Dioxanones to Form Enantiomerically Enriched Cyclopropanes.

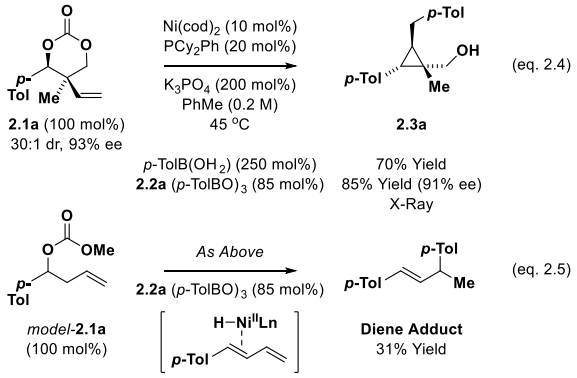
As for the step generating cyclopropane ring, no chiral ligand or chiral auxiliary was employed and asymmetric product could be obtained. The enantioselectivity origin from the first *tert*-(hydroxy)-prenylation step, which connects the ongoing investigations into the formation of C-C bonds via hydrogenation and transfer hydrogenation (scheme 2.4).[17]



Scheme 2.4 Iridium catalyzed *tert*-(hydroxy)-prenylation mediated by transfer hydrogenation.

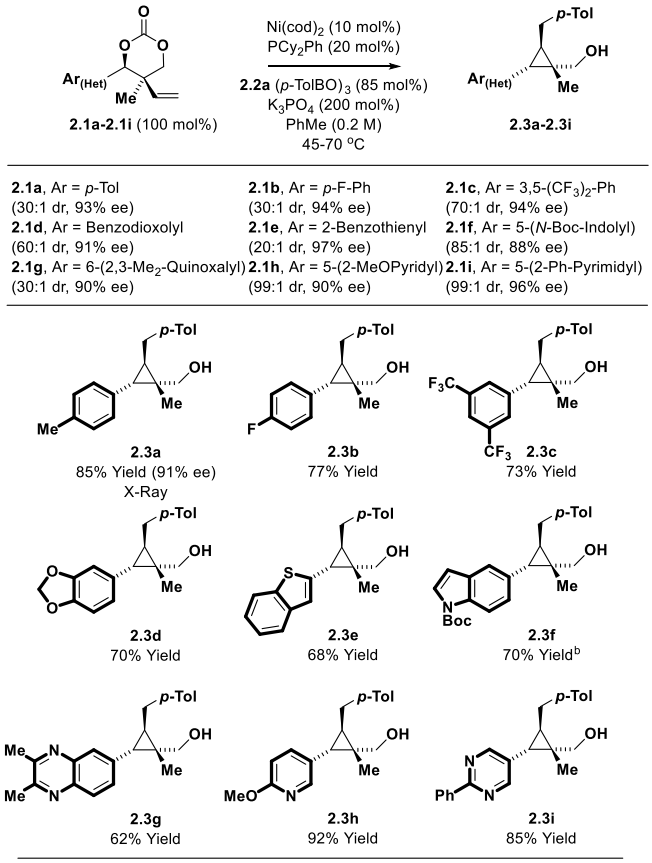
2.2 Reaction Development and Scope

We started from exposure of vinyl-dioxanone **2.1a** to the catalyst derived from $Ni(cod)_2$ (10 mol%) and ligand PCy_3 (20 mol%) in the presence of tri(*p*-tolyl)boroxine **2.2a** and K_3PO_4 (200 mol%) in toluene (0.1 M) at 60 °C. This condition gave the cyclopropane **2.3a** in 36% yield as a single diastereomer. By lowering the temperature to 45 °C, without changing any other conditions, the yield increased to 53%. Upon changing the ligand to PCy_2Ph (20 mol%), cyclopropane **2.3a** was isolated in 77% yield. Finally, a higher concentration (toluene, 0.2 M) enables an 85% yield of cyclopropane **2.3a**.



Scheme 2.5 Optimization of reaction conditions to Nickel Catalyzed Cross-Coupling of Vinyl-Dioxanones to Form Enantiomerically Enriched Cyclopropanes.

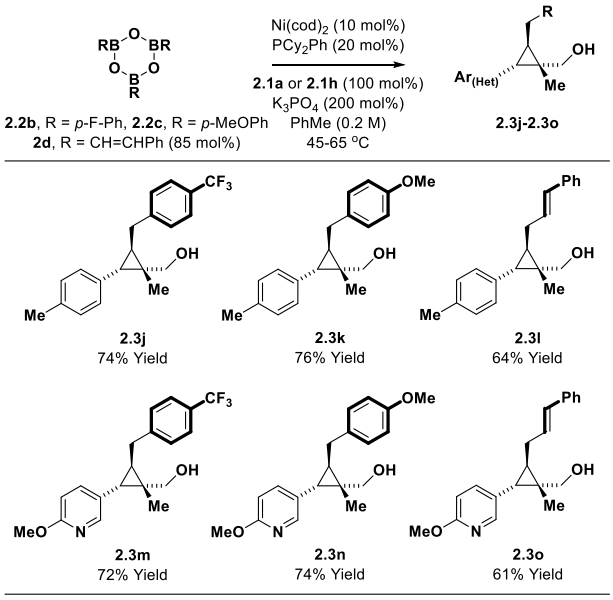
As an alternation to tri(*p*-tolyl)boroxine **2.2a**, *p*-Tolylboronic acid also gives cyclopropane **2.3a** (eq. 2.4), but in slightly lower yield. The 91% enantiomeric excess of cyclopropane **2.3a** corroborates a stereospecific process.[16] Single crystal X-ray diffraction analysis was employed to determine the relative stereochemistry of cyclopropane **2.3a**. However, applying the optimal conditions to unsubstituted methyl carbonate *model*-**2.1a** provides none of the corresponding cyclopropane; instead, product derived upon β-hydride elimination of the σ-benzyl intermediate was formed (eq. 2.5). These results confirm the significance of the homo-benzylic all-carbon quaternary center embodied by vinyl-dioxanone **2.1a** for generating the cyclopropane structure.



[a]Yields of material isolated by silica gel chromatography. All reactions were conducted using enantiomerically enriched starting materials. See Supporting Information for further experimental details.

Table 2.1 Stereospecific nickel-catalyzed cross coupling of vinyl-dioxanones **2.1a-2.1i** with tri(*p*-tolyl)boroxine **2.2a** to form cyclopropanes **2.3a-2.3i**.[a]

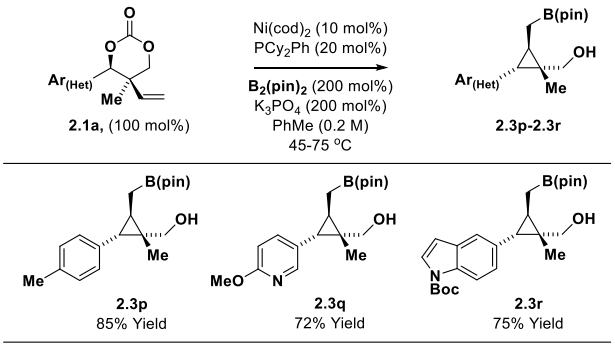
With the optimized condition in hand, the scope of this transformation was tested with diverse enantiomerically enriched vinyl-dioxanones **2.1a-2.1i** in the presence of tri(*p*-tolyl)boroxine **2.2a** (Table 2.1). Vinyl dioxanones with different substituted aromatic (**2.1a-2.1d**) and heteroaromatic (**2.1e-2.1i**) rings were transformed to the corresponding cyclopropanes **2.3a-2.3i** in good yield with complete levels of diastereoselectivity. Stereospecificity and relative stereochemistry associated with the formation cyclopropanes **2.3a-2.3i** is assigned in analogy to that determined for **2.3a** (*vide supra*). We then investigated the scope of the coupling partner boroxines **2.2b-2.2d** (Table 2.2). The corresponding cyclopropanes **2.3j-2.3o** were obtained in good yield in a completely stereopecific pathway.



[a]Yields of material isolated by silica gel chromatography. All reactions were conducted using enantiomerically enriched starting materials. See Supporting Information for further experimental details.

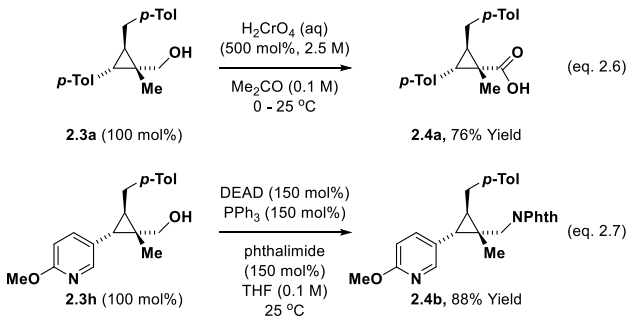
Table 2.2 Stereospecific nickel-catalyzed cross coupling of vinyl-dioxanones **2.1a** or **2.1h** with boroxines **2.2b**-**2.2d** to form cyclopropanes **2.3j**-**2.3o**.[a]

Furthermore, reactions of vinyl-dioxanones **2.1a**, **2.1h** and **2.1f** with $B_2(pin)_2$ under standard conditions generates the cyclopropylcarbinyl boronates **2.3p**-**2.3r** with good yields in a stereospecific manner (Table 2.2).[18] Variation of the boroxine along with the ability to access to cyclopropylcarbinyl boronates **2.3p**-**2.3r** greatly increases the diversity of products potentially available using this method.



[a]Yields of material isolated by silica gel chromatography. See Supporting Information for further experimental details.

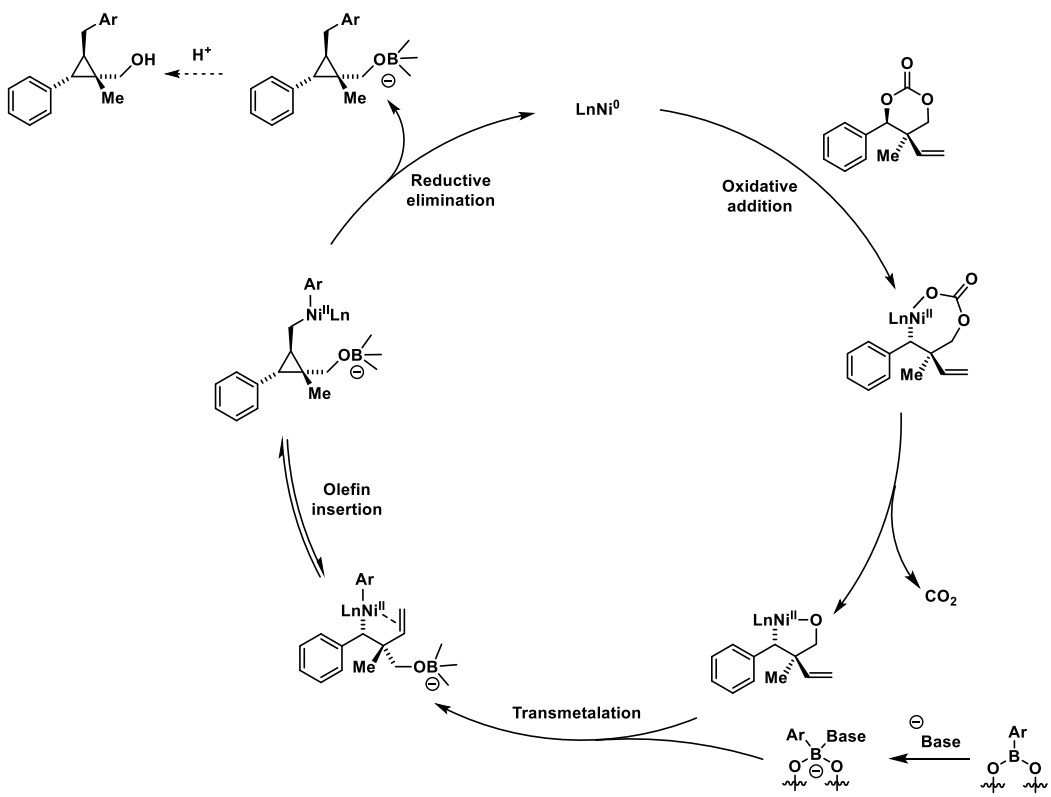
Table 2.3 Stereospecific nickel-catalyzed cross coupling of vinyl-dioxanones **2.1a**, **2.1h** or **2.1i** with $B_2(pin)_2$ to form cyclopropanes **2.3p**-**2.3r**.[a]



Scheme 2.6 Application of cyclopropane products.

The application of our cyclopropane products was also studies. As shown in eq. 2.3, Jones oxidation could deliver the cyclopropyl carboxylic acid **2.4a** in good yield from the neopentyl alcohol **2.3a**. In addition, Mitsunobu reactions transferred the cyclopropylcarbinyl alcohol **2.3h** to the amine **2.4b** in excellent yield in the presence of phthalimide (eq. 12).

2.3 Mechanism and Discussion



Scheme 2.7 General catalytic mechanism. Haptomeric equilibria are excluded for clarity.

A general mechanism for Ni-catalyzed cyclopropane formation is proposed as shown in Scheme 2.5. Oxidative addition of a nickel(0) species to the benzylic C-O bond in a stereospecific way gives the σ-benzylnickel(II) complex.[19] Decarboxylation gives the oxanickelacycle, which undergoes the transmetalation and reversible migratory insertion to deliver the (cyclopropylcarbinyl)nickel(II) complex. Finally, reductive elimination gives the cyclopropane as our final product and regenerate the nickel(0) catalyst to complete the catalytic cycle.

2.4 CONCLUSION

A new strategy for asymmetric construction of cyclopropanes was developed. In the presence of phosphine ligand, the nickel(0) catalyst react with enantiomerically enriched 3-aryl-4-vinyl-1,3-dioxanones to form (cyclopropylcarbinyl)nickel(II) species, which then couples with organoboron reagents to generate the cyclopropane in a stereospecific way. In this way, the enantioselective synthesis of tetra-substituted cyclopropanes bearing all-carbon quaternary stereocenters is achieved. The catalytic mechanism was proposed according to the collective data, involving nickel(0)-mediated benzylic oxidative addition with inversion of stereochemistry followed by reversible olefin insertion to form a (cyclopropylcarbinyl)nickel complex, which upon reductive elimination delivers the cyclopropane.

2.5 EXPERIMENT DETAILS

General Information

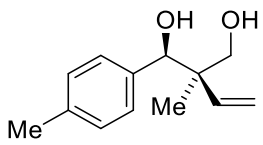
All reactions were run under an atmosphere of argon. Sealed tubes (13x100 mm) were purchased from Fischer Scientific (catalog number 14-959-35C) and were oven-dried followed by cooling in a desiccator. Tetrahydrofuran was distilled from sodium-benzophenone immediately prior to use. Ethyl Acetate was dried over potassium carbonate and distilled immediately prior to use. Anhydrous solvents were transferred by oven-dried syringes. Analytical thin-layer chromatography (TLC) was carried out using 0.25 mm commercial silica gel plates (Dynanmic Absorbents F_{254}). Visualization was accomplished with UV light followed by dipping in *p*-anisaldehyde stain solution then heating. Purification of reactions was carried out by flash chromatography using Silacycle silica gel (40-63 μm, unless indicated specifically). Potassium phosphate was purchased through Acros Organics, flame dried prior to use and stored in a desiccator. $Ni(cod)_2$ was purchased from Strem Chemicals. (*S*)-Ir-Tol-BINAP was synthesized according to literature procedures[1]. *p*-Tolyl-boroxine (**2a**)[2], 4-(trifluoromethyl)phenyl-boroxine (**2b**)[3], 4-methoxyphenyl-boroxine (**2c**)[3] and (*E*)-styryl-boroxine (**2d**)[3] were synthesized according to literature procedures.

Spectroscopy, Spectrometry, and Data Collection

Infrared spectra were recorded on a Perkin-Elmer 1600 spectrometer. Low-resolution mass spectra (HRMS) were obtained on a Karatos MS9 and are reported as m/z (relative intensity). Accurate masses are reported for the molecular ion (M, M+H, or M-H), or a suitable fragment ion. ^{1}H Nuclear magnetic resonance spectra were recorded using a 400 MHz or a 500 MHz spectrometer. Coupling constants are reported in Hertz (Hz) for $CDCl_3$ solutions, and chemical shifts are reported as parts per million (ppm) relative to residual $CHCl_3$ δ_H (7.26 ppm). ^{13}C Nuclear magnetic resonance spectra were recorded using a 100 MHz or a 125 MHz spectrometer for $CDCl_3$ solutions, and chemical shifts are reported as parts per million (ppm) relative to residual $CDCl_3$ δ_C (77.0 ppm). Fluorine-19 nuclear magnetic resonance (^{19}F NMR) spectra were recorded with a Varian Gemini 400 (100 MHz) or a Bruker 500 (125 MHz) spectrometer. Melting points were taken on a Stuart SMP3 melting point apparatus.

Procedures and Spectral Data for the Synthesis of Vinyl-Dioxanones 1a-1i:

(1*R*,2*R*)-2-methyl-1-(*p*-tolyl)-2-vinylpropane-1,3-diol (2.1a)



Detailed Procedures

An oven-dried pressure tube equipped with a magnetic stir bar was charged with K_3PO_4 (42.4 mg, 0.2 mmol, 5 mol%), (*S*)-Ir-Tol-BINAP (220 mg, 0.2 mmol, 5 mol%) and *p*-tolylmethanol (488 mg, 4.0 mmol, 100 mol%). Under an atmosphere of argon, anhydrous THF (8 mL, 0.5 M) and isoprene monoxide (1.18 mL, 12 mmol, 300 mol%) were sequentially added via syringe. After sealing the tube with cap, the reaction mixture was stirred at 45 ˚C for 24 h. The reaction was cooled to ambient temperature and concentrated *in vacuo*. The residue was subjected to flash column chromatography (SiO_2, methylene chloride: acetone = 30:1) to furnish the title compound as a yellow oil (626 mg, 3.0 mmol, *anti*:*syn* > 20:1) in 76% yield.

TLC (SiO_2) R_f = 0.30 (methylene chloride: acetone = 10:1).

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.20 – 7.07 (m, 4H), 6.03 (dd, *J* = 17.7, 11.0 Hz, 1H), 5.20 (dd, *J* = 11.0, 1.1 Hz, 1H), 5.01 (dd, *J* = 17.8, 1.2 Hz, 1H), 4.62 (s, 1H), 3.60 (d, *J* = 10.7 Hz, 1H), 3.51 (d, *J* = 10.7 Hz, 1H), 3.18 (brs, 1H), 2.90 (brs, 1H), 2.33 (s, 3H), 0.90 (s, 3H).

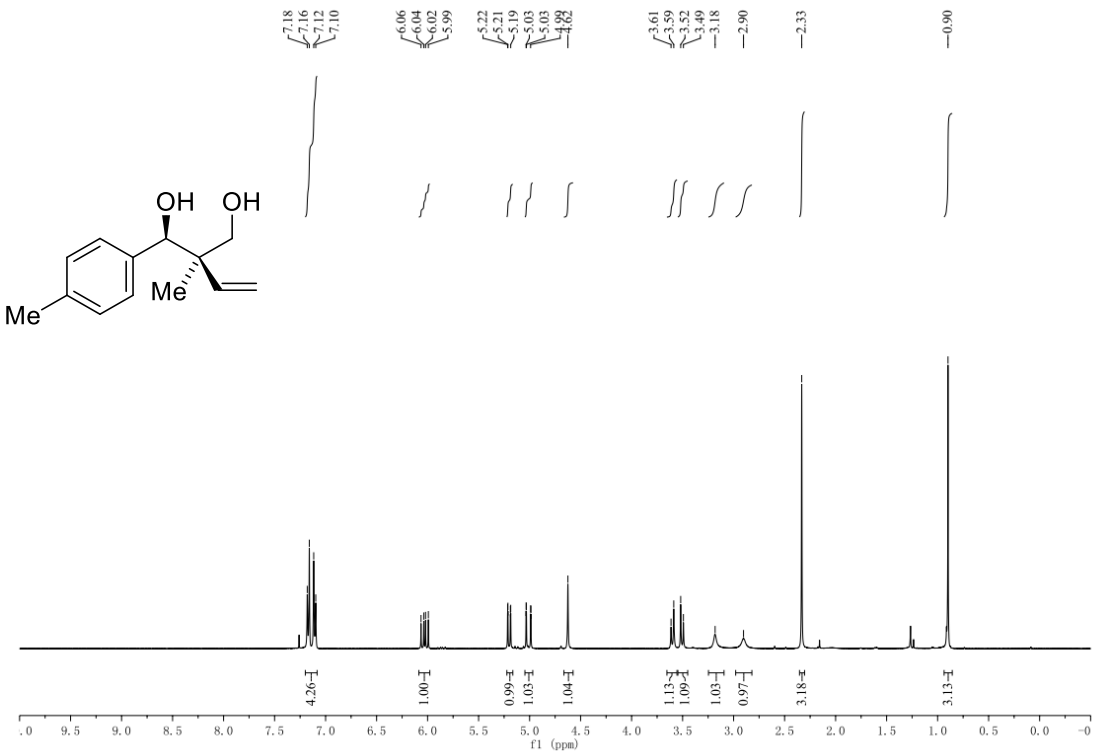
^{13}C NMR (100 MHz, $CDCl_3$) δ 139.6, 137.8, 137.2, 128.3, 127.6, 115.9, 79.9, 69.7, 46.2, 21.0, 17.8.

HRMS (ESI) Calcd. for $C_{13}H_{18}NaO_2^+$ $[M+Na]^+$: 229.1199, Found: 229.1201.

FTIR (neat): 3377, 2966, 2919, 2977, 1637, 1515, 1460, 1415, 1378, 1201, 1039, 1018, 919, 821, 678 cm^{-1}.

$[\alpha]_D^{33}$: -34.7 (*c* = 1.0, $CHCl_3$).

HPLC (two connected chiralcel OJ-H columns, hexanes:*i*-PrOH = 98:2, 0.80 mL/min, 230 nm), *anti*:*syn* = 35:1, ee = 93%.


OH
OH
Me
Me
7.18
7.16
7.12
7.10
6.06
6.04
6.02
5.99
5.22
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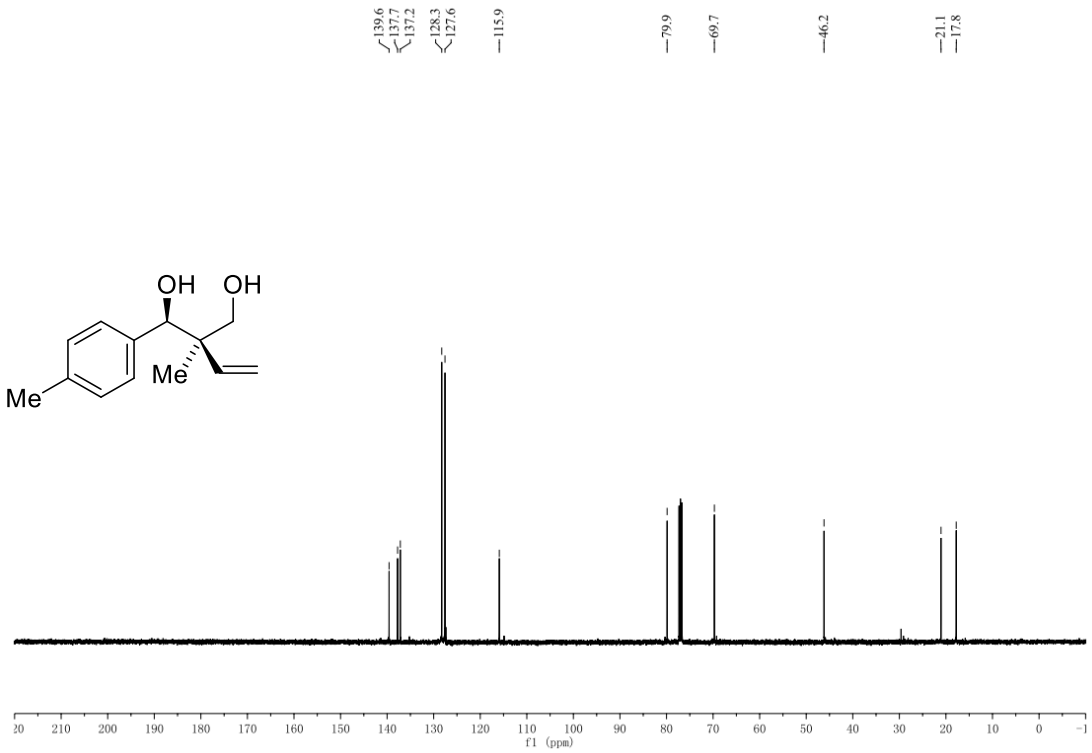
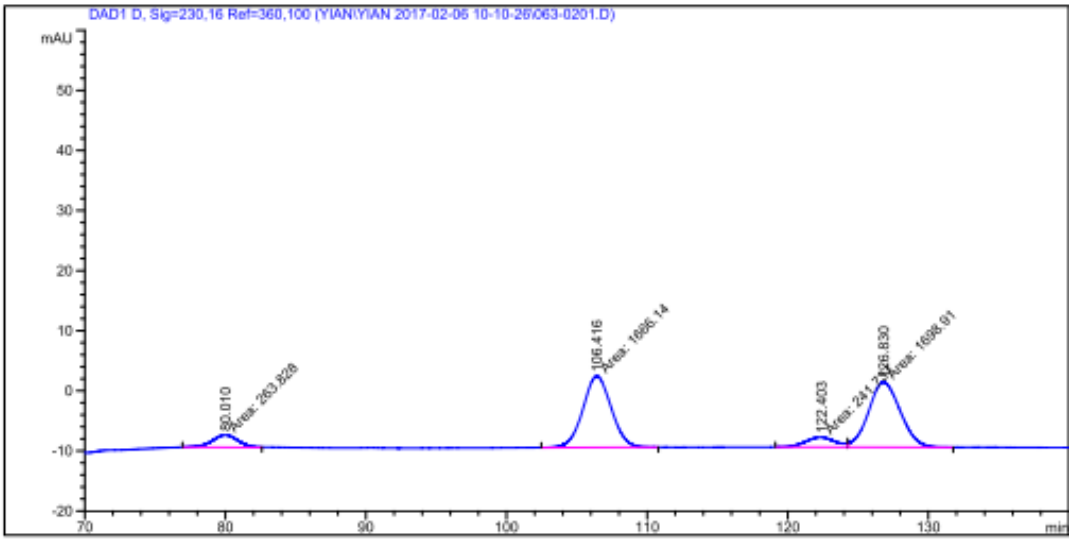
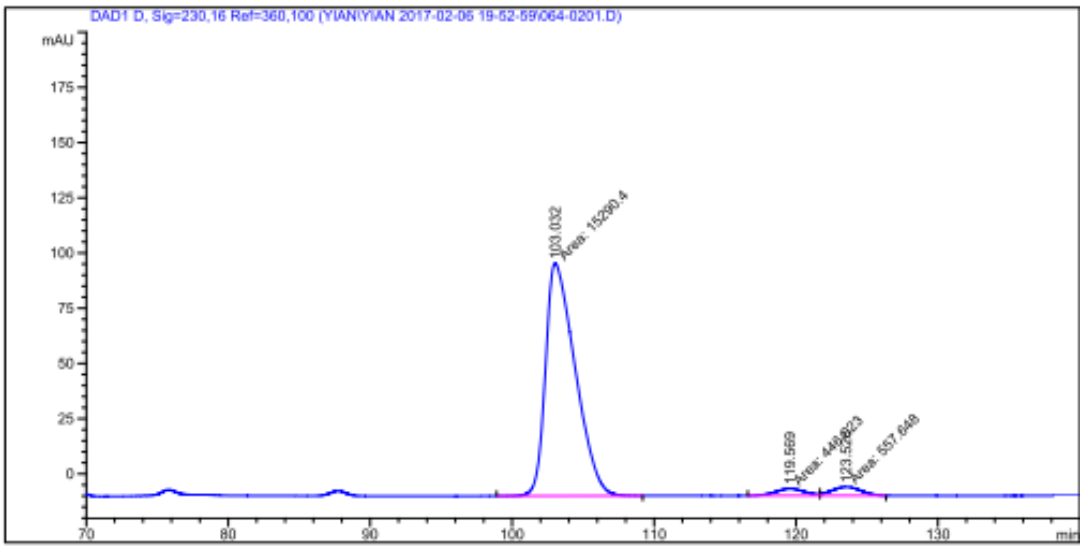
5.19
5.03
5.03
4.62
4.61
3.61
3.59
3.52
3.49
3.18
2.90
2.33
0.90
4.26
1.00
0.99
1.03
1.04
1.13
1.09
1.03
0.97
3.18
3.13
f1 (ppm)


OH
OH
Me
Me
139.6
137.7
137.2
128.3
127.6
115.9
79.9
69.7
46.2
21.1
17.8
f1 (ppm)

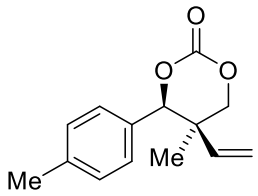


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	80.010	MM	2.1690	263.82803	2.02724	6.8162
2	106.416	MM	2.3370	1666.13733	11.88241	43.0458
3	122.403	MF	2.4703	241.73686	1.63098	6.2454
4	126.830	FM	2.6114	1698.91028	10.84294	43.8925



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	103.032	MM	2.4195	1.52904e4	105.32902	93.8403
2	119.569	MF	2.3737	446.02286	3.13167	2.7373
3	123.526	FM	2.3616	557.64777	3.93557	3.4224

(4*R*,5*R*)-5-methyl-4-(*p*-tolyl)-5-vinyl-1,3-dioxan-2-one (2.1a)



Detailed Procedures

An oven-dried vial equipped with a magnetic stir bar was charged with diol **2.1a** (50 mg, 0.24 mmol, 100 mol%). Under argon atmosphere, acetonitrile (2.4 mL, 0.1 M) was added via syringe. CDI (77.8 mg, 0.48 mmol, 200 mol%) was added in one portion at ambient temperature. The reaction mixture was stirred at 25 ˚C for 16 h. The reaction was concentrated *in vacuo*. The residue was subjected to flash column chromatography (SiO_2, hexanes: ethyl acetate = 3:1) to furnish the title compound as a white solid (46.3 mg, 0.20 mmol) in 82 % yield.

TLC (SiO_2) R_f = 0.25 (hexanes/ethyl acetate = 2:1).

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.20 – 7.12 (m, 4H), 5.65 (ddd, *J* = 17.6, 11.1, 0.8 Hz, 1H), 5.30 (d, *J* = 11.1 Hz, 1H), 5.25 (s, 1H), 5.23 (d, *J* = 17.6 Hz, 1H), 4.42 (d, *J* = 11.0 Hz, 1H), 4.30 (dd, *J* = 11.0, 0.9 Hz, 1H), 2.36 (s, 3H), 1.04 (s, 3H).

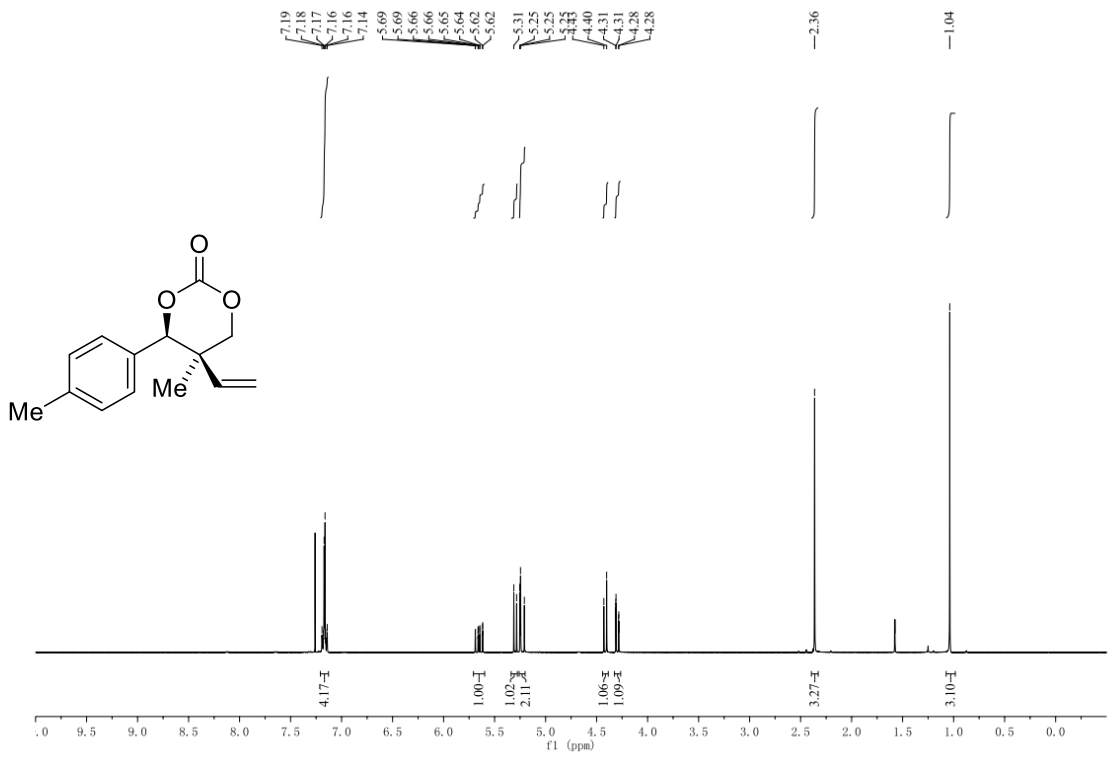
^{13}C NMR (100 MHz, $CDCl_3$) δ 148.4, 138.8, 134.4, 130.8, 128.7, 127.4, 117.8, 87.0, 75.1, 38.3, 21.2, 19.5.

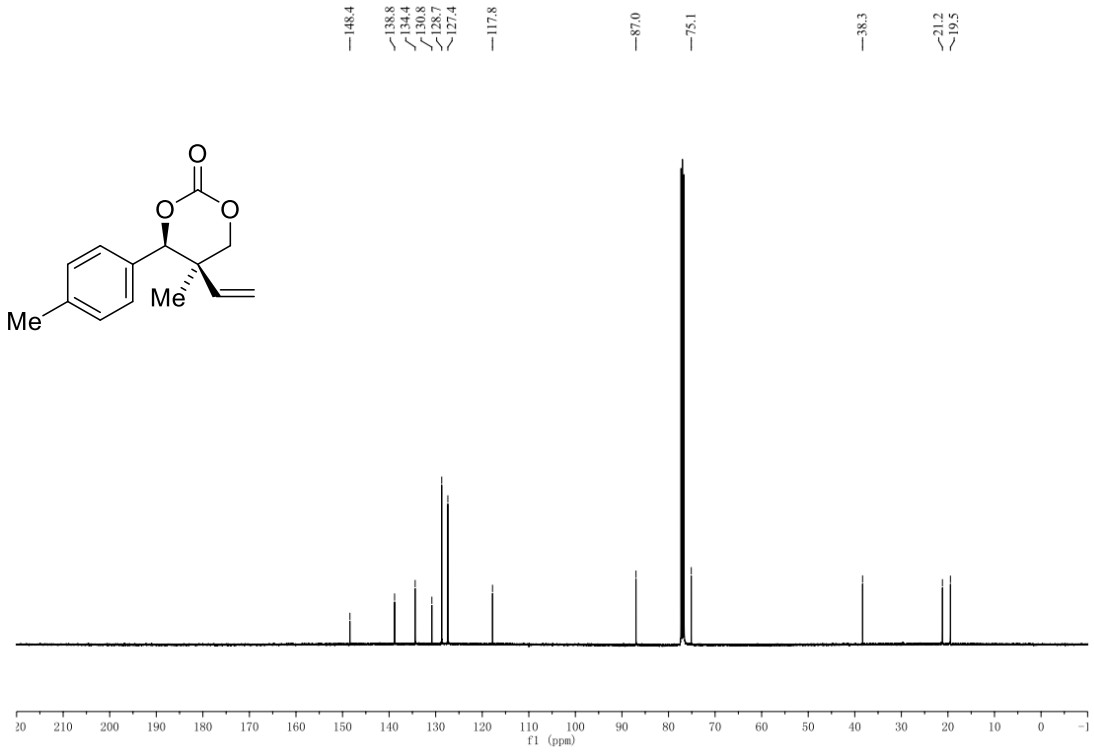
HRMS (ESI) Calcd. for $C_{14}H_{16}NaO_3^+$ $[M+Na]^+$: 255.0992, Found: 255.0994.

$[\alpha]_D^{33}$: -73.7 (*c* = 1.0, $CHCl_3$).

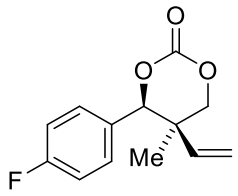
m.p. : 85-86 ˚C

FTIR (neat): 2977, 1747, 1517, 1478, 1456, 1399, 1378, 1341, 1241, 1200, 1712, 1135, 1102, 1007, 931, 819, 764, 688 cm^{-1}.


7.19
7.18
7.17
7.16
7.16
7.14
5.69
5.69
5.66
5.66
5.65
5.64
5.62
5.62
5.31
5.25
5.25
4.40
4.31
4.31
4.28
4.28
2.36
1.04
O
O
O
Me
Me
4.17
1.00
1.02
2.11
1.06
1.09
3.27
3.10
f1 (ppm)


148.4
138.8
134.4
130.8
128.7
127.4
117.8
87.0
75.1
38.3
21.2
19.5
O
O
O
Me
Me
f1 (ppm)

(4*R*,5*R*)-4-(4-fluorophenyl)-5-methyl-5-vinyl-1,3-dioxan-2-one (2.1b)



Detailed Procedures

An oven-dried vial equipped with a magnetic stir bar was charged with (1*R*,2*R*)-1-(4-fluorophenyl)-2-methyl-2-vinylpropane-1,3-diol[4] (100 mg, 0.48 mmol, 100 mol%). Under argon atmosphere, acetonitrile (4.8 mL, 0.1 M) was added via syringe. CDI (154 mg, 0.95 mmol, 200 mol%) was added in one portion at ambient temperature. The reaction mixture was stirred at 25 ˚C for 16 h. The reaction was concentrated *in vacuo*. The residue was subjected to flash column chromatography (SiO_2, hexanes: ethyl acetate = 3:1) to furnish the title compound as a white solid (90.7 mg, 0.38 mmol) in 81 % yield.

TLC (SiO_2) R_f = 0.23 (hexanes/ethyl acetate = 2:1).

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.28 – 7.23 (m, 2H), 7.10 – 7.03 (m, 2H), 5.64 (ddd, *J* = 17.6, 11.0, 0.7 Hz, 1H), 5.32 (d, *J* = 11.1 Hz, 1H), 5.28 (s, 1H), 5.22 (d, *J* = 17.6 Hz, 1H), 4.40 (d, *J* = 11.0 Hz, 1H), 4.33 (dd, *J* = 11.0, 0.8 Hz, 1H), 1.02 (s, 3H).

^{13}C NMR (100 MHz, $CDCl_3$) δ 162.9 (d, *J* = 248.3 Hz), 148.1, 133.9, 129.6 (d, *J* = 3.2 Hz), 129.3 (d, *J* = 8.3 Hz), 118.2, 115.1 (d, *J* = 21.7 Hz), 86.3, 75.2, 38.3, 19.2.

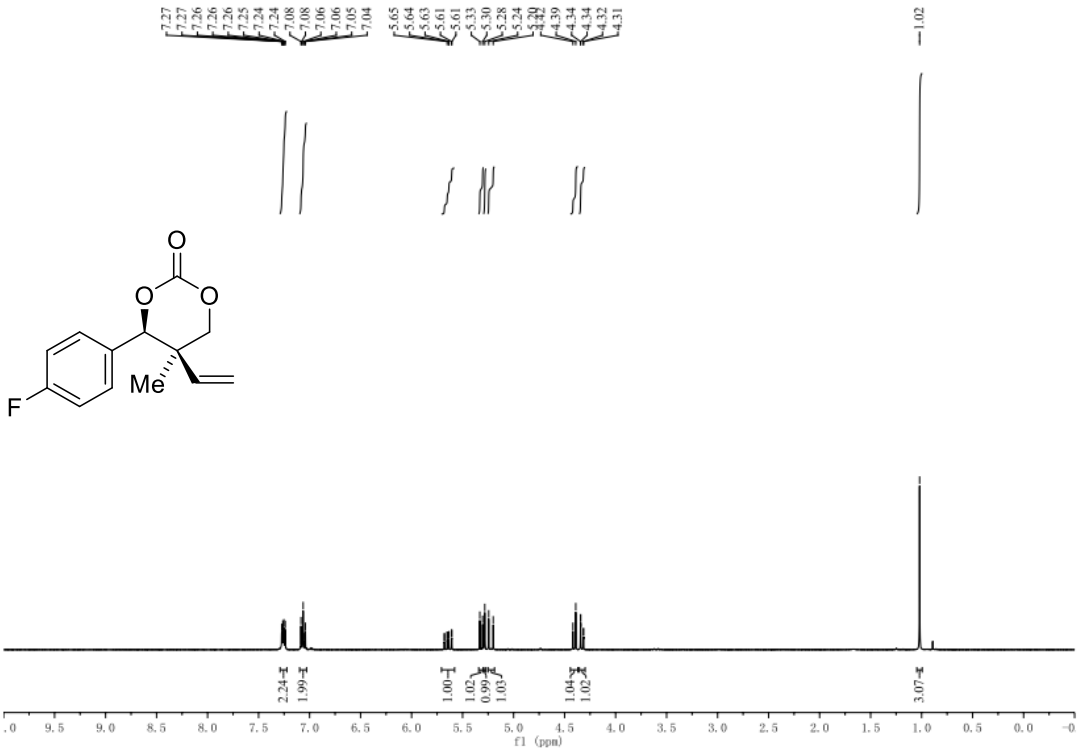
^{19}F NMR (376 MHz, $CDCl_3$) δ -112.4 (tt, *J* = 8.6, 5.2 Hz).

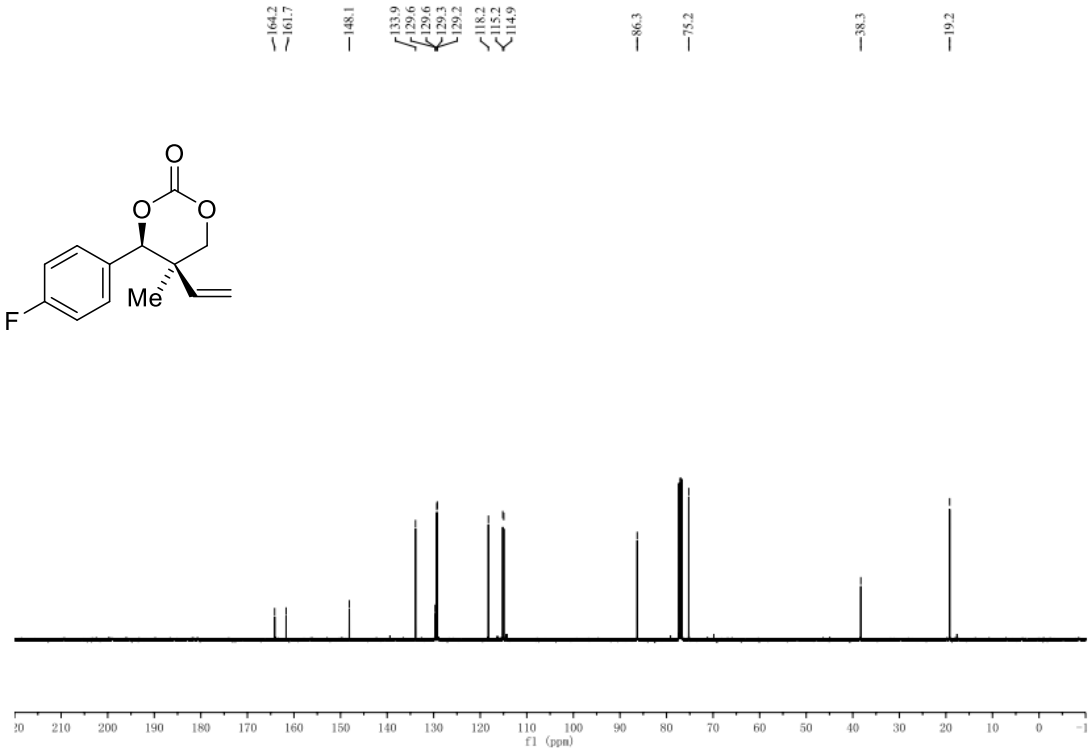
HRMS (ESI) Calcd. for $C_{13}H_{13}FNaO_3^+$ $[M+Na]^+$: 259.0741, Found: 259.0744.

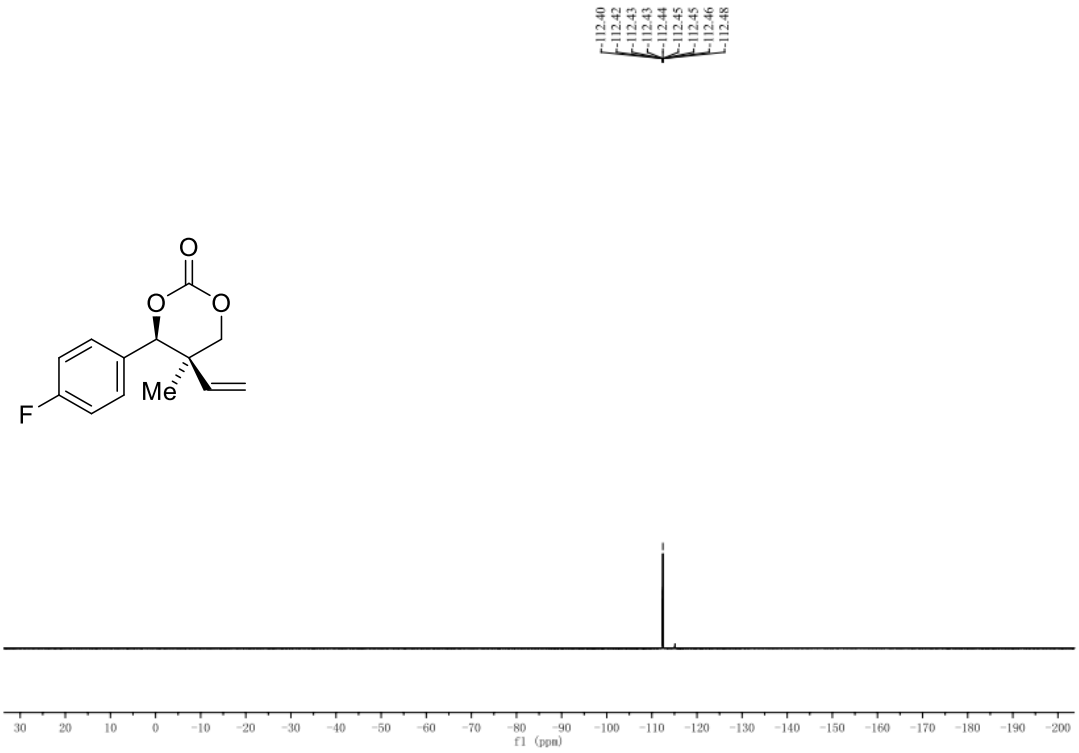
$[\alpha]_D^{33}$: -46.0 (*c* = 1.0, $CHCl_3$).

m.p. : 108-109 ˚C

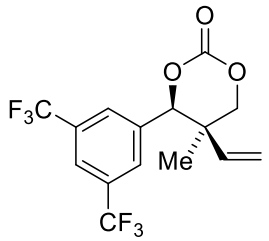
FTIR (neat): 2977, 1748, 1608, 1512, 1480, 1456, 1378, 1228, 1203, 1174, 1134, 1098, 929, 832, 769 cm^{-1}.


7.27
7.27
7.26
7.26
7.26
7.26
7.25
7.24
7.24
7.08
7.08
7.06
7.06
7.06
7.05
7.04
5.65
5.64
5.63
5.61
5.61
5.33
5.30
5.28
5.24
4.39
4.34
4.34
4.32
4.31
1.02
O
O
O
Me
F
2.24
1.99
1.00
1.02
0.99
1.03
1.04
1.02
3.07
f1 (ppm)


164.2
161.7
148.1
133.9
129.6
129.6
129.3
129.2
118.2
115.2
114.9
86.3
75.2
38.3
19.2
O
O
O
Me
F
f1 (ppm)


-112.40
-112.42
-112.43
-112.43
-112.44
-112.45
-112.45
-112.46
-112.48
O
O
O
Me
F
30 20 10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90 -100 -110 -120 -130 -140 -150 -160 -170 -180 -190 -200
f1 (ppm)

(4*R*,5*R*)-4-(3,5-bis(trifluoromethyl)phenyl)-5-methyl-5-vinyl-1,3-dioxan-2-one (2.1c)



Detailed Procedures

An oven-dried vial equipped with a magnetic stir bar was charged with (1*R*,2*R*)-1-(3,5-bis(trifluoromethyl)phenyl)-2-methyl-2-vinylpropane-1,3-diol[4] (164 mg, 0.5 mmol, 100 mol%). Under argon atmosphere, acetonitrile (5 mL, 0.1 M) was added via syringe. CDI (81 mg, 0.5 mmol, 100 mol%) was added in one portion at ambient temperature. The reaction mixture was stirred at 25 ˚C for 16 h. The reaction was concentrated *in vacuo*. The residue was subjected to flash column chromatography (SiO_2, hexanes: ethyl acetate = 3:1) to furnish the title compound as a white solid (115 mg, 0.32 mmol) in 65% yield.

TLC (SiO_2) R_f = 0.23 (hexanes/ethyl acetate = 2:1).

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.92 (s, 1H), 7.74 (d, *J* = 1.5 Hz, 2H), 5.65 (dd, *J* = 17.5, 11.0 Hz, 1H), 5.52 – 5.34 (m, 2H), 5.22 (d, *J* = 17.5 Hz, 1H), 4.55 – 4.18 (m, 2H), 1.07 (s, 3H).

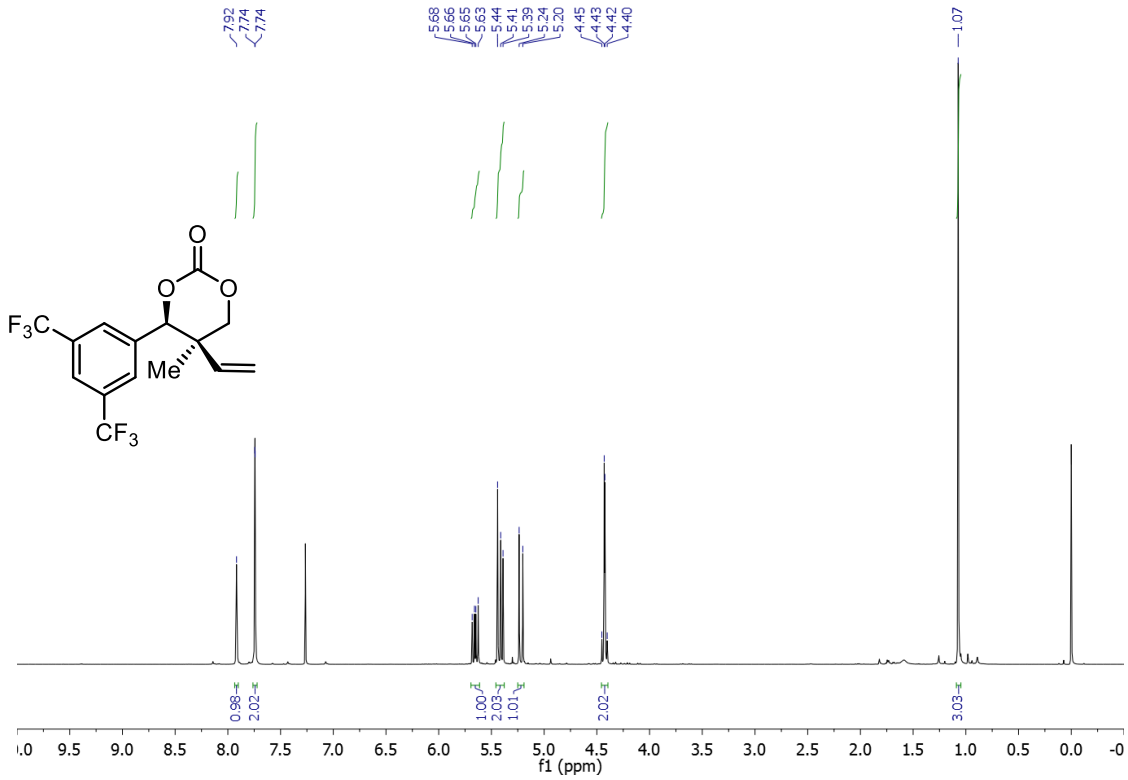
^{13}C NMR (125 MHz, $CDCl_3$) δ 147.3, 136.4, 132.6, 131.6 (q, *J* = 33.8 Hz), 127.6 (d, *J* = 4.1 Hz), 124.0, 123.3 – 122.7 (m), 121.8, 119.6, 85.4.

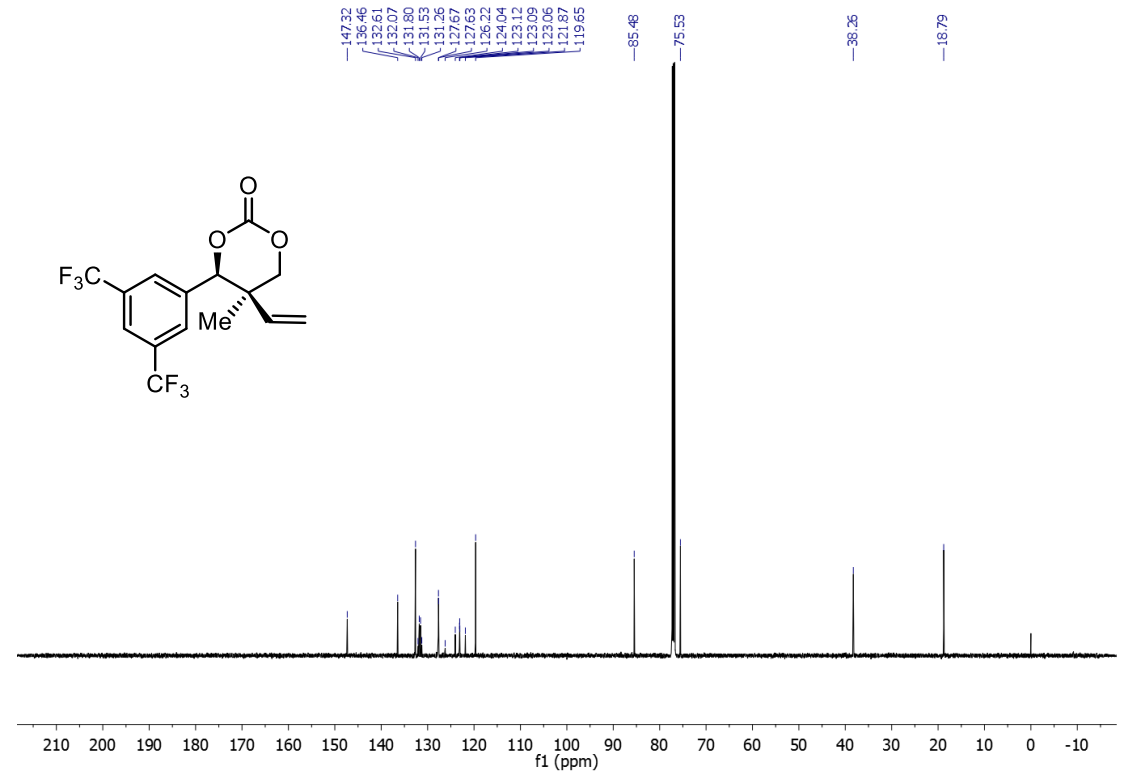
HRMS (ESI) Calcd. for $C_{15}H_{12}F_6NaO_3^+$ $[M+Na]^+$: 377.0583, Found: 377.0590.

$[\alpha]_D^{31}$: -44.0 (*c* = 1.0, $CHCl_3$).

m.p. : 61-62˚C

FTIR (neat): 2977, 1744, 1467, 1402, 1276, 1225, 1167, 1126, 1104, 1000, 904, 759, 681 cm^{-1}.


7.92
7.74
7.74
5.68
5.66
5.65
5.63
5.44
5.41
5.39
5.24
5.20
4.45
4.43
4.42
4.40
1.07
O
O
O
F3C
Me
CF3
0.98
2.02
1.00
2.03
1.01
2.02
3.03
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0
f1 (ppm)


147.32
136.46
132.61
132.07
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131.53
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127.63
126.22
124.04
123.12
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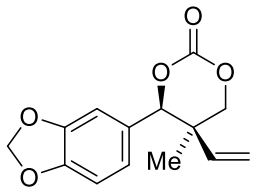
123.06
121.87
119.65
85.48
75.53
38.26
18.79
O
O
O
F3C
Me
CF3
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)

(4*R*,5*R*)-4-(benzo[*d*][1,3]dioxol-5-yl)-5-methyl-5-vinyl-1,3-dioxan-2-one (2.1d)



Detailed Procedures

An oven-dried vial equipped with a magnetic stir bar was charged with (1*R*,2*R*)-1-(benzo[*d*][1,3]dioxol-5-yl)-2-methyl-2-vinylpropane-1,3-diol[1] (90 mg, 0.38 mmol, 100 mol%). Under argon atmosphere, acetonitrile (3.8 mL, 0.1 M) was added via syringe. CDI (124 mg, 0.76 mmol, 200 mol%) was added in one portion at ambient temperature. The reaction mixture was stirred at 25 ˚C for 16 h. The reaction was concentrated *in vacuo*. The residue was subjected to flash column chromatography (SiO_2, hexanes: ethyl acetate = 2:1) to furnish the title compound as a white solid (99.6 mg, 0.32 mmol) in 84 % yield.

TLC (SiO_2) R_f = 0.20 (hexanes/ethyl acetate = 2:1).

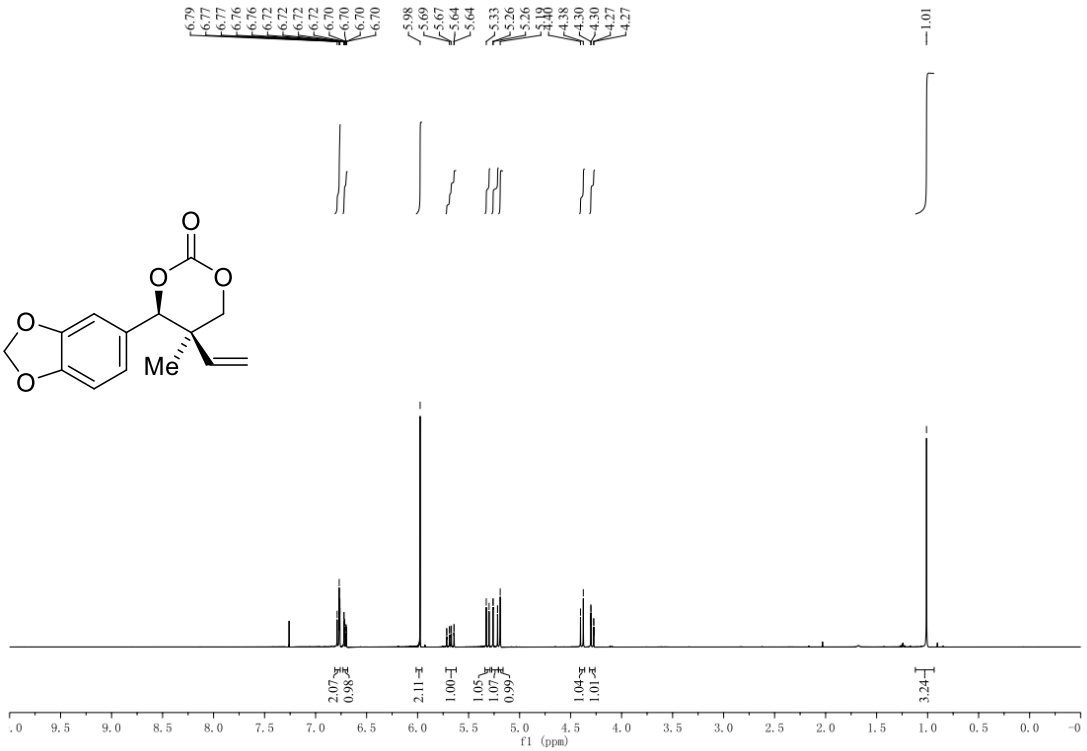
^{1}H NMR (400 MHz, $CDCl_3$) δ 6.80 – 6.75 (m, 2H), 6.71 (ddd, *J* = 8.0, 1.8, 0.5 Hz, 1H), 5.98 (s, 2H), 5.68 (ddd, *J* = 17.6, 11.1, 0.9 Hz, 1H), 5.31 (d, *J* = 11.0 Hz, 1H), 5.24 (d, *J* = 17.6 Hz, 1H), 5.19 (s, 1H), 4.39 (d, *J* = 11.0 Hz, 1H), 4.29 (dd, *J* = 11.0, 0.9 Hz, 1H), 1.01 (s, 3H).

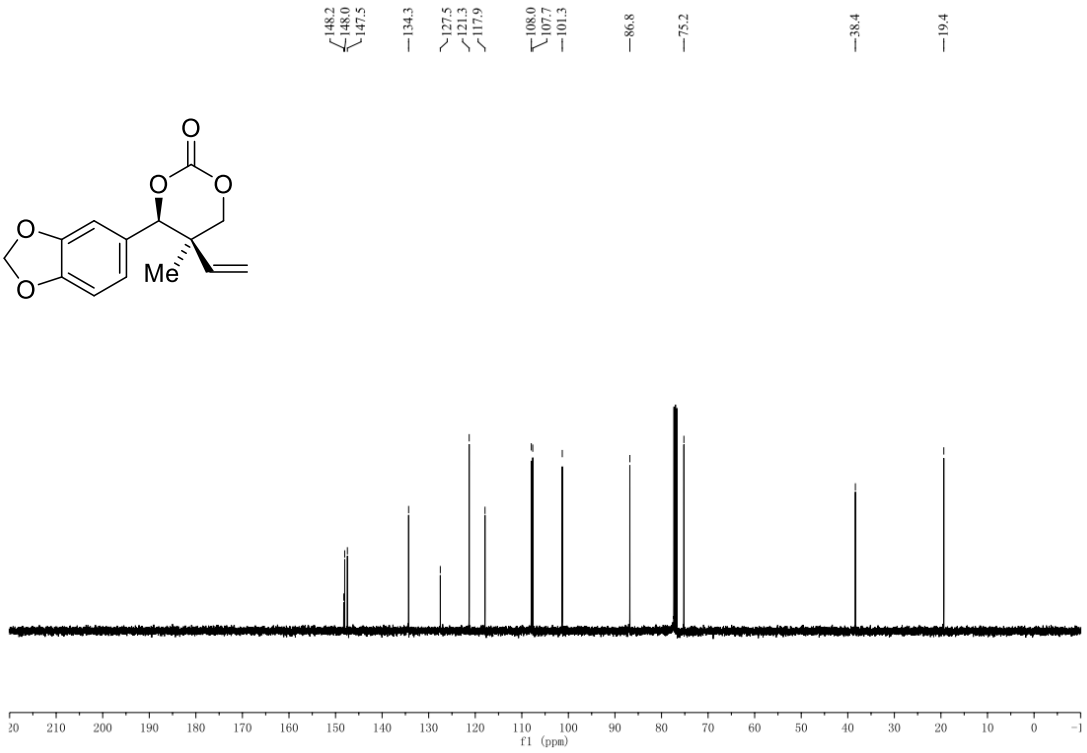
^{13}C NMR (100 MHz, $CDCl_3$) δ 148.2, 148.0, 147.5, 134.3, 127.5, 121.3, 117.9, 108.0, 107.6, 101.3, 86.8, 75.2, 38.4, 19.4.

HRMS (ESI) Calcd. for $C_{14}H_{14}NaO_5^+$ $[M+Na]^+$: 285.0733, Found: 285.0741.

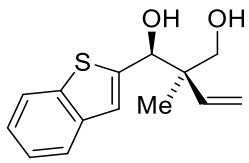
$[\alpha]_D^{33}$: -62.3 (*c* = 1.0, $CHCl_3$).

FTIR (neat): 2970, 2360, 2341, 1748, 1505, 1491, 1447, 1399, 1377, 1253, 1205, 1102, 1038, 933, 815, 768, 669 cm^{-1}


6.79
6.77
6.77
6.76
6.76
6.72
6.72
6.72
6.72
6.70
6.70
6.70
6.70
5.98
5.69
5.67
5.64
5.64
5.33
5.26
5.26
4.38
4.30
4.30
4.27
4.27
1.01
O
O
O
O
O
Me
2.07
0.98
2.11
1.00
1.05
1.07
0.99
1.04
1.01
3.24
f1 (ppm)


148.2
148.0
147.5
134.3
127.5
121.3
117.9
108.0
107.7
101.3
86.8
75.2
38.4
19.4
O
O
O
O
O
Me
f1 (ppm)

(1S,2R)-1-(benzo[b]thiophen-2-yl)-2-methyl-2-vinylpropane-1,3-diol (2.1e)



Detailed Procedures

An oven-dried pressure tube equipped with a magnetic stir bar was charged with K_3PO_4 (10.6 mg, 0.05 mmol, 5 mol%), (*S*)-Ir-Tol-BINAP (55.0 mg, 0.05 mmol, 5 mol%) and benzo[*b*]thiophen-2-ylmethanol (82.1 mg, 0.5 mmol, 100 mol%). Under an atmosphere of argon, anhydrous THF (1.0 mL, 0.5 M) and isoprene monoxide (147 µL, 15 mmol, 300 mol%) were sequentially added via syringe. After sealing the tube with cap, the reaction mixture was stirred at 45 ˚C for 24 h. The reaction was cooled to ambient temperature and concentrated *in vacuo*. The residue was subjected to flash column chromatography (SiO_2, methylene chloride: acetone = 30:1) to furnish the title compound as a yellow oil (102 mg, 0.41 mmol, *anti*:*syn* > 20:1) in 82% yield.

TLC (SiO_2) R_f = 0.32 (dichloromethane/acetone = 10:1).

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.20 – 7.07 (m, 4H), 6.03 (dd, *J* = 17.7, 11.0 Hz, 1H), 5.20 (dd, *J* = 11.0, 1.1 Hz, 1H), 5.01 (dd, *J* = 17.8, 1.2 Hz, 1H), 4.62 (s, 1H), 3.60 (d, *J* = 10.7 Hz, 1H), 3.51 (d, *J* = 10.7 Hz, 1H), 3.18 (brs, 1H), 2.90 (brs, 1H), 2.33 (s, 3H), 0.90 (s, 3H).

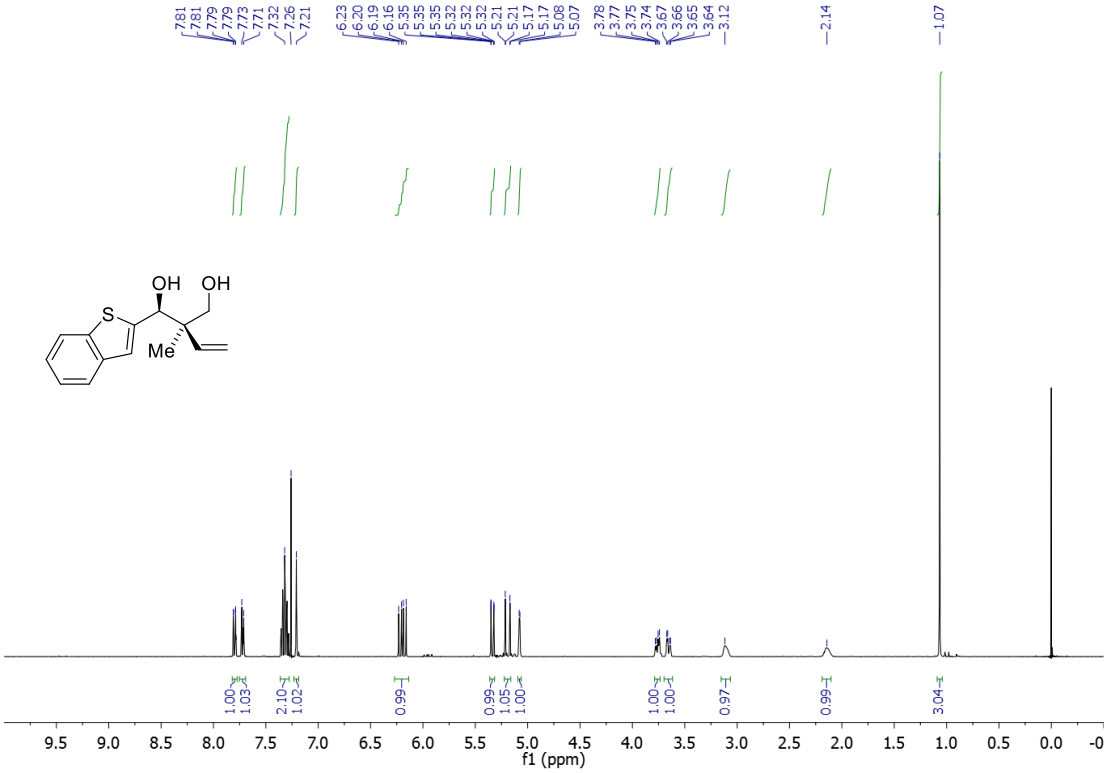
^{13}C NMR (100 MHz, $CDCl_3$) δ 145.2, 139.5, 139.1, 139.0, 124.1, 124.1, 123.3, 122.2, 122.1, 117.0, 69.7, 46.4, 18.0.

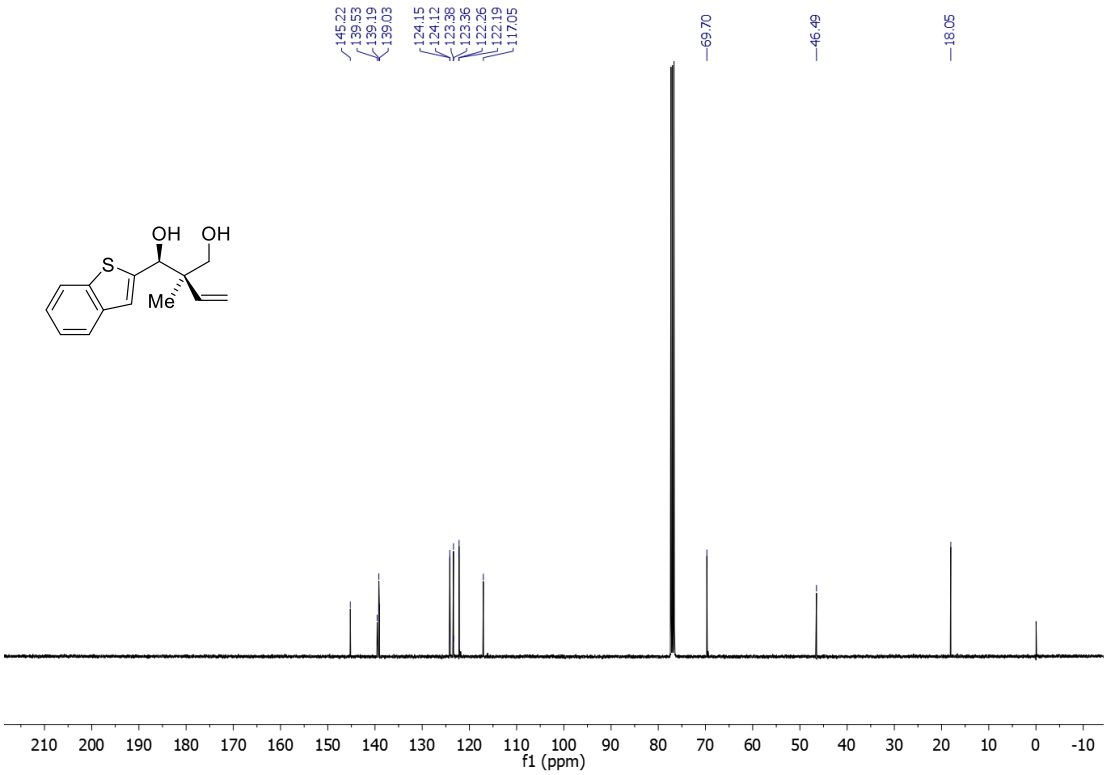
HRMS (ESI) Calcd. for $C_{14}H_{16}NaO_2S^+$ $[M+Na]^+$: 271.0763, Found: 271.0772.

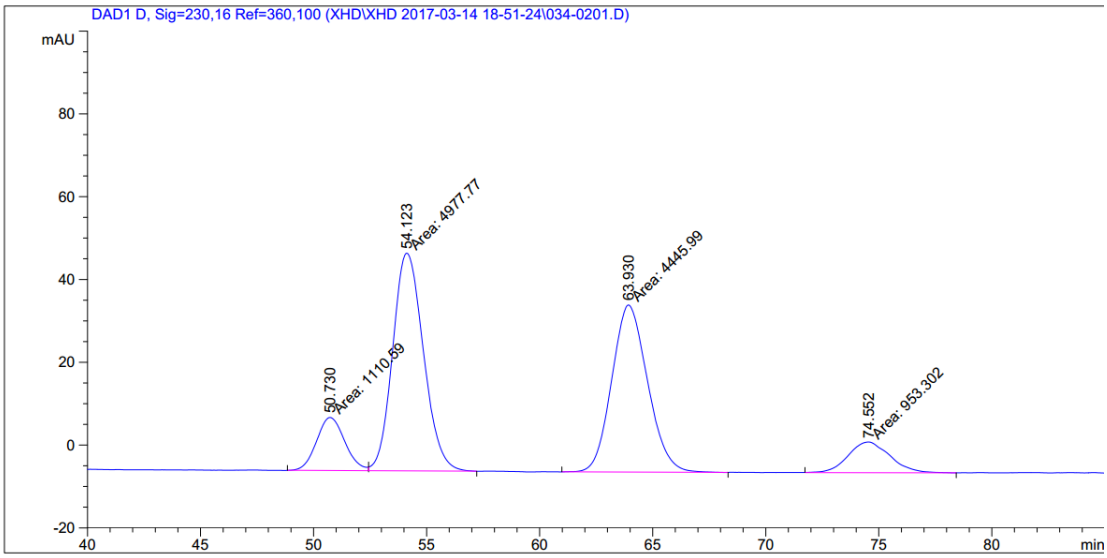
FTIR (neat): 3345, 2964, 1636, 1457, 1415, 1124, 1014, 921. 832, 745, 725, 709 cm^{-1}.

$[\alpha]_D^{33}$: -26.2 (*c* = 1.0, $CHCl_3$).

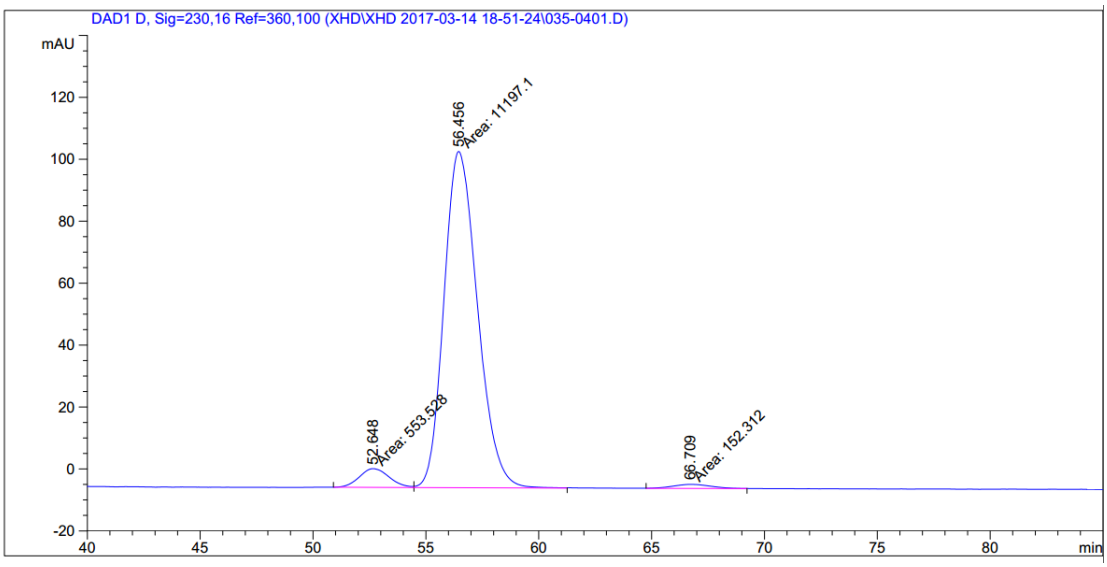
HPLC (one chiralcel OD-H columns, hexanes:*i*-PrOH = 97:3, 1.0 mL/min, 30 nm), *anti*:*syn* = 20:1, ee = 93%.


7.81
7.81
7.79
7.79
7.73
7.71
7.32
7.26
7.21
6.23
6.20
6.19
6.16
5.35
5.35
5.32
5.32
5.32
5.21
5.21
5.17
5.17
5.08
5.07
3.78
3.77
3.75
3.74
3.67
3.66
3.65
3.64
3.12
2.14
1.07
OH
OH
S
Me
1.00
1.03
2.10
1.02
0.99
0.99
1.05
1.00
1.00
1.00
0.97
0.99
3.04
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0
f1 (ppm)


145.22
139.53
139.19
139.03
124.15
124.12
123.38
123.36
122.26
122.19
117.05
69.70
46.49
18.05
OH
OH
S
Me
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)



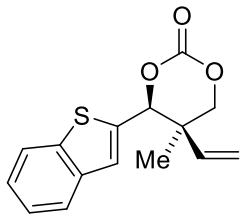
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	50.730	MF	1.4454	1110.58508	12.80605	9.6676
2	54.123	FM	1.5781	4977.77246	52.56989	43.3315
3	63.930	MM	1.8361	4445.99365	40.35715	38.7024
4	74.552	MM	2.1445	953.30170	7.40889	8.2985
Totals :				1.14877e4	113.14198	



Signal 1: DAD1 D, Sig=230,16 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	52.648	MF	1.5267	553.52832	6.04287	4.6504
2	56.456	FM	1.7190	1.11971e4	108.56383	94.0700
3	66.709	MM	1.9341	152.31200	1.31253	1.2796
Totals :				1.19029e4	115.91923	

(4*S*,5*R*)-4-(benzo[b]thiophen-2-yl)-5-methyl-5-vinyl-1,3-dioxan-2-one (2.1e)



Detailed Procedures

An oven-dried vial equipped with a magnetic stir bar was charged with diol **2.1e** (99.3 mg, 0.4 mmol, 100 mol%). Under argon atmosphere, acetonitrile (4 mL, 0.1 M) was added via syringe. CDI (65 mg, 0.4 mmol, 100 mol%) was added in one portion at ambient temperature. The reaction mixture was stirred at 25 ˚C for 16 h. The reaction was concentrated *in vacuo*. The residue was subjected to flash column chromatography (SiO_2, hexanes: ethyl acetate = 3:1) to furnish the title compound as a white solid (83.3 mg, 0.30 mmol) in 75% yield.

TLC (SiO_2) R_f = 0.32 (dichloromethane/acetone = 10:1).

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.86 – 7.80 (m, 1H), 7.79 – 7.76 (m, 1H), 7.40 – 7.35 (m, 2H), 7.32 (t, *J* = 0.7 Hz, 1H), 5.92 (ddd, *J* = 17.6, 11.1, 0.7 Hz, 1H), 5.59 (s, 1H), 5.38 (d, *J* = 11.1 Hz, 1H), 5.34 (d, *J* = 17.6 Hz, 1H), 4.46 (d, *J* = 11.1 Hz, 1H), 4.33 (dd, *J* = 11.0, 0.8 Hz, 1H), 1.21 (s, 3H).

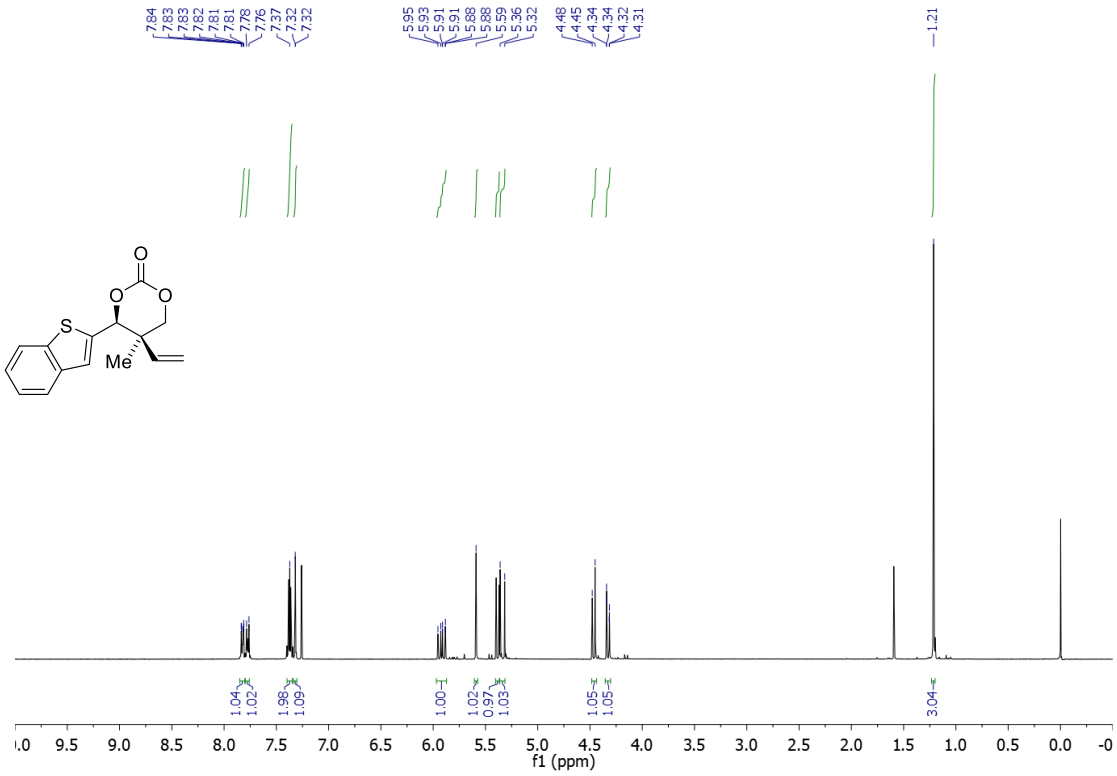
^{13}C NMR (125 MHz, $CDCl_3$) δ 147.4, 139.7, 138.5, 136.7, 134.2, 125.0, 124.6, 124.2, 123.9, 122.2, 118.6, 84.1, 75.3, 38.5, 19.4.

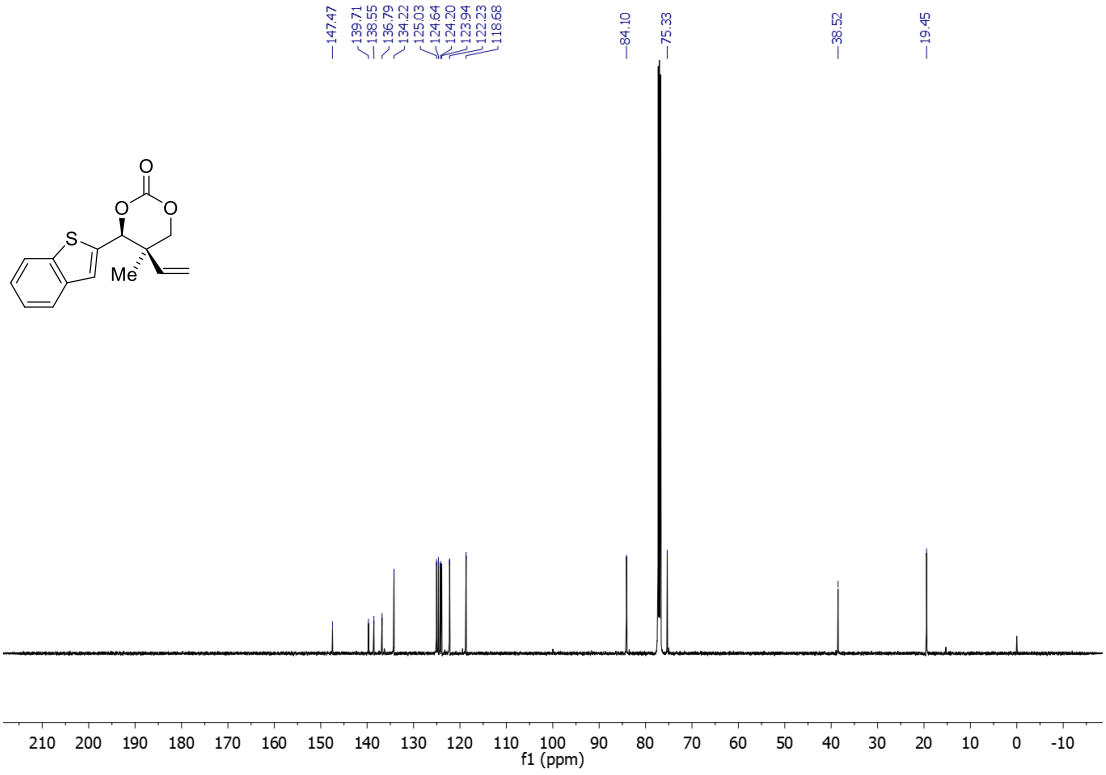
HRMS (ESI) Calcd. for $C_{15}H_{14}NaO_3S^+$ $[M+Na]^+$: 297.0556, Found: 2970561.

$[\alpha]_D^{32}$: -37.1 (*c* = 1.0, $CHCl_3$).

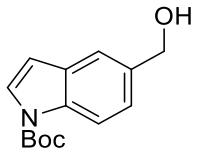
m.p. : 146-147 ˚C

FTIR (neat): 2979, 17332, 1488, 1404, 1332, 1222, 1180, 1127, 1091, 1046, 944, 840, 758, 728, 661 cm^{-1}.


7.84
7.83
7.83
7.82
7.81
7.81
7.78
7.76
7.37
7.32
7.32
5.95
5.93
5.91
5.91
5.88
5.88
5.59
5.36
5.32
4.48
4.45
4.34
4.34
4.32
4.31
1.21
O
O
O
S
Me
1.04
1.02
1.98
1.09
1.00
1.02
0.97
1.03
1.05
1.05
3.04
f1 (ppm)


147.47
139.71
138.55
136.79
134.22
125.03
124.64
124.20
123.94
122.23
118.68
84.10
75.33
38.52
19.45
O
O
O
S
Me
f1 (ppm)

***tert*-butyl 5-(hydroxymethyl)-1*H*-indole-1-carboxylate (2.4)**



Detailed Procedures

To a round-bottomed flask charged with *tert*-butyl 5-formyl-1*H*-indole-1-carboxylate[5] (1.70 g, 6.88 mmol, 100 mol%) under an argon atmosphere was added EtOH (26.0 mL, 0.3 M). The reaction vessel was placed in an ice bath. After 10 minutes, sodium borohydride (390 mg, 10.32 mmol, 150 mol%) was added and the mixture was stirred for 1 h. Water (20 mL) was added to the reaction mixture and the mixture was extracted with CH_2Cl_2 (30 mL × 3). The combined organic layers were washed with brine (100 mL), dried ($MgSO_4$), filtered and concentrated under reduced pressure. The resulting oily residue was subjected to flash column chromatography (SiO_2, hexanes: ethyl acetate = 10:1–5:1) to furnish the title compound as a colorless oil (1.60 g, 6.5 mmol) in 94% yield.

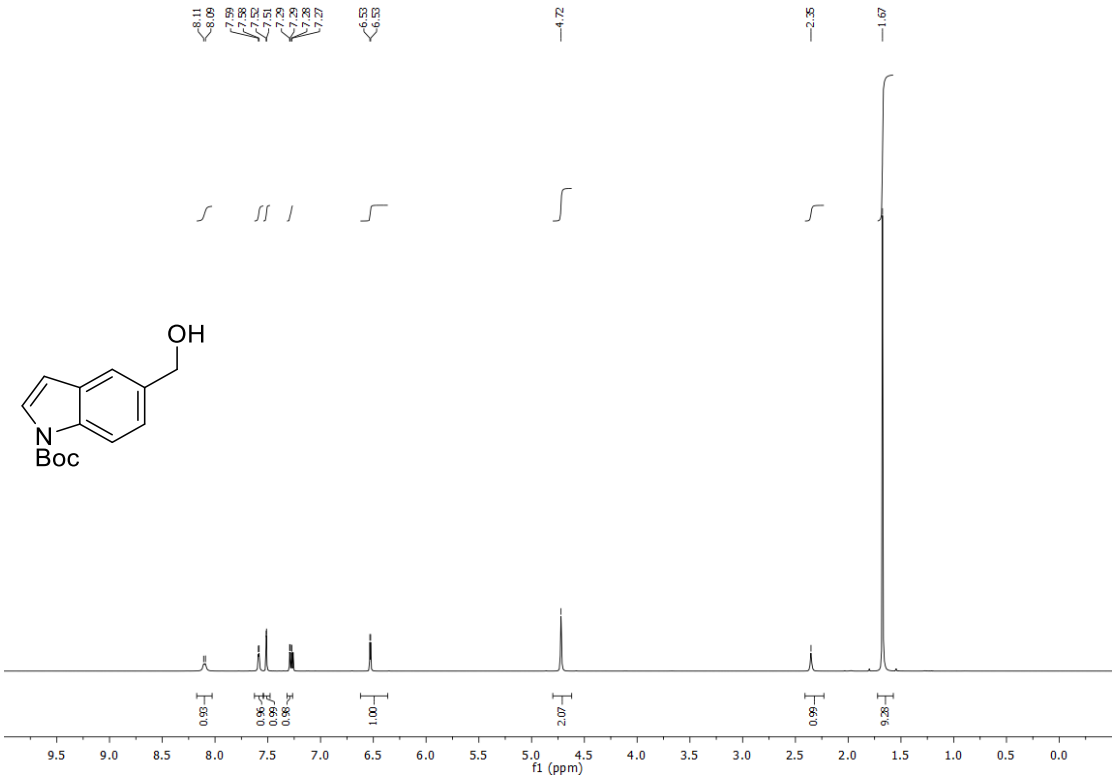
TLC (SiO_2) R_f = 0.39 (hexanes/ethyl acetate = 2:1).

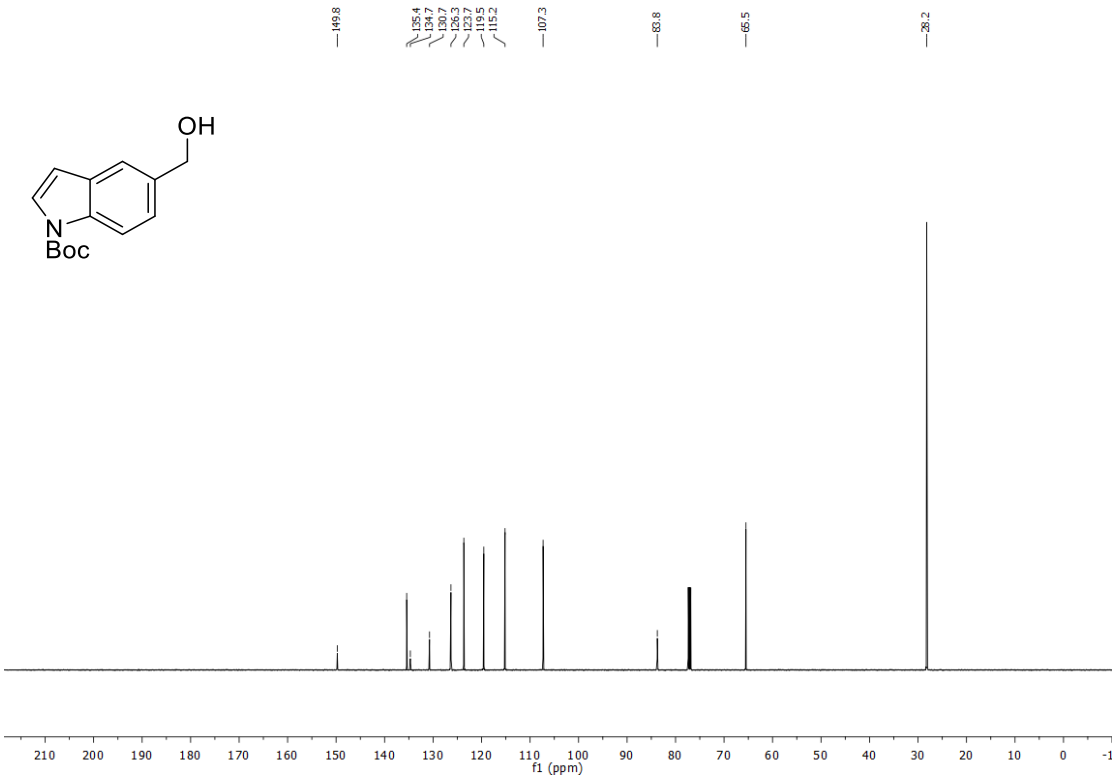
^{1}H NMR (500 MHz, $CDCl_3$) δ 8.10 (d, *J* = 8.6 Hz, 1H), 7.59 (d, *J* = 3.7 Hz, 1H), 7.51 (d, *J* = 1.6 Hz, 1H), 7.28 (dd, *J* = 8.5, 1.7 Hz, 1H), 6.53 (d, *J* = 3.7 Hz, 1H), 4.72 (s, 2H), 2.35 (s, 1H), 1.67 (s, 9H).

^{13}C NMR (125 MHz, $CDCl_3$) δ 149.8, 135.4, 134.7, 130.7, 126.3, 123.7, 119.5, 115.2, 107.3, 83.8, 65.5, 28.2.

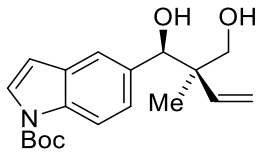
HRMS (ESI) Calcd. for $C_{14}H_{17}NO_3$ $[M+Na]^+$: 270.1101, Found: 270.1101.

FTIR (neat): 3357, 2978, 1729, 1472, 1369, 1218, 1158, 1081, 1021, 759, 723 cm^{-1}.


8.11
8.09
7.59
7.58
7.52
7.51
7.29
7.28
7.27
6.53
6.53
4.72
2.35
1.67
OH
N
Boc
0.93
0.96
0.99
0.98
1.00
2.07
0.99
9.28
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)


149.8
135.4
134.7
130.7
126.3
123.7
119.5
115.2
107.3
83.8
65.5
28.2
OH
N
Boc
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)

***tert*-butyl 5-((1R,2R)-1-hydroxy-2-(hydroxymethyl)-2-methylbut-3-en-1-yl)-1H-indole-1-carboxylate (2.1f)**



Detailed Procedures

An oven-dried pressure tube equipped with a magnetic stir bar was charged with K_3PO_4 (4.2 mg, 0.02 mmol, 5 mol%), (*S*)-Ir-Tol-BINAP (22 mg, 0.02 mmol, 5 mol%) and alcohol **2.4** (100 mg, 0.40 mmol, 100 mol%). Under an atmosphere of argon, anhydrous THF (0.8 mL, 0.5 M) and isoprene monoxide (0.12 mL, 1.2 mmol, 300 mol%) were sequentially added via syringe. After sealing the tube with cap, the reaction mixture was stirred at 45 ˚C for 48 h. The reaction was cooled to ambient temperature and concentrated *in vacuo*. The residue was subjected to flash column chromatography (SiO_2, hexanes: ethyl acetate = 6:1–4:1) to furnish the title compound as a yellow oil (98 mg, 0.30 mmol, *anti*:*syn* > 20:1) in 74% yield.

TLC (SiO_2) R_f = 0.28 (hexanes/ethyl acetate = 2:1).

^{1}H NMR (500 MHz, $CDCl_3$) δ 8.08 (d, *J* = 8.5 Hz, 1H), 7.61 (d, *J* = 3.7 Hz, 1H), 7.54 (d, *J* = 1.5 Hz, 1H), 7.31 – 7.27 (m, 1H), 6.57 (d, *J* = 3.7 Hz, 1H), 6.12 (dd, *J* = 17.8, 11.0 Hz, 1H), 5.27 (dd, *J* = 11.0, 1.2 Hz, 1H), 5.08 (dd, *J* = 17.8, 1.3 Hz, 1H), 4.85 (d, *J* = 2.5 Hz, 1H), 3.68 (dd, *J* = 10.7, 6.1 Hz, 1H), 3.62 (dd, *J* = 10.7, 5.1 Hz, 1H), 2.73 (d, *J* = 2.8 Hz, 1H), 2.34 (t, *J* = 5.8 Hz, 1H), 1.69 (s, 9H), 0.98 (s, 3H).

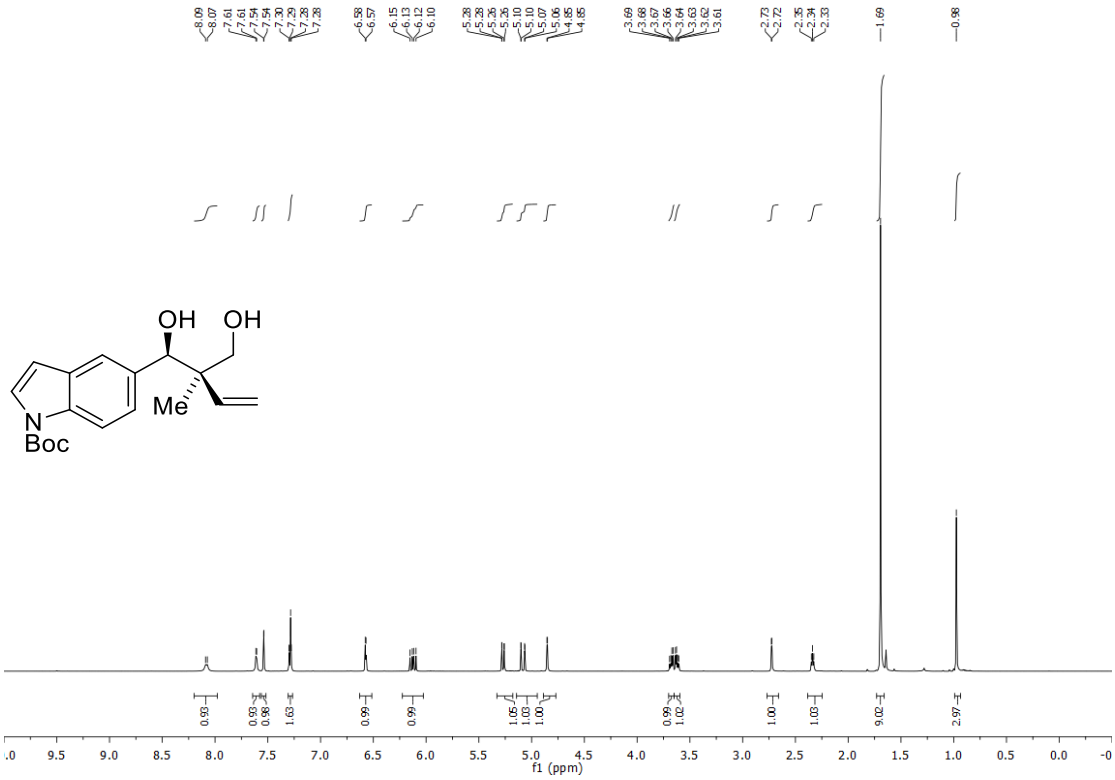
^{13}C NMR (100 MHz, $CDCl_3$) δ 149.7, 139.8, 135.2, 134.7, 130.1, 126.2, 124.1, 120.0, 116.2, 114.2, 107.4, 83.7, 80.1, 69.9, 46.7, 28.2, 17.7.

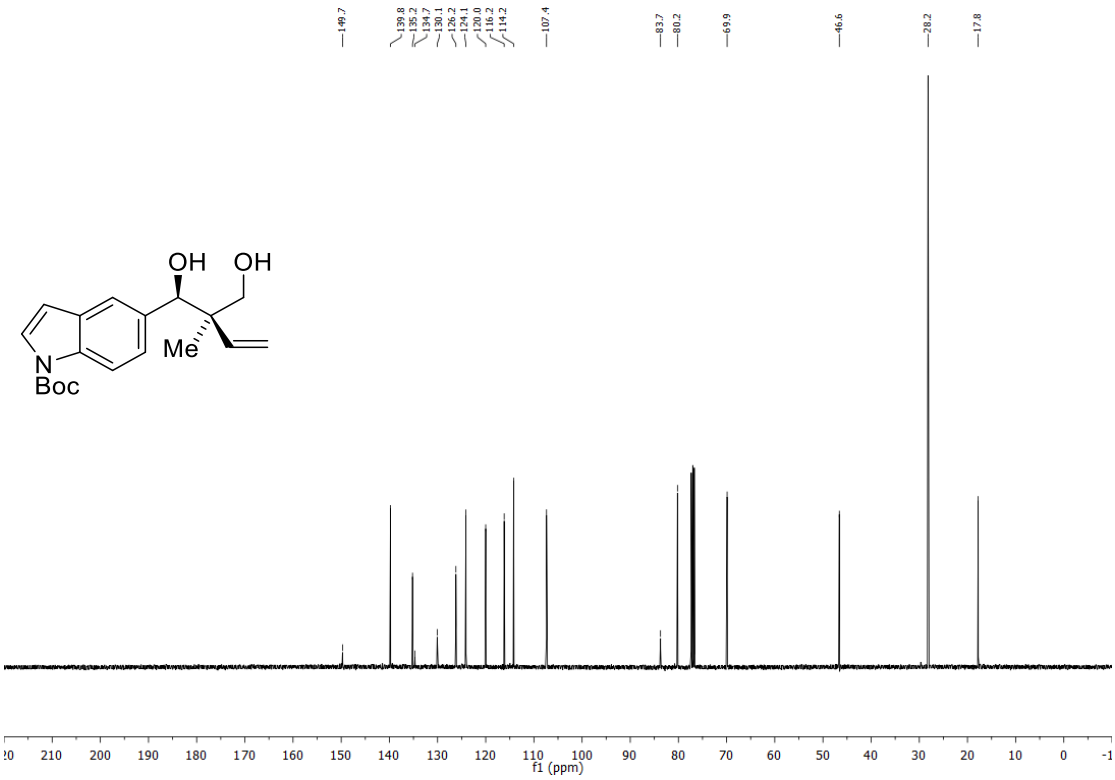
HRMS (ESI) Calcd. for $C_{19}H_{25}NO_4$ $[M+Na]^+$: 354.1676, Found: 354.1680.

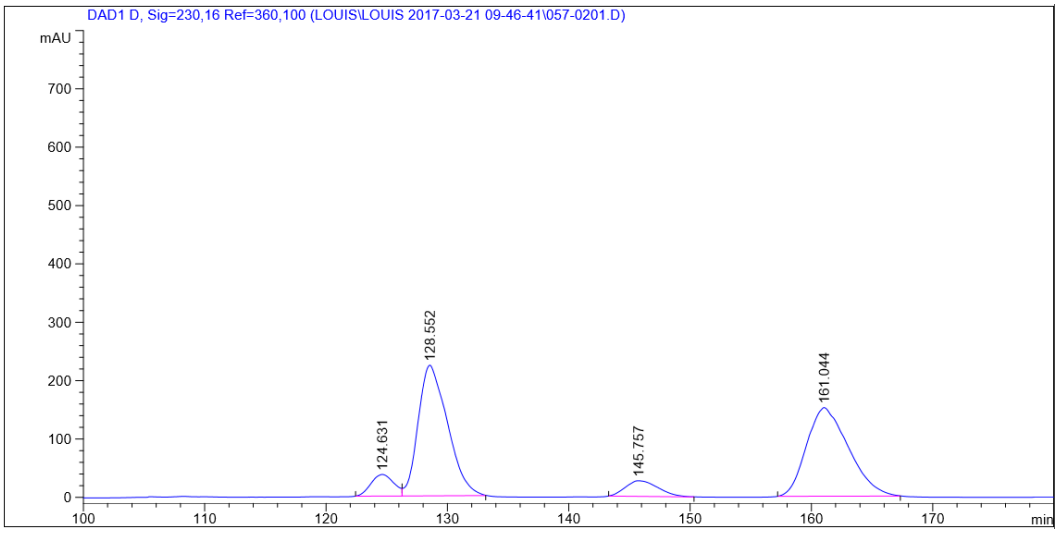
FTIR (neat): 3384, 2978, 1732, 1469, 1352, 1255, 1160, 1022, 754 cm^{-1}.

$[\alpha]_D^{29}$: –24.0 (*c* = 1.0, $CHCl_3$).

HPLC (Chiralcel AS-H columns, hexanes:*i*-PrOH = 99:1 (100 minutes) – 98:2 (100 minutes), 1.00 mL/min, 230 nm), *anti*:*syn* = 85:1, ee = 88%.

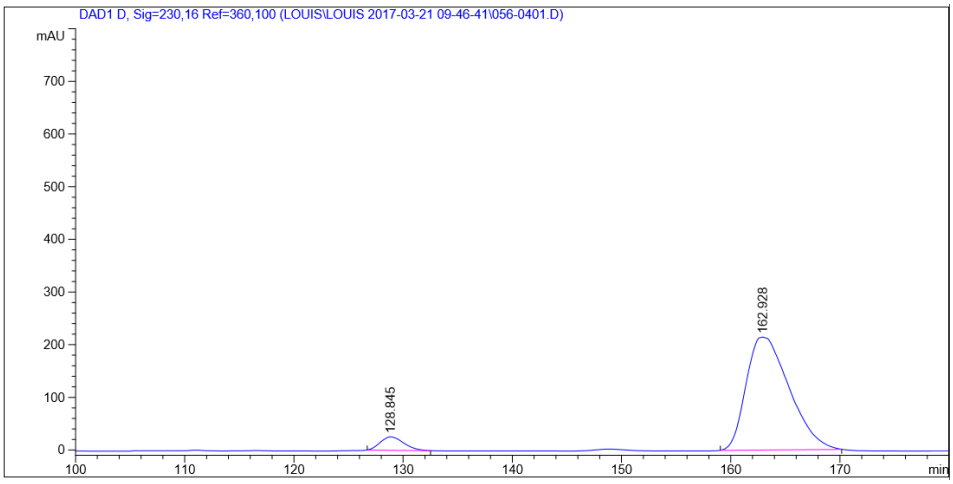

OH
OH
Me
N
Boc
f1 (ppm)





Signal 1: DAD1 D, Sig=230,16 Ref=360,100

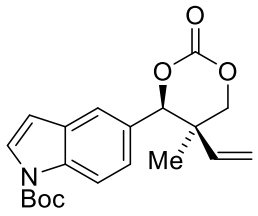
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	124.631	BV	1.7583	4827.00732	36.99244	5.7545
2	128.552	VB	2.3487	3.76106e4	223.79434	44.8377
3	145.757	BB	2.1991	4984.88232	26.66442	5.9427
4	161.044	BB	2.9672	3.64593e4	151.84721	43.4650



Signal 1: DAD1 D, Sig=230,16 Ref=360,100

Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	128.845	BB	1.8847	3805.69751	25.50686	6.0828
2	162.928	BB	3.2629	5.87588e4	214.43245	93.9172

***tert*-butyl 5-((4*R*,5*R*)-5-methyl-2-oxo-5-vinyl-1,3-dioxan-4-yl)-1H-indole-1-carboxylate (2.1f)**



Detailed Procedures

An oven-dried vial equipped with a magnetic stir bar was charged with diol **2.1f** (160 mg, 0.48 mmol, 100 mol%). Under argon atmosphere, acetonitrile (4.8 mL, 0.1 M) was added via syringe. CDI (156 mg, 0.97 mmol, 200 mol%) was added in one portion at ambient temperature. The reaction mixture was stirred at 25 ˚C for 16 h. The reaction was concentrated *in vacuo*. The residue was subjected to flash column chromatography (SiO_2, hexanes: ethyl acetate = 2:1) to furnish the title compound as a white solid (147 mg, 0.41 mmol) in 85% yield.

TLC (SiO_2) R_f = 0.45 (hexanes/ethyl acetate = 1:1).

^{1}H NMR (500 MHz, $CDCl_3$) δ 8.13 (d, *J* = 8.8 Hz, 1H), 7.62 (d, *J* = 3.7 Hz, 1H), 7.49 (d, *J* = 1.7 Hz, 1H), 7.19 (dd, *J* = 8.6, 1.8 Hz, 1H), 6.57 (d, *J* = 3.8 Hz, 1H), 5.68 (dd, *J* = 17.6, 11.1 Hz, 1H), 5.38 (s, 1H), 5.30 (d, *J* = 11.1 Hz, 1H), 5.23 (d, *J* = 17.7 Hz, 1H), 4.44 (d, *J* = 11.0 Hz, 1H), 4.33 (d, *J* = 10.9 Hz, 1H), 1.67 (s, 9H), 1.05 (s, 3H).

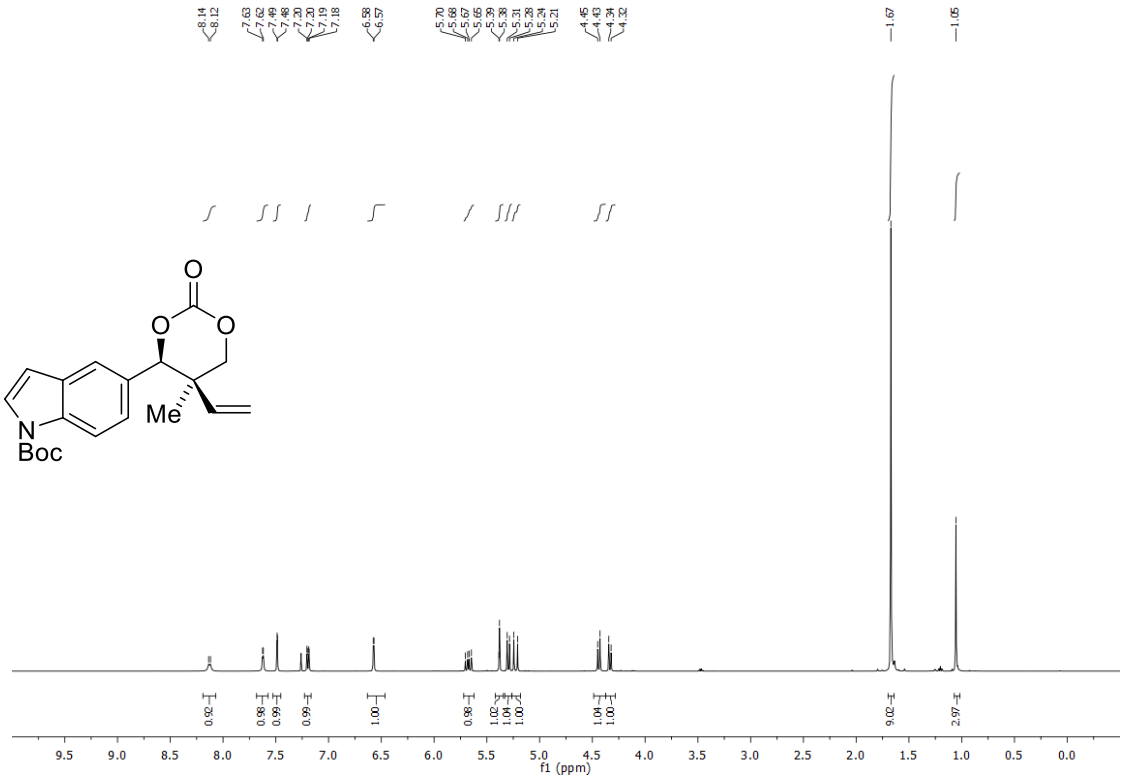
^{13}C NMR (100 MHz, $CDCl_3$) δ 149.5, 148.5, 135.3, 134.5, 130.2, 128.1, 126.7, 123.6, 120.1, 117.8, 114.5, 107.2, 87.3, 84.0, 75.1, 38.5, 28.1, 19.6.

HRMS (ESI) Calcd. for $C_{20}H_{23}NO_5$ $[M+Na]^+$: 380.1468, Found: 380.1468.

$[\alpha]_D^{29}$: –43.3 (*c* = 1.0, $CHCl_3$).

m.p. : 158–162 ˚C

FTIR (neat): 2978, 1734, 1473, 1358, 1222, 1161, 1102, 1024, 760 cm^{-1}.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7.62
7.49
7.48
7.20
7.19
7.18
6.58
6.57
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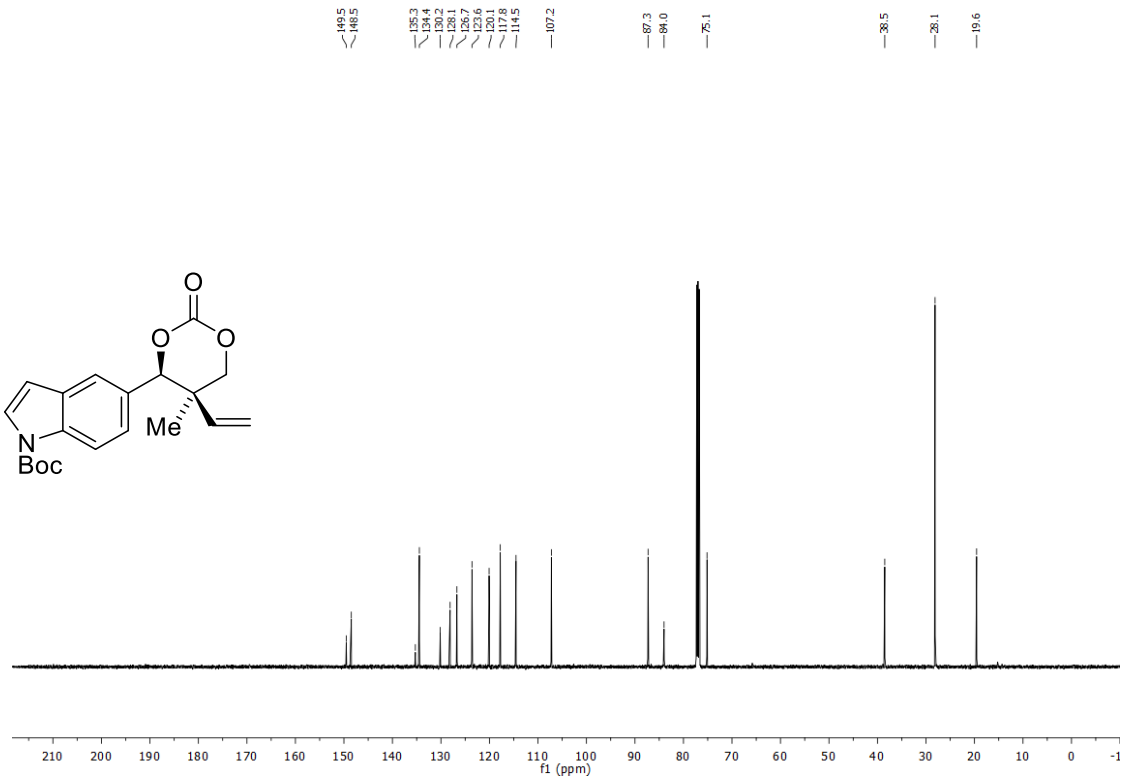
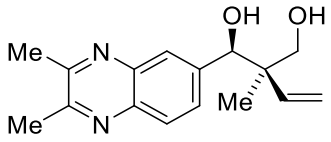
5.67
5.65
5.39
5.38
5.31
5.28
5.24
5.21
4.45
4.43
4.34
4.32
1.67
1.05
O
O
O
Me
N
Boc
0.92
0.98
0.99
0.99
1.00
0.98
1.02
1.04
1.00
1.04
1.00
9.02
2.97
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)


149.5
148.5
135.3
134.4
130.2
128.1
126.7
123.6
120.1
117.8
114.5
107.2
87.3
84.0
75.1
38.5
28.1
19.6
O
O
O
Me
N
Boc
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)

(1*R*,2*R*)-1-(2,3-dimethylquinoxalin-6-yl)-2-methyl-2-vinylpropane-1,3-diol (2.1g)



Detailed Procedures

An oven-dried pressure tube equipped with a magnetic stir bar was charged with K_3PO_4 (4.2 mg, 0.02 mmol, 5 mol%), (*S*)-Ir-Tol-BINAP (22.0 mg, 0.02 mmol, 5 mol%) and (2,3-dimethylquinoxalin-6-yl)methanol[6] (75.2 mg, 0.4 mmol, 100 mol%). Under an atmosphere of argon, anhydrous THF (0.8 mL, 0.5 M) and isoprene monoxide (0.16 mL, 1.6 mmol, 400 mol%) were sequentially added via syringe. After sealing the tube with cap, the reaction mixture was stirred at 60 ˚C for 24 h. The reaction was cooled to ambient temperature and concentrated *in vacuo*. The residue was subjected to flash column chromatography (SiO_2, hexanes: ethyl acetate = 1:10) to furnish the title compound as a yellow oil (92.0 mg, 0.34 mmol, *anti*:*syn* > 20:1) in 85% yield.

TLC (SiO_2) R_f = 0.31 (hexanes/ethyl acetate = 1:20).

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.87 (d, *J* = 1.3 Hz, 1H), 7.84 (d, *J* = 8.6 Hz, 1H), 7.64 (dd, *J* = 8.6, 1.7 Hz, 1H), 6.12 (dd, J = 17.7, 11.0 Hz, 1H), 5.20 (dd, *J* = 11.0, 0.8 Hz, 1H), 4.98 (dd, *J* = 17.8, 0.9 Hz, 1H), 4.93 (s, 1H), 4.04 (brs, 1H), 3.71 (d, *J* = 10.6 Hz, 1H), 3.61 (d, *J* = 10.6 Hz, 1H), 3.24 (brs, 1H), 2.68 (s, 3H), 2.67 (s, 3H), 0.95 (s, 3H).

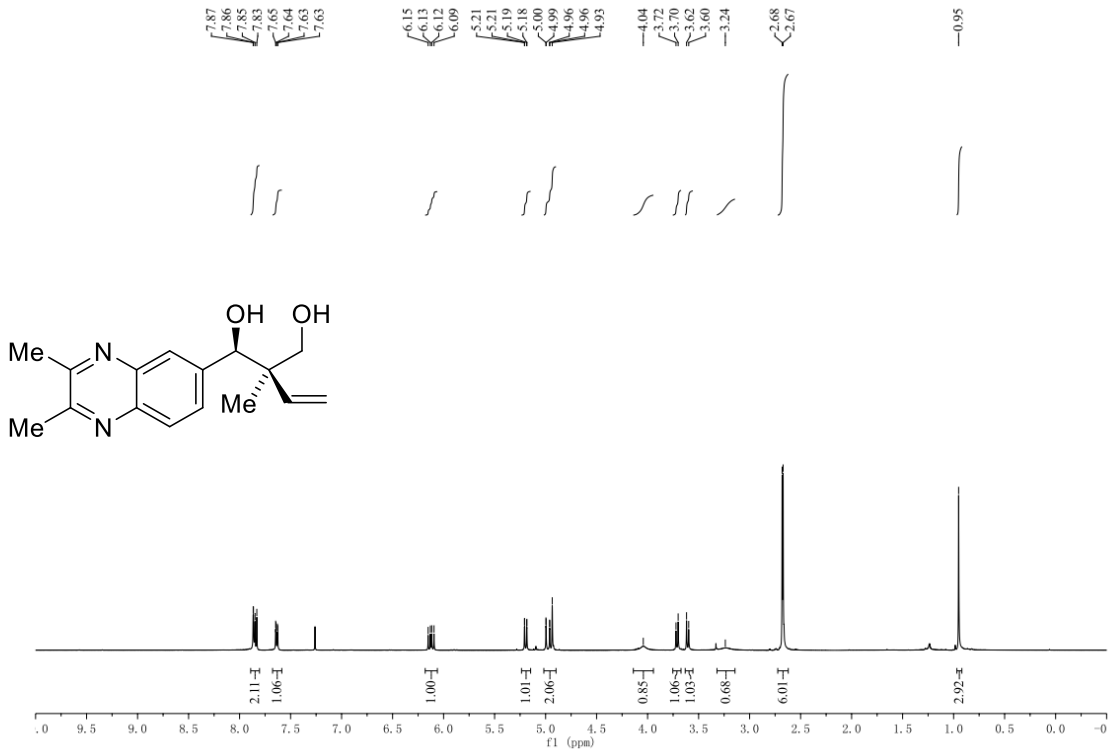
^{13}C NMR (125 MHz, $CDCl_3$) δ 153.5, 153.4, 142.3, 140.4, 140.1, 139.3, 129.0, 127.1, 126.8, 116.3, 79.5, 69.7, 46.4, 23.0, 18.0.

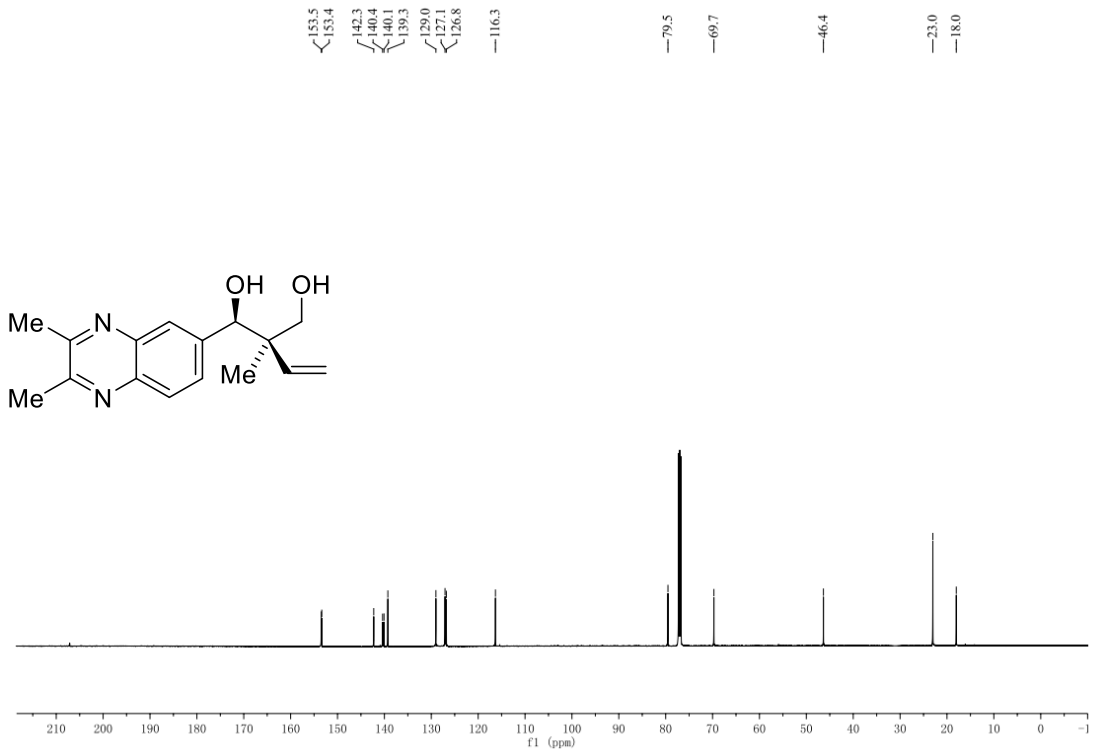
HRMS (ESI) Calcd. for $C_{16}H_{21}N_2O_2^+$ $[M+H]^+$: 273.1598, Found: 273.1597.

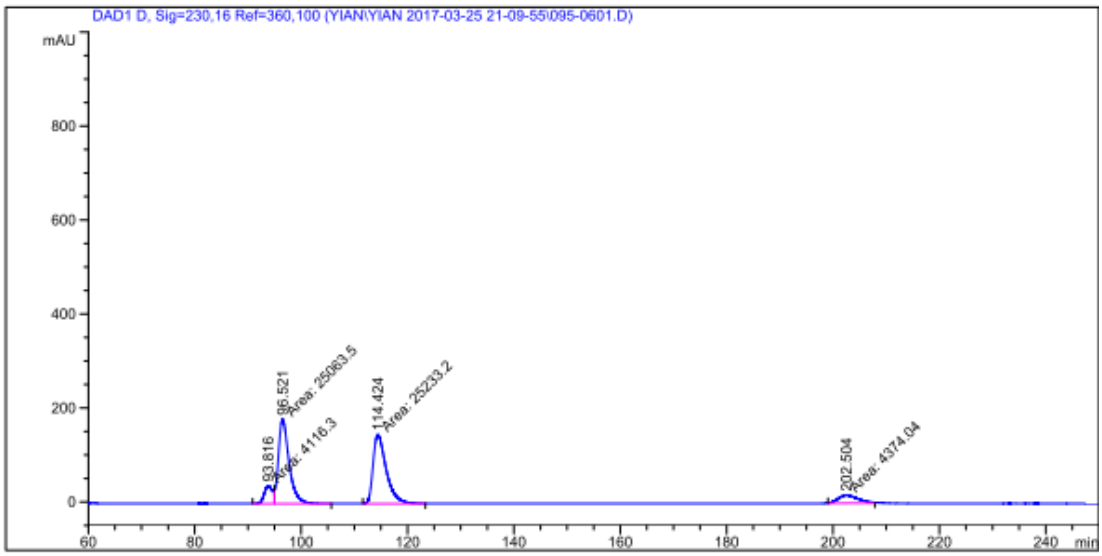
FTIR (neat): 3325, 2965, 2877, 1637, 1496, 1450, 1405, 1380, 1334, 1254, 1164, 1148, 1043, 021, 838, 809, 757, 666 cm^{-1}.

$[\alpha]_D^{33}$: -23.8 (*c* = 1.0, $CHCl_3$).

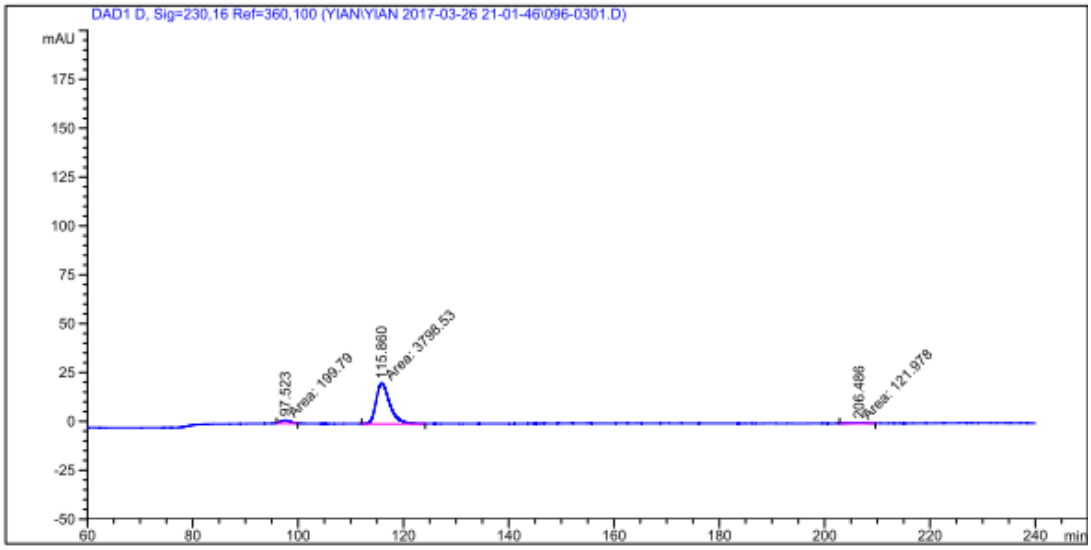
HPLC (two connected chiralcel AD-H columns, hexanes:*i*-PrOH = 95:5, 0.80 mL/min, 230 nm), *anti*:*syn* = 30:1, ee = 90%.


7.87
7.86
7.85
7.83
7.65
7.64
7.63
7.63
6.15
6.13
6.12
6.09
5.21
5.21
5.19
5.18
5.00
4.99
4.96
4.96
4.93
4.04
3.72
3.70
3.62
3.60
3.24
2.68
2.67
0.95
OH
OH
Me
N
Me
N
Me
2.11
1.06
1.00
1.01
2.06
0.85
1.06
1.03
0.68
6.01
2.92
f1 (ppm)


153.5
153.4
142.3
140.4
140.1
139.3
129.0
127.1
126.8
116.3
79.5
69.7
46.4
23.0
18.0
OH
OH
Me
N
Me
N
Me
f1 (ppm)

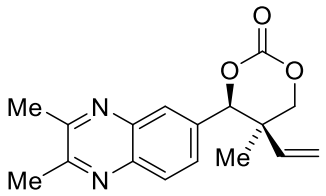


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	93.816	MF	1.8229	4116.30322	37.63605	7.0021
2	96.521	FM	2.3351	2.50635e4	178.88995	42.6344
3	114.424	MM	2.8763	2.52332e4	146.21553	42.9231
4	202.504	MM	4.3698	4374.04248	16.68301	7.4405



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	97.523	MM	2.2133	199.78983	1.50443	4.8489
2	115.860	MM	3.0432	3798.53394	20.80317	92.1907
3	206.486	MM	4.6694	121.97781	4.35381e-1	2.9604

(4*R*,5*R*)-4-(2,3-dimethylquinoxalin-6-yl)-5-methyl-5-vinyl-1,3-dioxan-2-one (2.1g)



Detailed Procedures

An oven-dried vial equipped with a magnetic stir bar was charged with diol **2.1g** (65.0 mg, 0.24 mmol, 100 mol%). Under argon atmosphere, acetonitrile (2.4 mL, 0.1 M) was added via syringe. CDI (77.4 mg, 0.48 mmol, 200 mol%) was added in one portion at ambient temperature. The reaction mixture was stirred at 25 ˚C for 16 h. The reaction was concentrated *in vacuo*. The residue was subjected to flash column chromatography (SiO_2, hexanes: ethyl acetate = 1:10) to furnish the title compound as a yellow solid (51.0 mg, 0.17 mmol) in 72 % yield.

TLC (SiO_2) R_f = 0.37 (hexanes/ethyl acetate = 1:10).

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.98 (d, *J* = 8.7 Hz, 1H), 7.88 (d, *J* = 1.4 Hz, 1H), 7.60 (dd, *J* = 8.7, 1.8 Hz, 1H), 5.69 (dd, *J* = 17.6, 11.1 Hz, 1H), 5.50 (s, 1H), 5.32 (d, *J* = 11.1 Hz, 1H), 5.22 (d, *J* = 17.6 Hz, 1H), 4.45 (d, *J* = 11.0 Hz, 1H), 4.39 (d, *J* = 11.1 Hz, 1H), 2.74 (s, 3H), 2.74 (s, 3H), 1.10 (s, 3H).

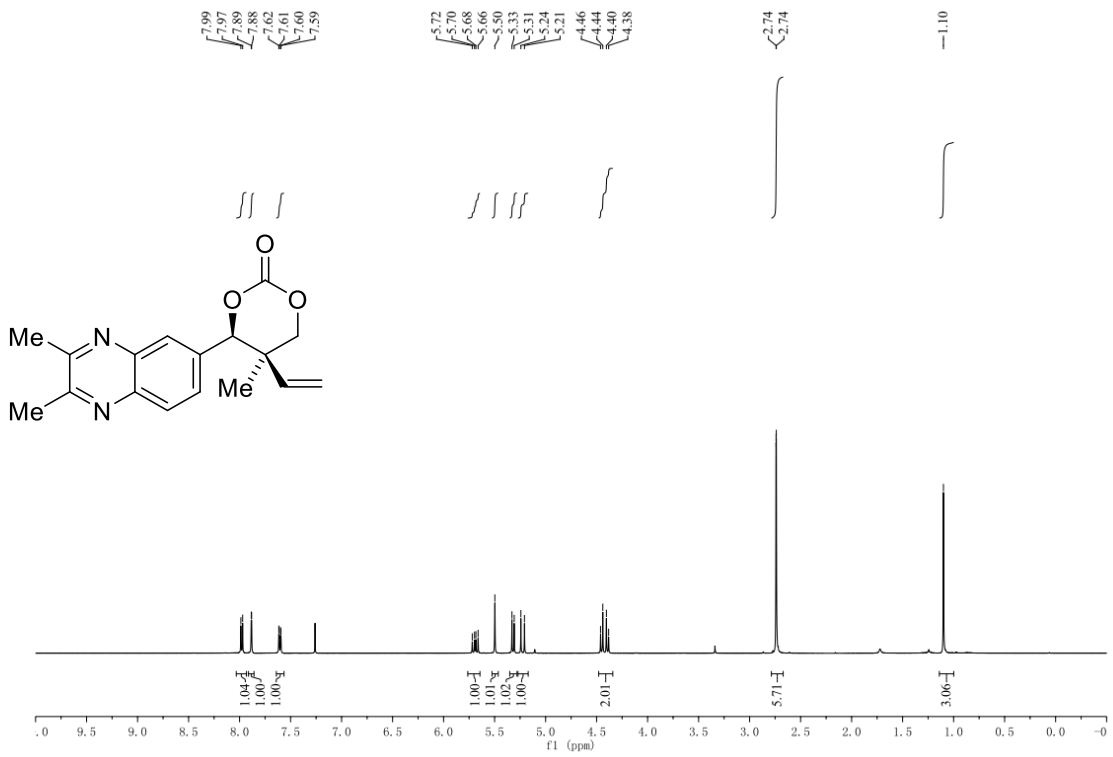
^{13}C NMR (125 MHz, $CDCl_3$) δ 154.5, 154.4, 147.9, 141.0, 140.2, 134.6, 133.9, 128.2, 127.7, 127.4, 118.4, 86.6, 75.2, 38.5, 23.2, 23.2, 19.4.

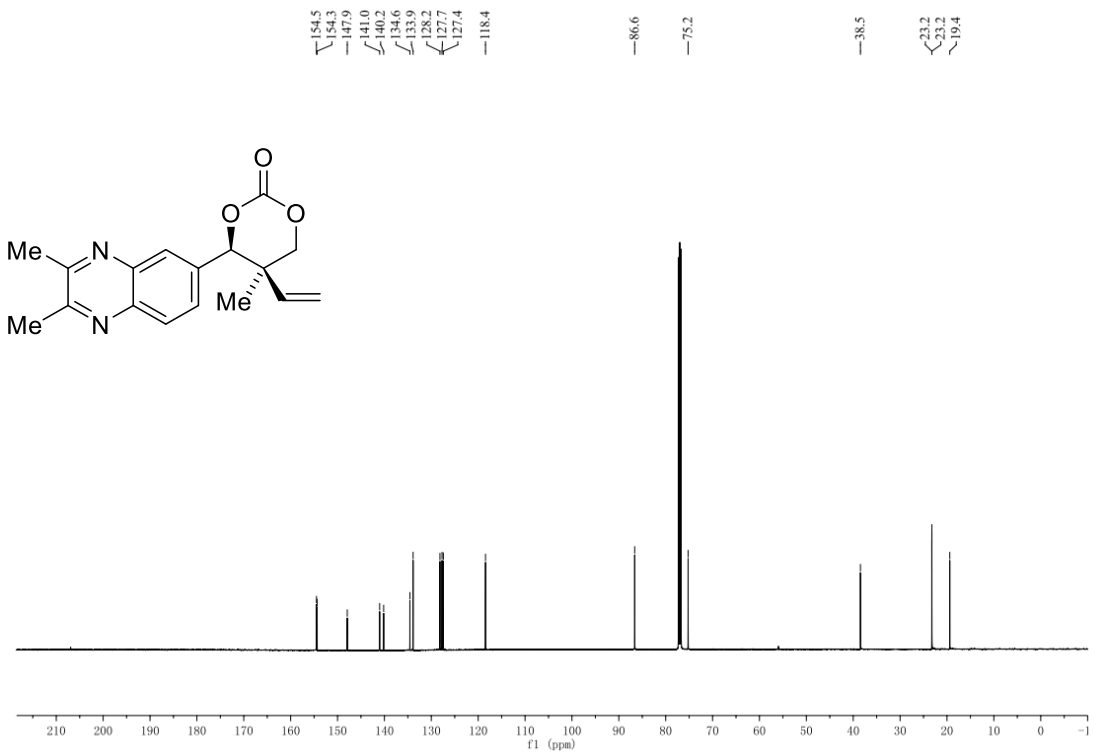
HRMS (ESI) Calcd. for $C_{17}H_{19}N_2O_3^+$ $[M+Na]^+$: 299.1390, Found: 299.1392.

$[\alpha]_D^{33}$: -70.8 (*c* = 1.0, $CHCl_3$).

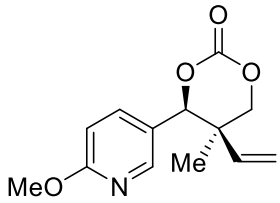
m.p. : 218-220 ˚C (decomposed)

FTIR (neat): 2970, 1747, 1456, 1401, 1335, 1240, 1210, 1166, 1134, 1103, 999, 974, 841, 767, 670 cm^{-1}.


7.99
7.97
7.89
7.88
7.62
7.61
7.60
7.59
5.72
5.70
5.68
5.66
5.50
5.33
5.31
5.24
5.21
4.46
4.44
4.40
4.38
2.74
2.74
1.10
Me
Me
N
N
O
O
O
Me
1.04
1.00
1.00
1.00
1.01
1.02
1.00
2.01
5.71
3.06
f1 (ppm)


154.5
154.3
147.9
141.0
140.2
134.6
133.9
128.2
127.7
127.4
118.4
86.6
75.2
38.5
23.2
23.2
19.4
Me
Me
N
N
O
O
O
Me
f1 (ppm)

(*4R,5R*)-4-(6-methoxypyridin-3-yl)-5-methyl-5-vinyl-1,3-dioxan-2-one (2.1h)



Detailed Procedures

An oven-dried vial equipped with a magnetic stir bar was charged with (1*R*,2*R*)-1-(6-methoxypyridin-3-yl)-2-methyl-2-vinylpropane-1,3-diol[4] (558 mg, 2.5 mmol, 100 mol%). Under argon atmosphere, acetonitrile (25 mL, 0.1 M) was added via syringe. CDI (810 mg, 5.0 mmol, 200 mol%) was added in one portion at ambient temperature. The mixture was stirred at 25 ˚C for 16 h. The reaction was concentrated in *vacuo*. The residue was subjected to flash column chromatography (SiO_2, hexanes: ethyl acetate = 1:1) to furnish the title compounds as a white solid (418 mg, 1.68 mmol) in 82% yield.

TLC (SiO_2) R_f = 0.31 (hexanes/ethyl acetate = 1:1).

^{1}H NMR (500 MHz, $CDCl_3$) δ 8.07 (d, *J* = 2.6 Hz, 1H), 7.56 (dd, *J* = 8.7, 2.5 Hz, 1H), 6.78 (d, *J* = 8.7 Hz, 1H), 5.74 (dd, *J* = 17.6, 11.1 Hz, 1H), 5.38 (d, *J* = 11.1 Hz, 1H), 5.28 (s, 1H), 5.25 (d, *J* = 15.0 Hz, 1H), 4.42 (d, *J* = 11.0 Hz, 1H), 4.36 (d, *J* = 11.0 Hz, 1H), 3.97 (s, 3H), 1.04 (s, 3H).

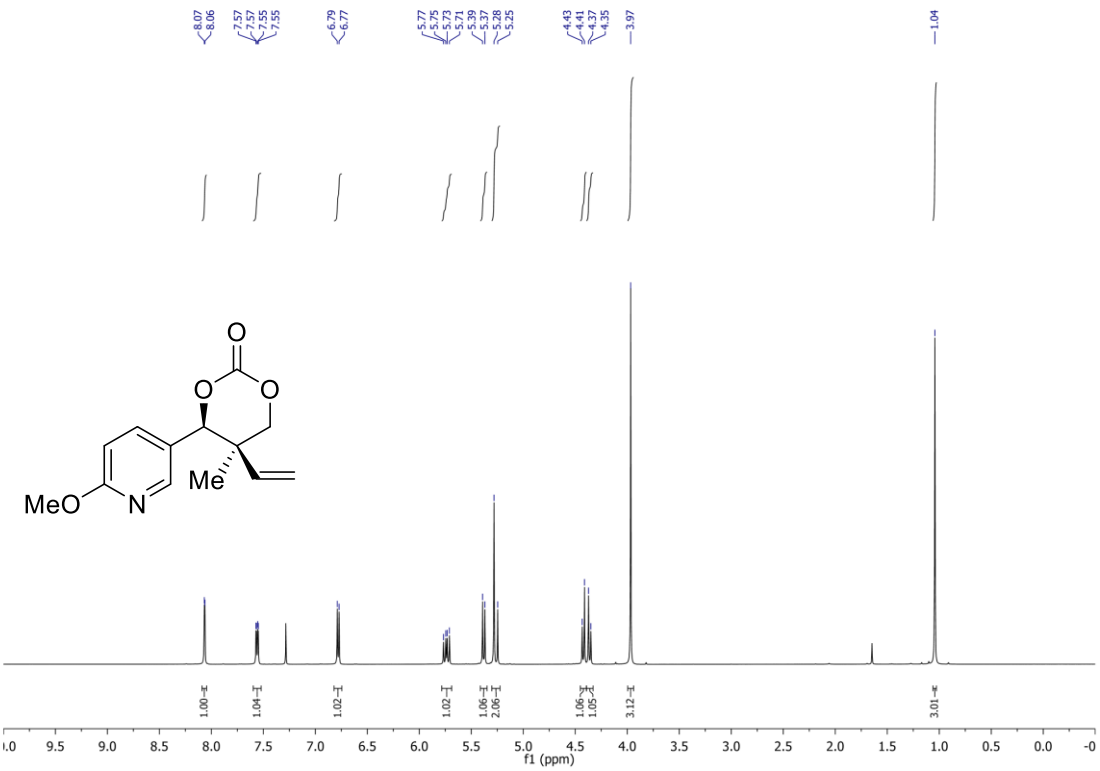
^{13}C NMR (125 MHz, $CDCl_3$) δ 164.7, 148.1, 146.0, 137.9, 133.7, 122.5, 118.7, 110.6, 85.0, 75.5, 53.6, 38.4, 19.0.

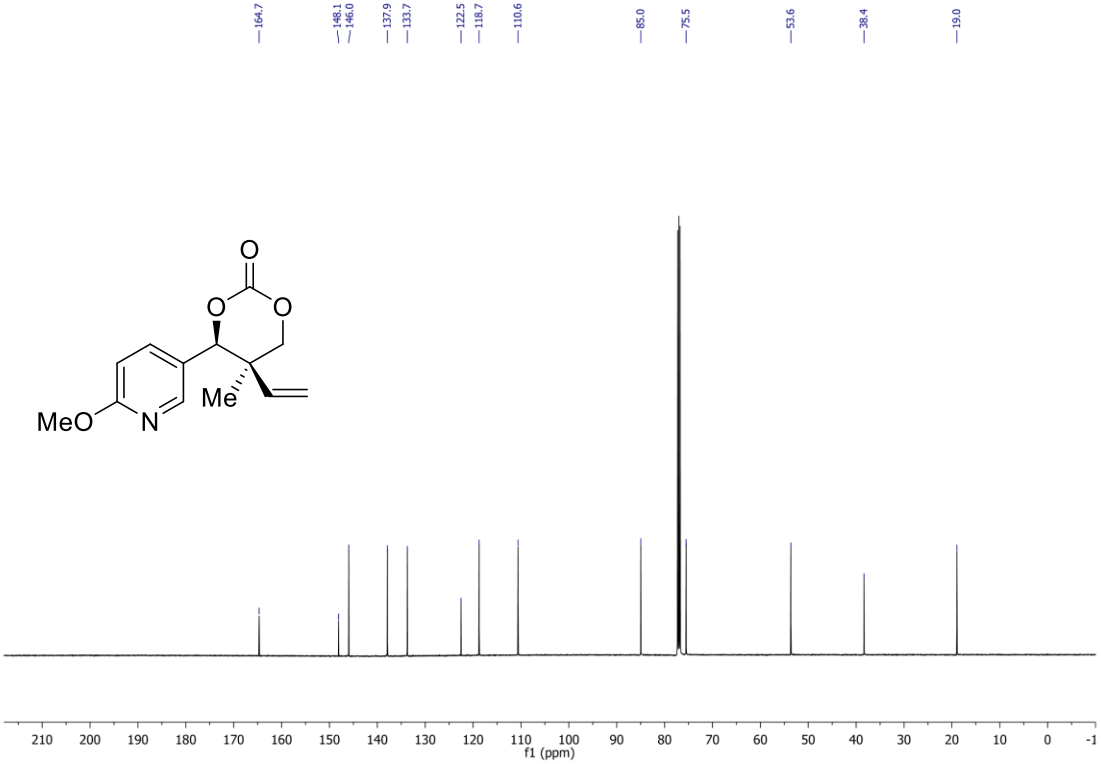
HRMS (ESI) Calcd. for $C_{13}H_{15}NNaO_4^+$ $[M+Na]^+$: 272.0894, Found: 272.0892

$[\alpha]_D^{30}$: +110.9 (c = 0.61, $CHCl_3$)

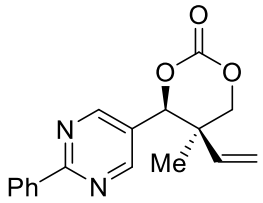
m.p.: 102 – 104 ˚C

FTIR (neat): 1733, 1608, 1495, 1400, 1286, 1242, 1207, 1130, 1100, 1025, 940, 832, 768 cm^{-1}.


8.07
8.06
7.57
7.57
7.55
7.55
6.79
6.77
5.77
5.75
5.73
5.71
5.39
5.37
5.28
5.25
4.43
4.41
4.37
4.35
3.97
1.04
O
O
O
Me
MeO
N
1.00
1.04
1.02
1.02
1.06
2.06
1.06
1.05
3.12
3.01
f1 (ppm)


164.7
148.1
146.0
137.9
133.7
122.5
118.7
110.6
85.0
75.5
53.6
38.4
19.0
O
O
O
Me
MeO
N
f1 (ppm)

(*4R,5R*)-5-methyl-4-(2-phenylpyrimidin-5-yl)-5-vinyl-1,3-dioxan-2-one (2.1i)



Detailed Procedures

An oven-dried vial equipped with a magnetic stir bar was charged with (1*R*,2*R*)-2-methyl-1-(2-phenylpyrimidin-5-yl)-2-vinylpropane-1,3-diol[4] (162 mg, 0.6 mmol, 100 mol%). Under argon atmosphere, acetonitrile (6 mL, 0.1 M) was added via syringe. CDI (194 mg, 1.2 mmol, 200 mol%) was added in one portion at ambient temperature. The mixture was stirred at 25 ˚C for 16 h. The reaction was concentrated in *vacuo*. The residue was subjected to flash column chromatography (SiO_2, hexanes: ethyl acetate = 1:1) to furnish the title compounds as a white solid (128 mg, 0.43 mmol) in 72% yield.

TLC (SiO_2) R_f = 0.25 (hexanes/ethyl acetate = 1:1).

^{1}H NMR (500 MHz, $CDCl_3$) δ 8.75 (s, 2H), 8.52 – 8.40 (m, 2H), 7.57 – 7.48 (m, 3H), 5.82 (dd, *J* = 17.5, 11.0 Hz, 1H), 5.47 (d, *J* = 11.0 Hz, 1H), 5.39 (s, 1H), 5.29 (d, *J* = 17.5 Hz, 1H), 4.46 (d, *J* = 11.0 Hz, 1H), 4.43 (d, *J* = 11.1 Hz, 1H), 1.11 (s, 3H).

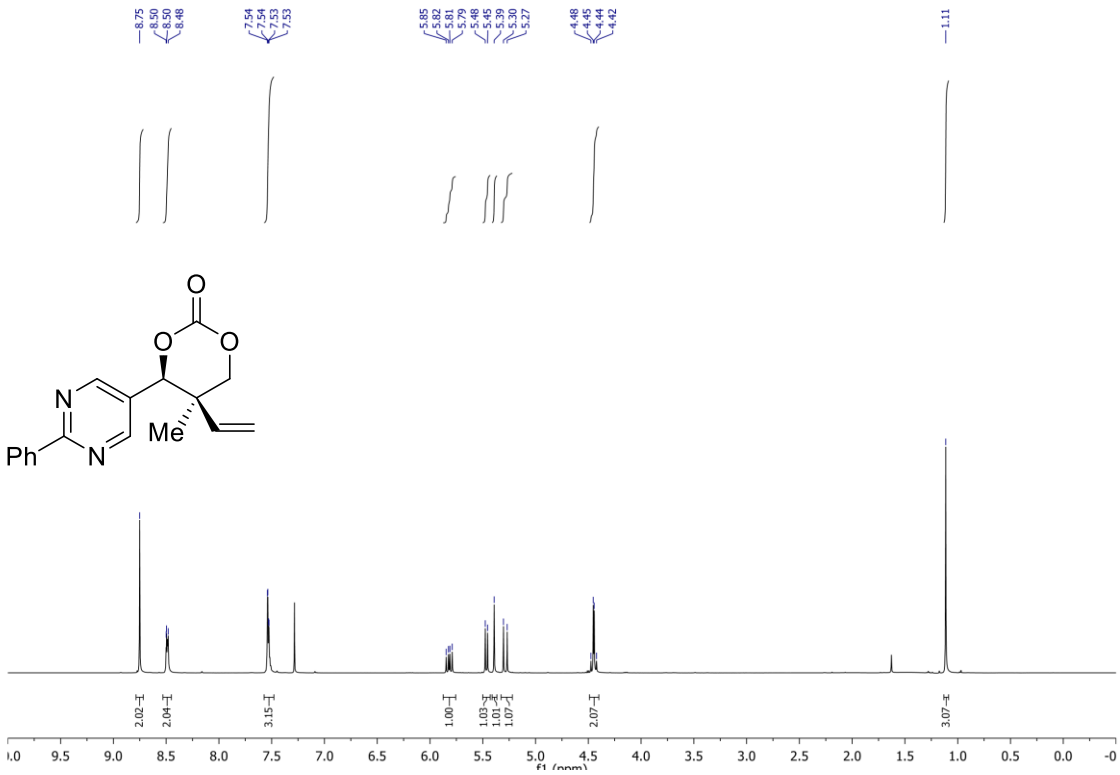
^{13}C NMR (125 MHz, $CDCl_3$) δ 165.2, 156.1, 147.4, 136.7, 132.8, 131.3, 128.7, 128.4, 125.1, 119.9, 83.50, 75.7, 38.3, 18.6.

HRMS (ESI) Calcd. for $C_{17}H_{16}N_2NaO_3^+$ $[M+Na]^+$: 319.1054, Found: 319.1059

$[\alpha]_D^{30}$: +139.9 (c = 0.56, $CHCl_3$)

m.p.: 153 – 154 ˚C

FTIR (neat): 1736, 1722, 1588, 1544, 1434, 1398, 1242, 1211, 1133, 1102, 753, 730, 693 cm^{-1}.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8.50
8.48
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7.54
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7.53
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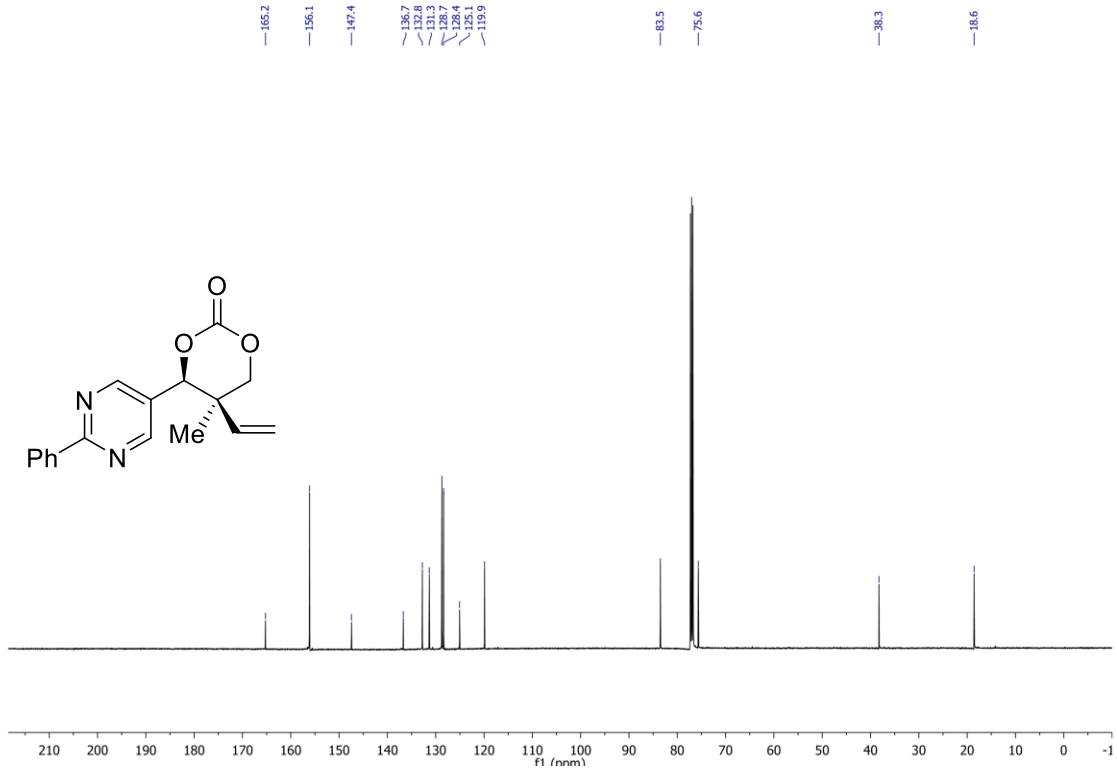
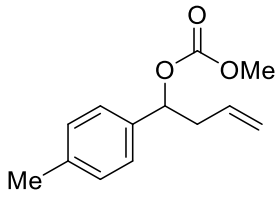
5.82
5.81
5.79
5.48
5.45
5.39
5.30
5.27
4.48
4.45
4.44
4.42
1.11
O
O
O
N
Me
Ph
N
2.02
2.04
3.15
1.00
1.03
1.01
1.07
2.07
3.07
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0


165.2
156.1
147.4
136.7
132.8
131.3
128.7
128.4
125.1
119.9
83.5
75.6
38.3
18.6
O
O
O
N
Me
Ph
N
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-1

Procedures and Spectral Data for the Model study of Cyclopropane Formation: methyl (1-(*p*-tolyl)but-3-en-1-yl) carbonate (*model*-2.1a)



Detailed Procedures

An oven-dried vial equipped with a magnetic stir bar was charged with 1-(*p*-tolyl)but-3-en-1-ol (324 mg, 2.0 mmol, 100 mol%) and 4-dimethylaminopyridine (439 mg, 3.6 mmol, 180 mol%). Under argon atmosphere, DCM (5 mL, 0.4 M) was added via syringe. Then, methyl chloroformate (0.23 mL, 3.0 mmol, 150 mol%) was added dropwise at 0 ˚C. The reaction mixture was stirred at ambient temperature for 16 h. Saturated aqueous ammonium chloride (15 mL) was added. The aqueous layer was extracted with ethyl acetate (30 mL x 2). The combined organic layers were washed with brine (20 mL), dried (Na_2SO_4), filtered and concentrated *in vacuo*. The residue was subjected to flash column chromatography (SiO_2, hexanes: ethyl acetate = 30:1) to furnish the title compound as a colorless oil (356 mg, 1.7 mmol) in 86% yield.

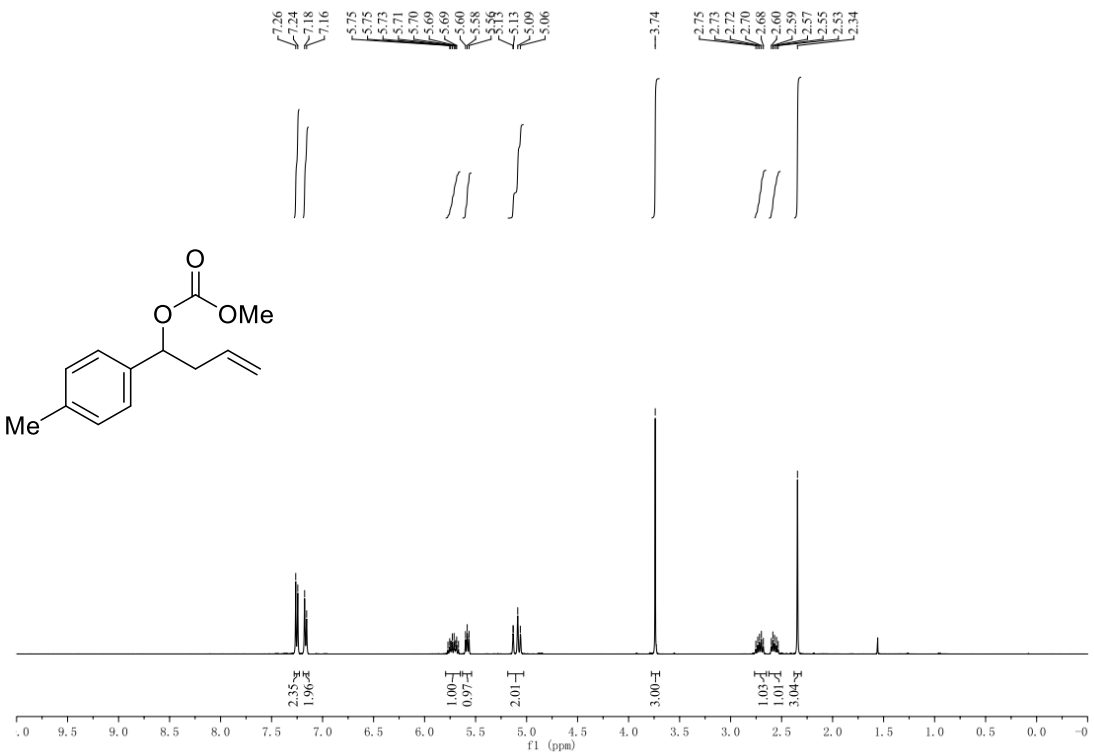
TLC (SiO_2) R_f = 0.35 (hexanes/ethyl acetate = 10:1).

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.25 (d, *J* = 8.0 Hz, 2H), 7.17 (d, *J* = 7.9 Hz, 2H), 5.72 (ddt, *J* = 17.2, 10.2, 7.0 Hz, 1H), 5.61 – 5.55 (m, 1H), 5.15 – 5.04 (m, 2H), 3.74 (s, 3H), 2.77 – 2.65 (m, 1H), 2.62 – 2.51 (m, 1H), 2.34 (s, 3H).

^{13}C NMR (100 MHz, $CDCl_3$) δ 155.2, 138.0, 136.5, 133.0, 129.2, 126.5, 118.2, 79.4, 54.7, 40.6, 21.2.

HRMS (ESI) Calcd. for $C_{11}H_{13}^+$ $[M\text{-}OCO_2Me]^+$: 145.1012, Found: 145.1011.

FTIR (neat): 2955, 1745, 1516, 1441, 1261, 1110, 1041, 939, 866, 791, 720 cm^{-1}.


7.26
7.24
7.18
7.16
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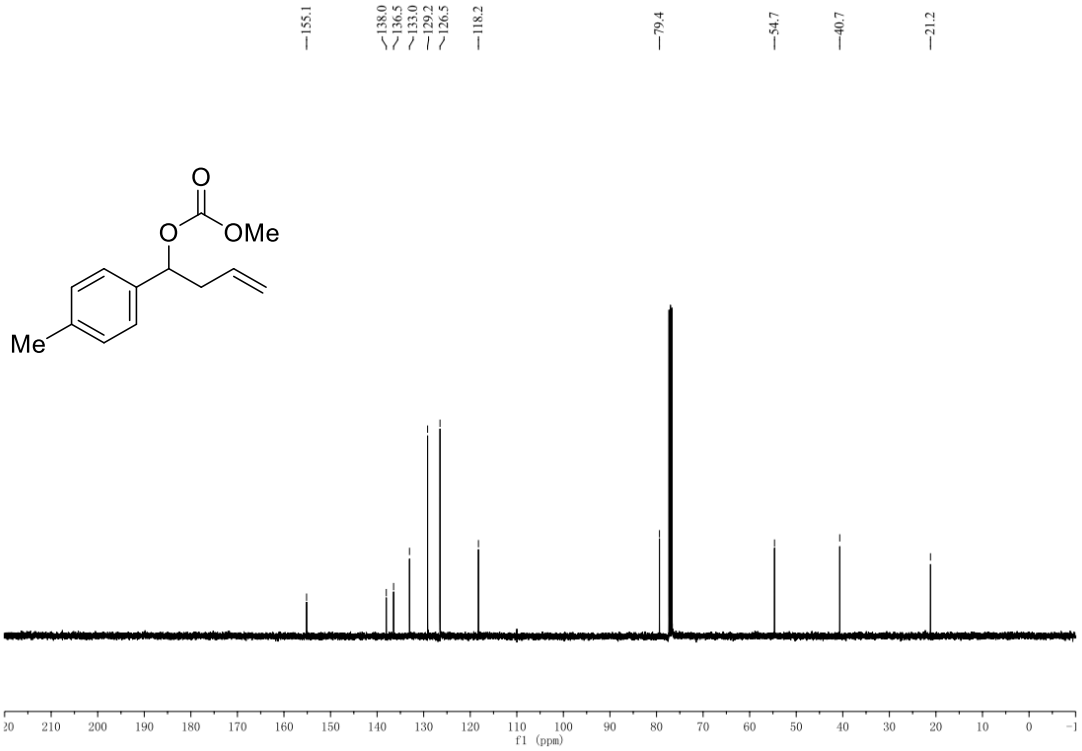
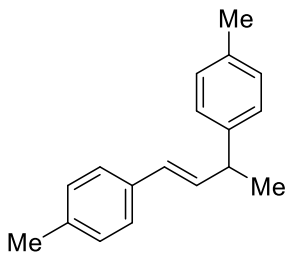
5.75
5.73
5.71
5.70
5.69
5.69
5.60
5.58
5.16
5.15
5.13
5.09
5.06
3.74
2.75
2.73
2.72
2.70
2.68
2.60
2.59
2.57
2.55
2.53
2.34
O
O
OMe
Me
2.35
1.96
1.00
0.97
2.01
3.00
1.03
1.01
3.04
f1 (ppm)


155.1
138.0
136.5
133.0
129.2
126.5
118.2
79.4
54.7
40.7
21.2
O
O
OMe
Me
f1 (ppm)

(*E*)-4,4'-(but-1-ene-1,3-diyl)bis(methylbenzene) (2.5)



Detailed Procedures

An oven-dried sealed tube equipped with a magnetic stir bar was charged with carbonate *model*-**2.1a** (22.0 mg, 0.1 mmol, 100 mol%), tri(*p*-tolyl)boroxine (30.1 mg, 0.085 mmol, 85 mol%) **2.2a**, dicyclohexylphenylphosphine (5.8 mg, 0.02 mmol, 20 mol%, 95%wt) and potassium phosphate (42.4 mg, 0.2 mmol, 200 mol%). This tube was transferred into an argon-atmosphere glovebox. $Ni(cod)_2$ (2.8 mg, 0.01 mmol, 10 mol%) and toluene (0.5 mL, 0.2 M) were added. After sealing the tube with cap, the tube was removed from the glovebox and the reaction mixture was stirred at 45 ˚C for 48 h. The reaction was cooled to ambient temperature, diluted with Et_2O (1 mL) and filtered through a plug of silica gel, which was rinsed with Et_2O (2 mL). The combined organic solution was concentrated *in vacuo*. The residue was subjected to flash column chromatography (SiO_2, hexanes) to furnish the known title compound[7] as a colorless oil (7.3 mg, 0.03 mmol) in 31% yield.

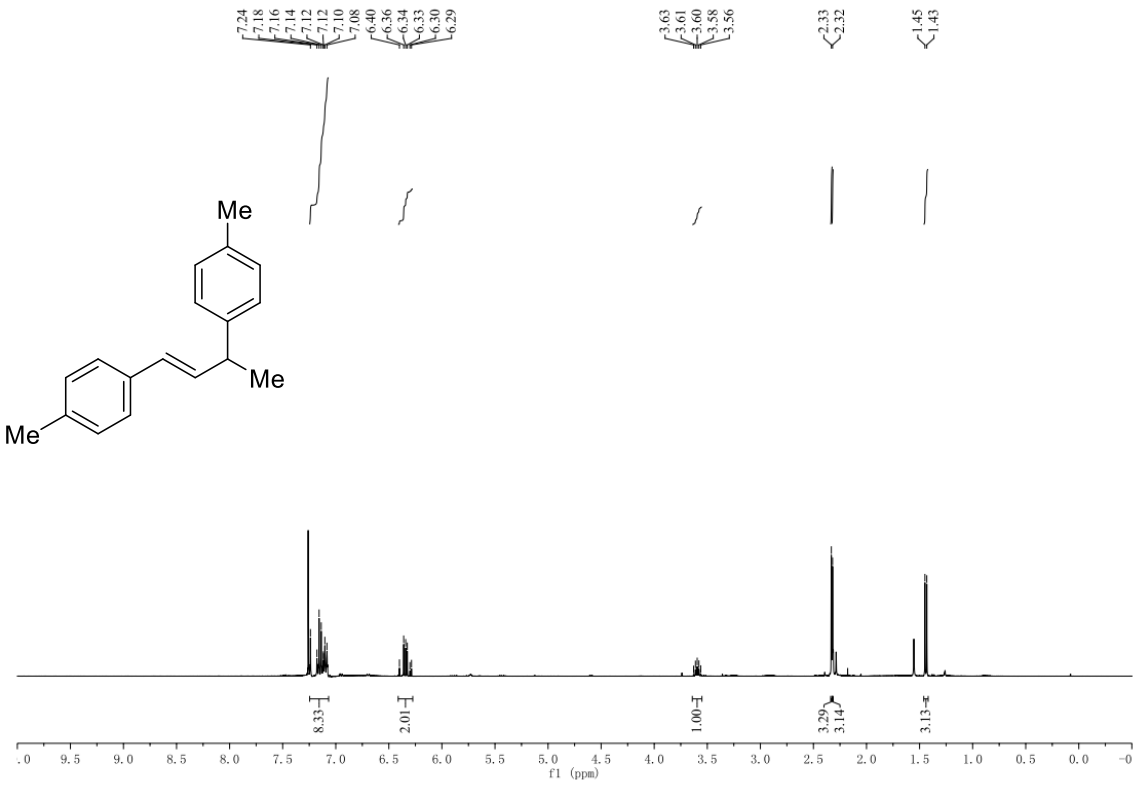
TLC (SiO_2) R_f = 0.28 (hexanes).

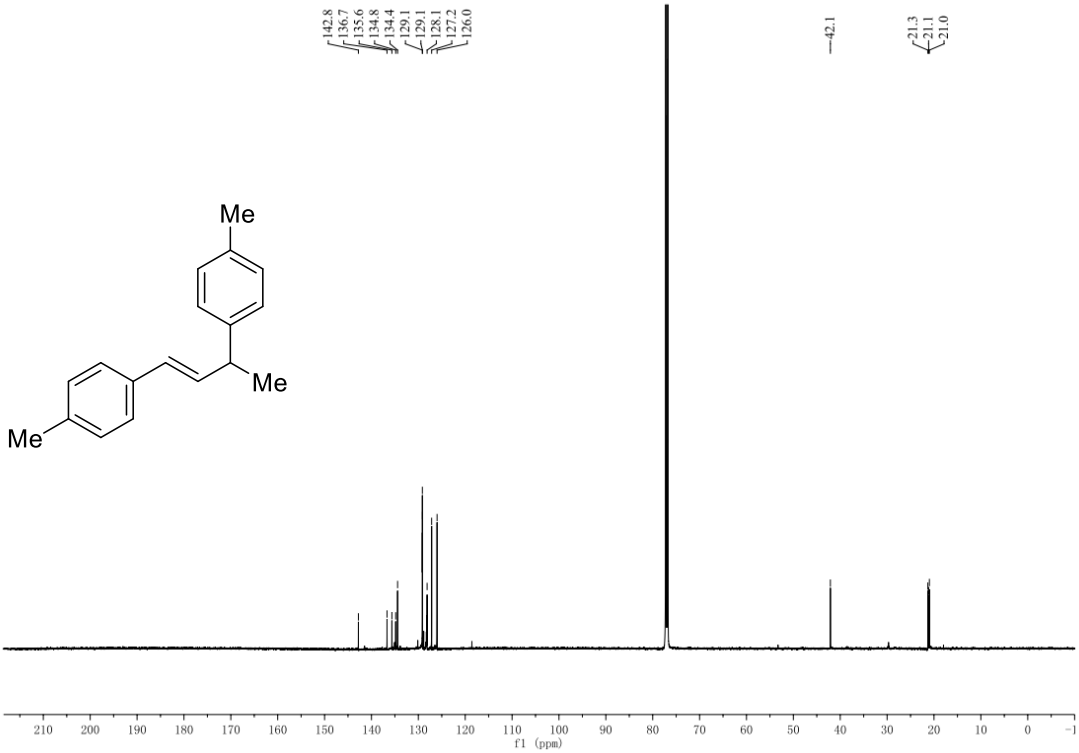
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.24 – 7.07 (m, 8H), 6.38 (d, *J* = 16.0 Hz, 1H), 6.31 (dd, *J* = 15.9, 6.2 Hz, 1H), 3.64 – 3.56 (m, 1H), 2.33 (s, 3H), 2.32 (s, 3H), 1.44 (d, *J* = 6.8 Hz, 3H).

^{13}C NMR (125 MHz, $CDCl_3$) δ 142.8, 136.7, 135.6, 134.8, 134.4, 129.1, 129.1, 128.1, 127.2, 126.0, 42.1, 21.3, 21.1, 21.0.

HRMS (CI) Calcd. for $C_{18}H_{20}^+$ $[M]^+$: 236.1560, Found: 236.1570.

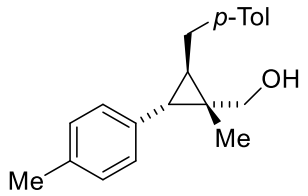
FTIR (neat): 3020, 2962, 2922, 2865, 1513, 1451, 1371, 1111, 1015, 967, 816, 798, 723 cm^{-1}


7.24
7.18
7.16
7.14
7.12
7.12
7.12
7.10
7.08
6.40
6.36
6.34
6.33
6.30
6.29
3.63
3.61
3.60
3.58
3.56
2.33
2.32
1.45
1.43
Me
Me
Me
8.33
2.01
1.00
3.29
3.14
3.13
f1 (ppm)


142.8
136.7
135.6
134.8
134.4
129.1
129.1
128.1
127.2
126.0
42.1
21.3
21.1
21.0
Me
Me
Me
f1 (ppm)

Procedures and Spectral Data for the Synthesis of Enantiomerically Enriched Cyclopropanes 3a-3r:

((1*S*,2*R*,3*S*)-1-methyl-2-(4-methylbenzyl)-3-(*p*-tolyl)cyclopropyl)methanol (2.3a)



Detailed Procedures

An oven-dried sealed tube equipped with a magnetic stir bar was charged with vinyl-dioxanone **2.1a** (23.2 mg, 0.1 mmol, 100 mol%), tri(*p*-tolyl)boroxine (30.1 mg, 0.085 mmol, 85 mol%) **2.2a**, dicyclohexylphenylphosphine (5.8 mg, 0.02 mmol, 20 mol%, 95%wt) and potassium phosphate (42.4 mg, 0.2 mmol, 200 mol%). This tube was transferred into an argon-atmosphere glovebox. $Ni(cod)_2$ (2.8 mg, 0.01 mmol, 10 mol%) and toluene (0.5 mL, 0.2 M) were added. After sealing the tube with cap, the tube was removed from the glovebox and the reaction mixture was stirred at 45 ˚C for 48 h. The reaction was cooled to ambient temperature, diluted with Et_2O (1 mL) and filtered through a plug of silica gel, which was rinsed with Et_2O (2 mL). The combined organic solution was concentrated *in vacuo*. The residue was subjected to flash column chromatography (SiO_2, hexanes: ethyl acetate = 10:1) to furnish the title compound as a white solid (23.8 mg, 0.08 mmol) in 85% yield.

TLC (SiO_2) R_f = 0.45 (hexanes/ethyl acetate = 3:1).

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.20 – 7.05 (m, 8H), 3.39 (dd, *J* = 11.6, 7.6 Hz, 1H), 3.24 (dd, *J* = 11.6, 4.4 Hz, 1H), 2.89 – 2.74 (m, 2H), 2.33 (s, 3H), 2.31 (s, 3H), 1.89 (d, *J* = 5.9 Hz, 1H), 1.52 (dd, *J* = 13.0, 7.1 Hz, 1H), 1.41 (s, 3H), 0.93 – 0.87 (m, 1H).

^{13}C NMR (100 MHz, $CDCl_3$) δ 138.7, 135.7, 135.7, 135.3, 129.1, 129.1, 128.3, 128.0, 68.2, 35.1, 34.2, 29.6, 27.4, 21.0, 21.0, 17.2.

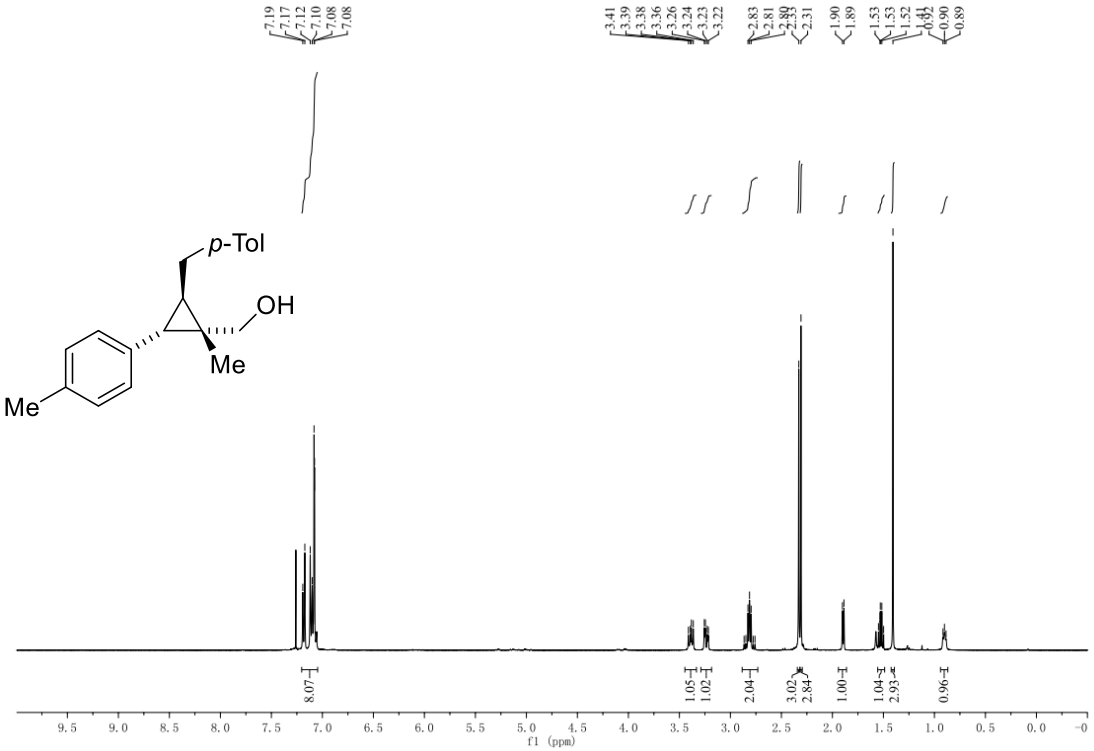
HRMS (ESI) Calcd. for $C_{20}H_{24}NaO^+$ $[M+Na]^+$: 303.1719, Found: 303.1720.

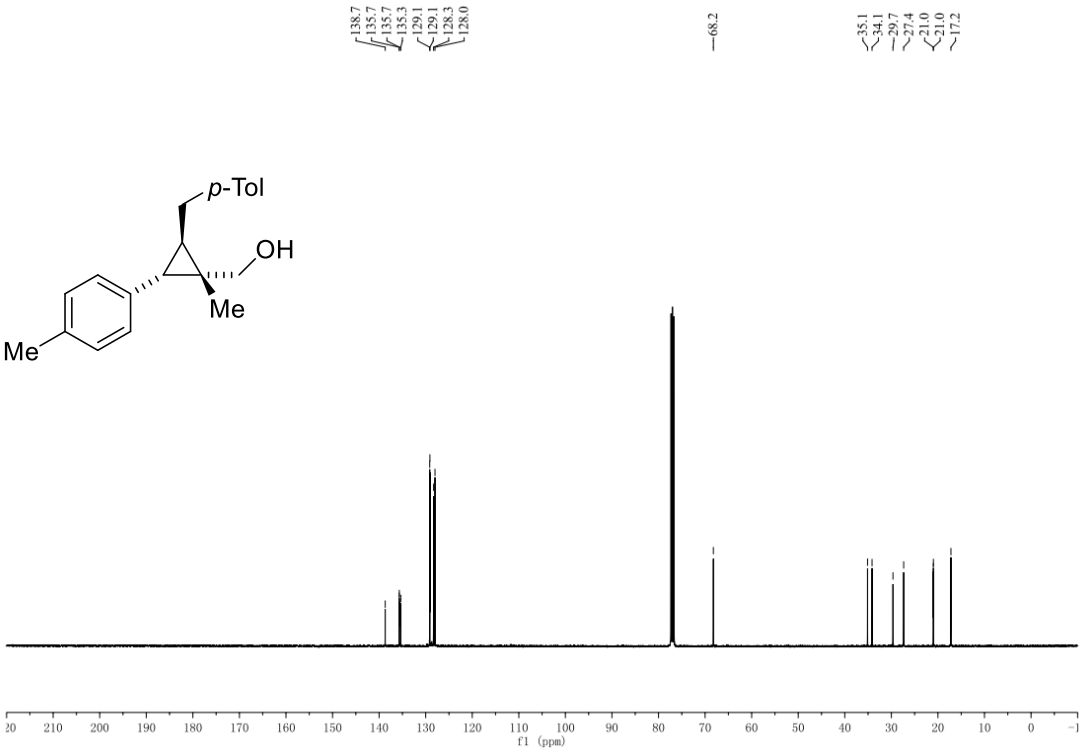
$[\alpha]_D^{33}$: +24.0 (*c* = 1.0, $CHCl_3$).

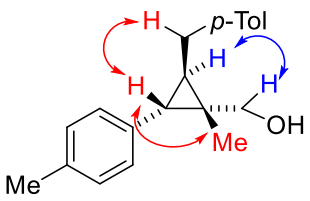
m.p. : 59-60 ˚C

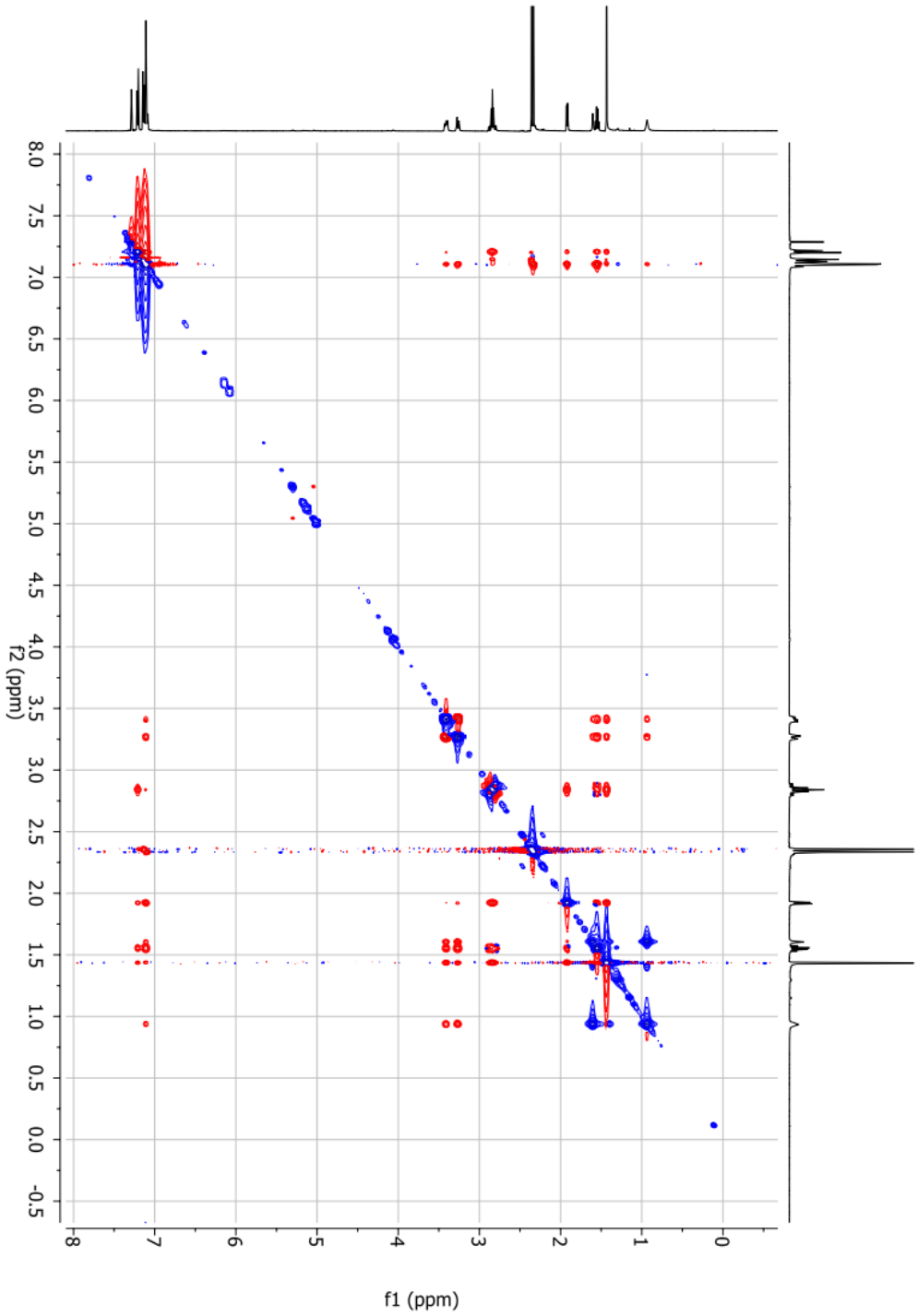
FTIR (neat): 3394, 2920, 2361, 2342, 1514, 1460, 1113, 1020, 825, 807, 759, 669 cm^{-1}

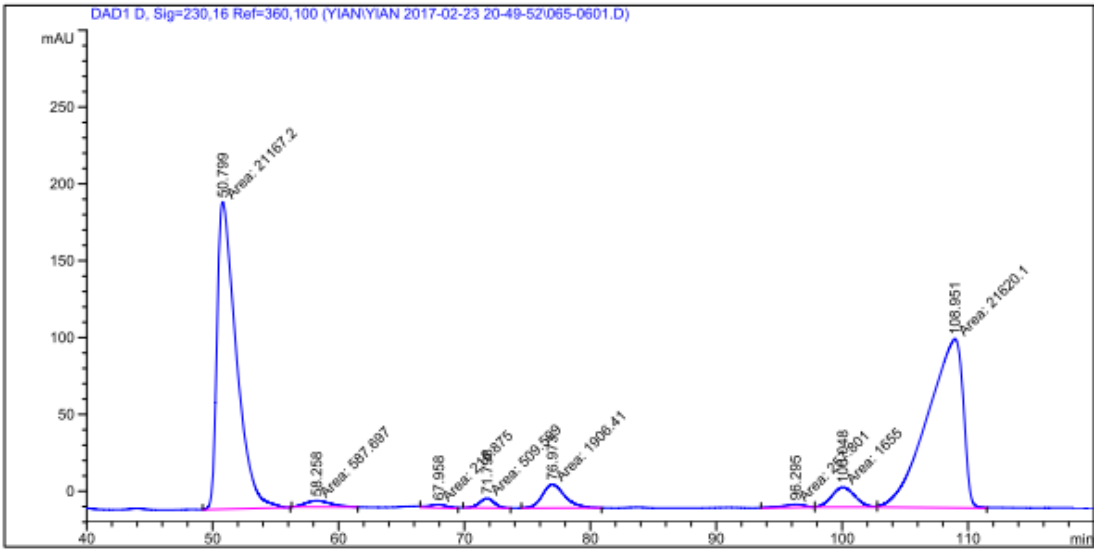
HPLC (two connected chiralcel OJ-H columns, hexanes:*i*-PrOH = 98:2, 1.0 mL/min, 230 nm), ee = 91%.



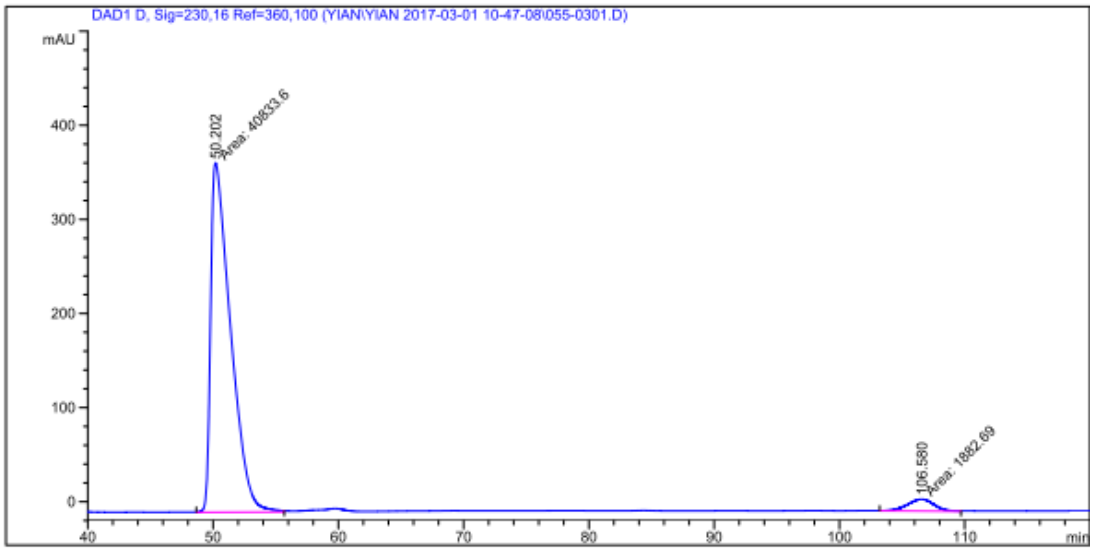



H
p-Tol
H
H
H
OH
Me
Me


f2 (ppm)
f1 (ppm)

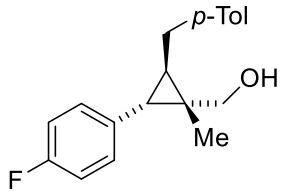


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	50.799	MM	1.7645	2.11672e4	199.93961	44.1714
2	58.258	MM	2.3894	587.69690	4.09932	1.2264
3	67.958	MM	1.7158	216.87540	2.10667	0.4526
4	71.798	MM	1.3703	509.59866	6.19798	1.0634
5	76.973	MM	2.0695	1906.41321	15.35360	3.9783
6	96.295	MM	2.1431	257.80118	2.00491	0.5380
7	100.048	MM	2.1311	1654.99817	12.94301	3.4536
8	108.951	MM	3.2794	2.16201e4	109.87929	45.1164



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	50.202	MM	1.8339	4.08336e4	371.09204	95.5926
2	106.580	MM	2.4865	1882.69165	12.61956	4.4074

((1*S*,2*S*,3*R*)-2-(4-fluorophenyl)-1-methyl-3-(4-methylbenzyl)cyclopropyl)methanol (2.3b)



Detailed Procedures

An oven-dried sealed tube equipped with a magnetic stir bar was charged with vinyl-dioxanone **2.1a** (23.6 mg, 0.1 mmol, 100 mol%), tri(*p*-tolyl)boroxine (30.1 mg, 0.085 mmol, 85 mol%) **2.2a**, dicyclohexylphenylphosphine (5.8 mg, 0.02 mmol, 20 mol%, 95%wt) and potassium phosphate (42.4 mg, 0.2 mmol, 200 mol%). This tube was transferred into an argon-atmosphere glovebox. $Ni(cod)_2$ (2.8 mg, 0.01 mmol, 10 mol%) and toluene (0.5 mL, 0.2 M) were added. After sealing the tube with cap, the tube was removed from the glovebox and the reaction mixture was stirred at 45 ˚C for 48 h. The reaction was cooled to ambient temperature, diluted with Et_2O (1 mL) and filtered through a plug of silica gel, which was rinsed with Et_2O (2 mL). The combined organic solution was concentrated *in vacuo*. The residue was subjected to flash column chromatography (SiO_2, hexanes: ethyl acetate = 10:1) to furnish the title compound as a white solid (21.9 mg, 0.08 mmol) in 77% yield.

TLC (SiO_2) R_f = 0.31 (hexanes/ethyl acetate = 3:1).

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.20 – 7.10 (m, 6H), 6.98 – 6.91 (m, 2H), 3.35 (d, *J* = 11.5 Hz, 1H), 3.22 (d, *J* = 11.5 Hz, 1H), 2.88 – 2.73 (m, 2H), 2.34 (s, 3H), 1.89 (d, J = 5.9 Hz, 1H), 1.50 – 1.44 (m, 1H), 1.41 (s, 3H).

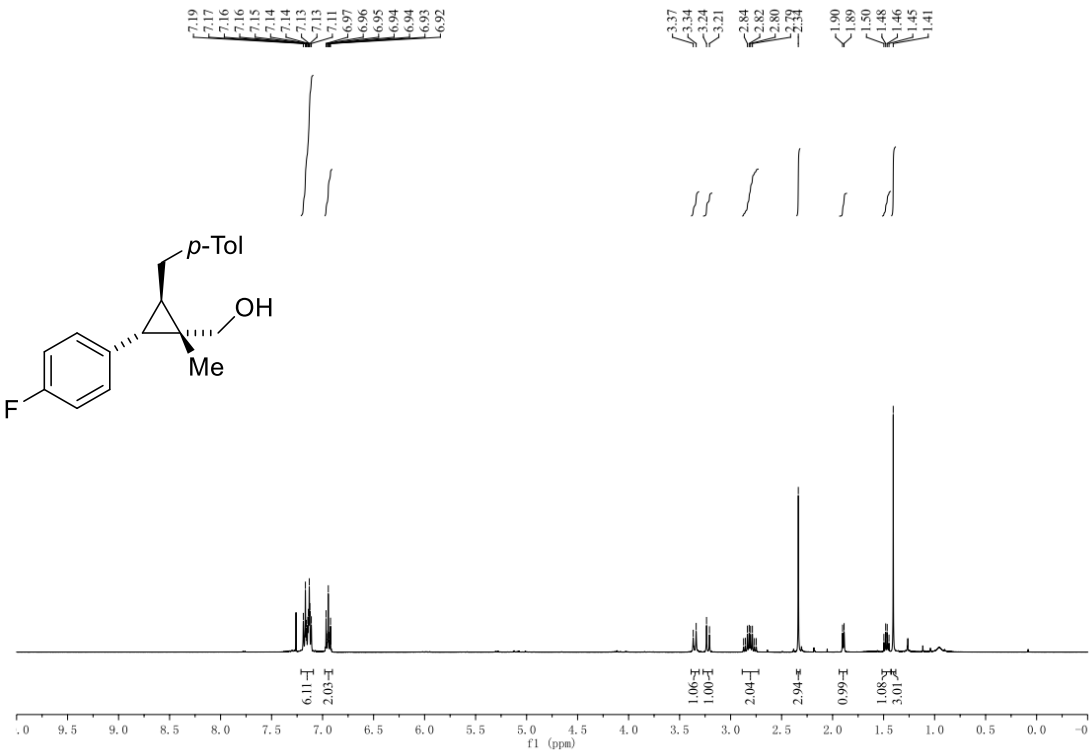
^{13}C NMR (100 MHz, $CDCl_3$) δ 161.4 (d, *J* = 244.5 Hz), 138.5, 135.4, 134.5 (d, *J* = 3.1 Hz), 130.0 (d, *J* = 7.8 Hz), 129.2, 128.0, 115.1 (d, J = 21.2 Hz), 68.1, 34.7, 34.1, 29.5, 27.9, 21.0, 17.1.

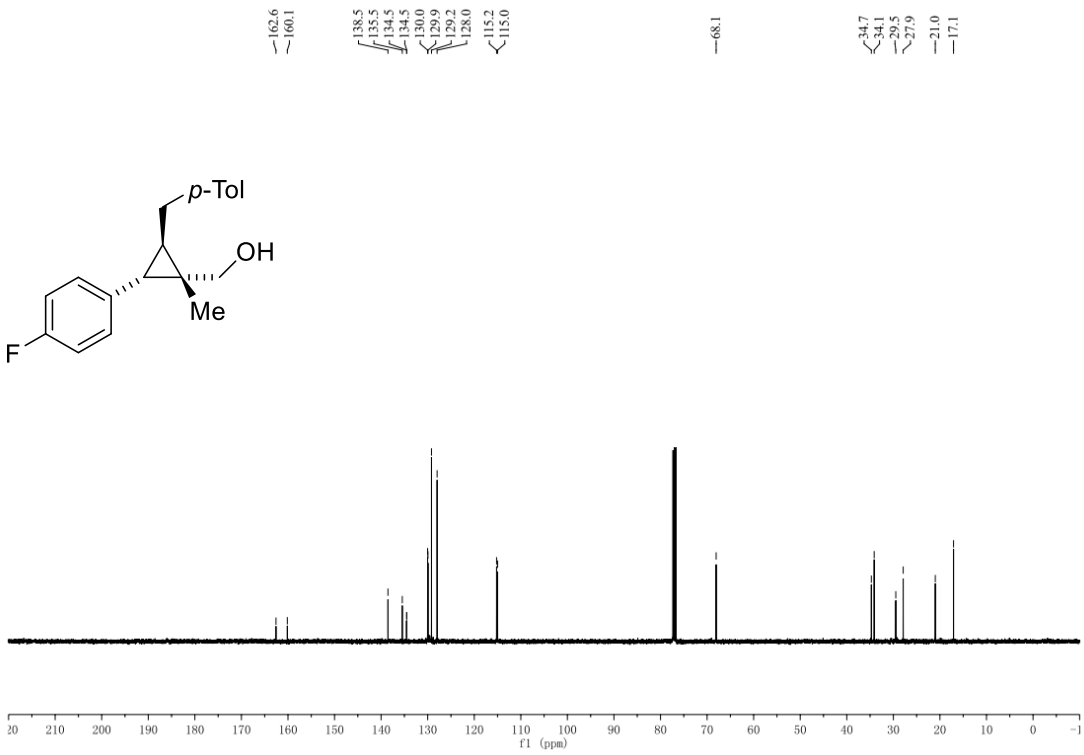
^{19}F NMR (376 MHz, $CDCl_3$) δ -116.8 – -116.9 (m).

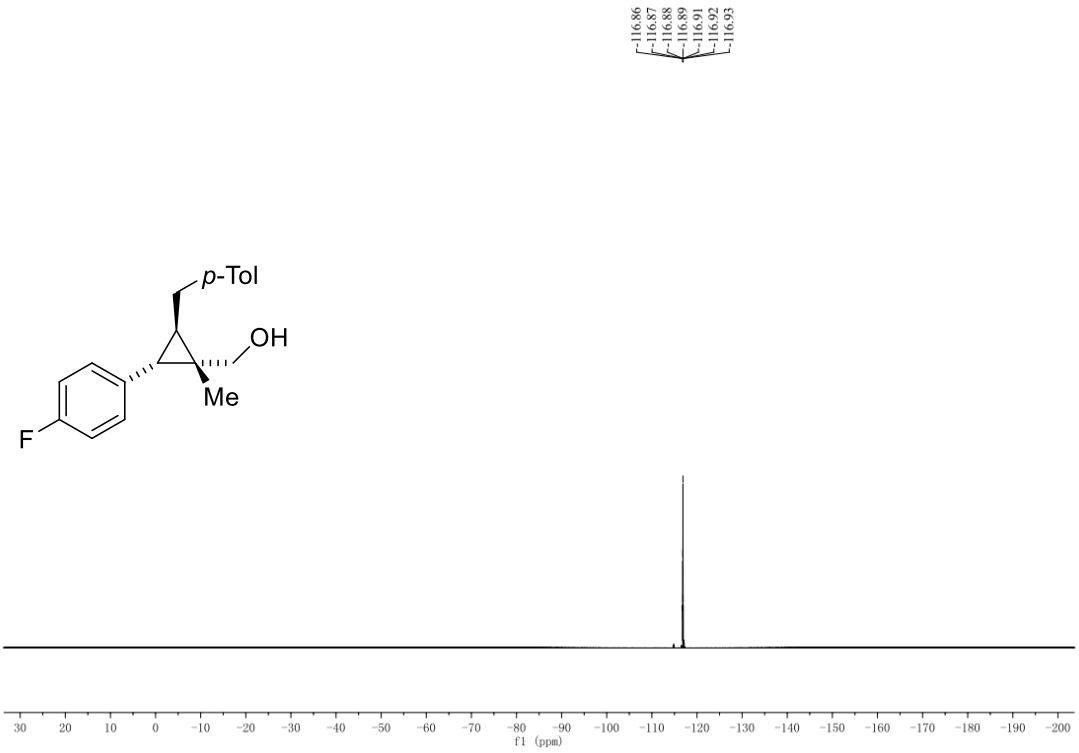
HRMS (CI) Calcd. for $C_{19}H_{20}FO^+$ $[M-H]^+$: 283.1493, Found: 283.1492.

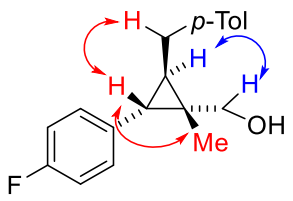
$[\alpha]_D^{33}$: +26.7 (*c* = 1.0, $CHCl_3$).

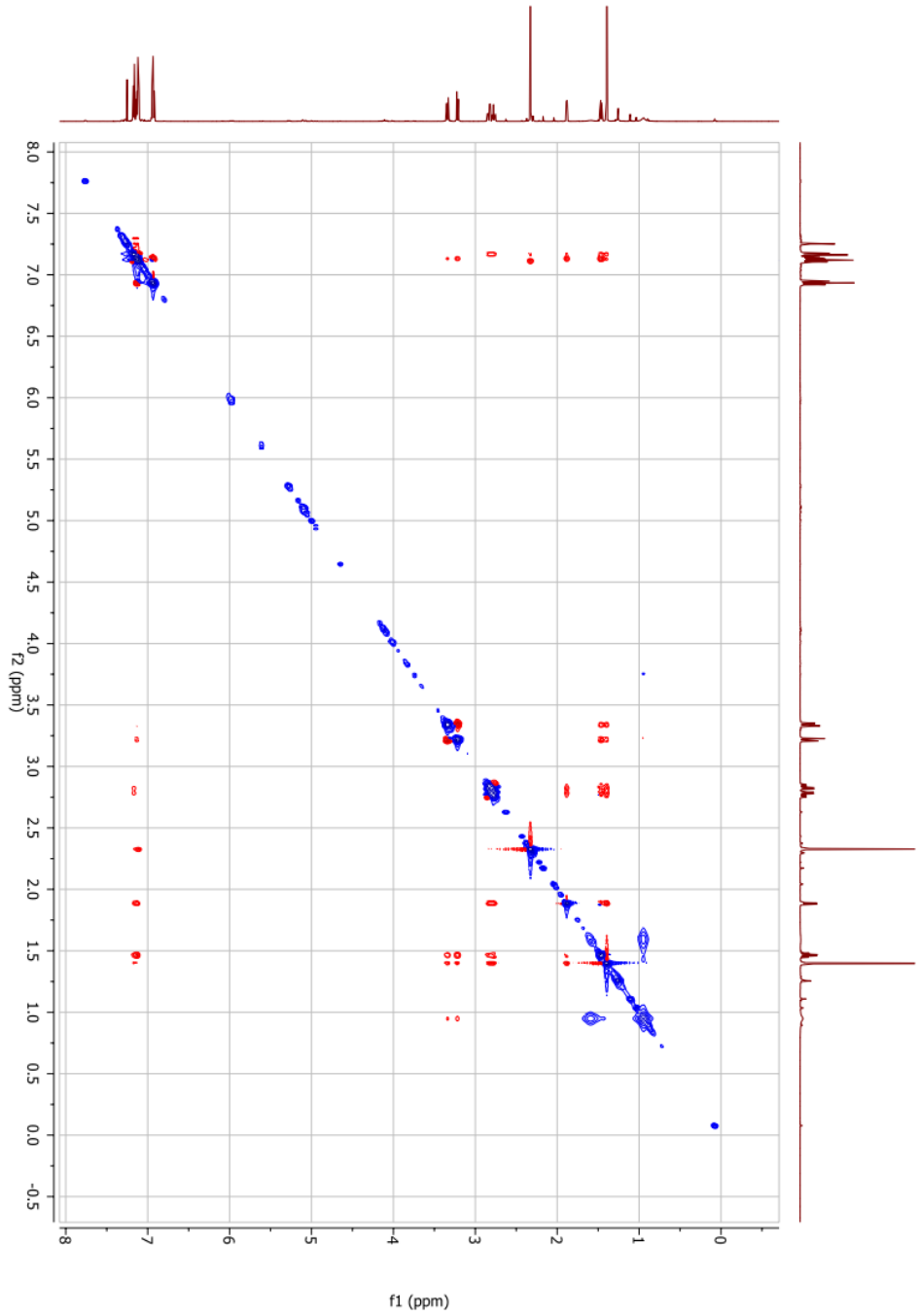
FTIR (neat): 3360, 2921, 1604, 1510, 1456, 1222, 1157, 1103, 1069, 1015, 838, 769 cm^{-1}


p-Tol
OH
Me
F
f1 (ppm)

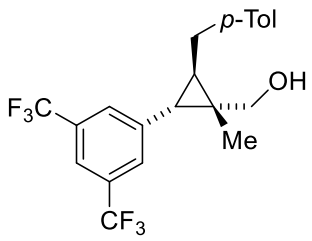

p-Tol
OH
Me
F
f1 (ppm)


-116.86
-116.87
-116.88
-116.89
-116.91
-116.92
-116.93
p-Tol
OH
Me
F
30 20 10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90 -100 -110 -120 -130 -140 -150 -160 -170 -180 -190 -200
f1 (ppm)


H
p-Tol
H
H
H
OH
Me
F


f2 (ppm)
f1 (ppm)

((1*S*,2*R*,3*S*)-1-methyl-2-(4-methylbenzyl)-3-(*p*-tolyl)cyclopropyl)methanol (2.3a)



Detailed Procedures

An oven-dried sealed tube equipped with a magnetic stir bar was charged with vinyl-dioxanone **2.1a** (35.4 mg, 0.1 mmol, 100 mol%), tri(p-tolyl)boroxine (30.1 mg, 0.085 mmol, 85 mol%) **2.2a**, dicyclohexylphenylphosphine (5.8 mg, 0.02 mmol, 20 mol%, 95%wt) and potassium phosphate (42.4 mg, 0.2 mmol, 200 mol%). This tube was transferred into an argon-atmosphere glovebox. $Ni(cod)_2$ (2.8 mg, 0.01 mmol, 10 mol%) and toluene (0.5 mL, 0.2 M) were added. After sealing the tube with cap, the tube was removed from the glovebox and the reaction mixture was stirred at 55 ˚C for 48 h. The reaction was cooled to ambient temperature, diluted with Et_2O (1 mL) and filtered through a plug of silica gel, which was rinsed with Et_2O (2 mL). The combined organic solution was concentrated *in vacuo*. The residue was subjected to flash column chromatography (SiO_2, hexanes: ethyl acetate = 20:1) to furnish the title compound as a colorless oil (22.7 mg, 0.07 mmol) in 73% yield.

TLC (SiO_2) R_f = 0.41 (hexanes/ethyl acetate = 5:1).

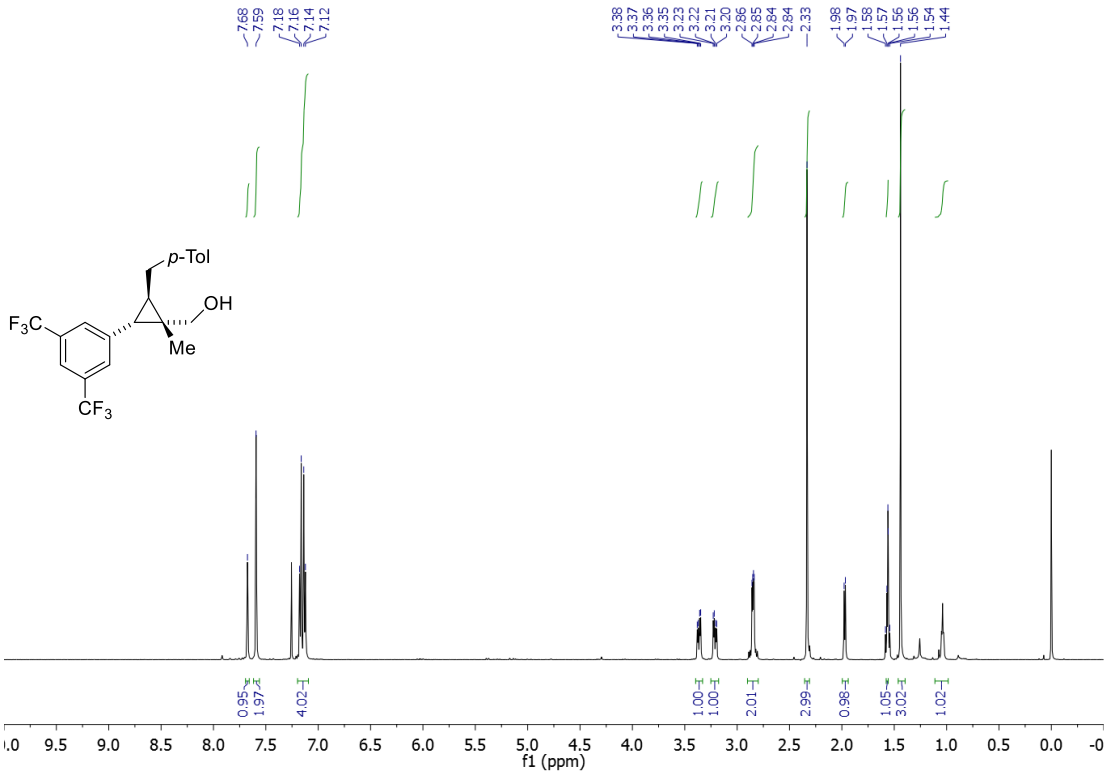
^{1}H NMR (500 MHz, CDCl3) δ 7.68 (s, 1H), 7.59 (s, 2H), 7.23 – 7.04 (m, 4H), 3.36 (dd, *J* = 11.3, 4.9 Hz, 1H), 3.21 (dd, *J* = 11.3, 5.0 Hz, 1H), 2.84-2.86 (m, *J* = 7.2, 3.5 Hz, 2H), 2.33 (s, 3H), 1.97 (d, *J* = 6.0 Hz, 1H), 1.64 – 1.48 (m, 1H), 1.44 (s, 3H), 1.04 (t, *J* = 5.4 Hz, 1H).

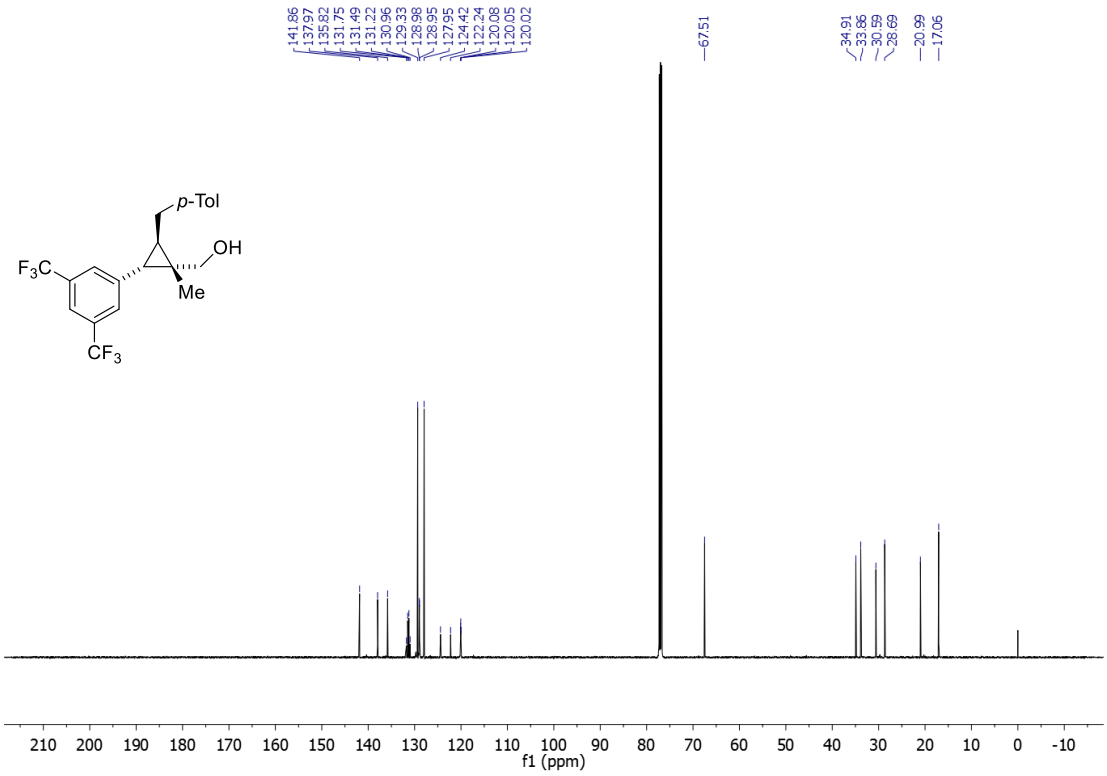
^{13}C NMR (125 MHz, CDCl3) δ 141.8, 137.9, 135.8, 131.3 (q, *J* = 33.1 Hz), 129.3, 128.9 (d, *J* = 3.7 Hz), 127.9, 124.4, 122.2, 120.8 – 119.6 (m), 67.5, 34.9, 33.8, 30.5, 28.69, 20.9, 17.0.

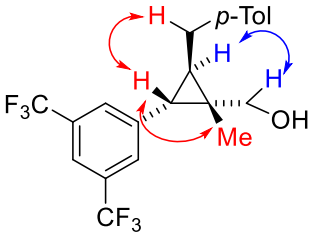
HRMS (ESI) Calcd. for $C_{21}H_{20}F_6NaO^+$ $[M+Na]^+$: 425.1311, Found: 425.1315.

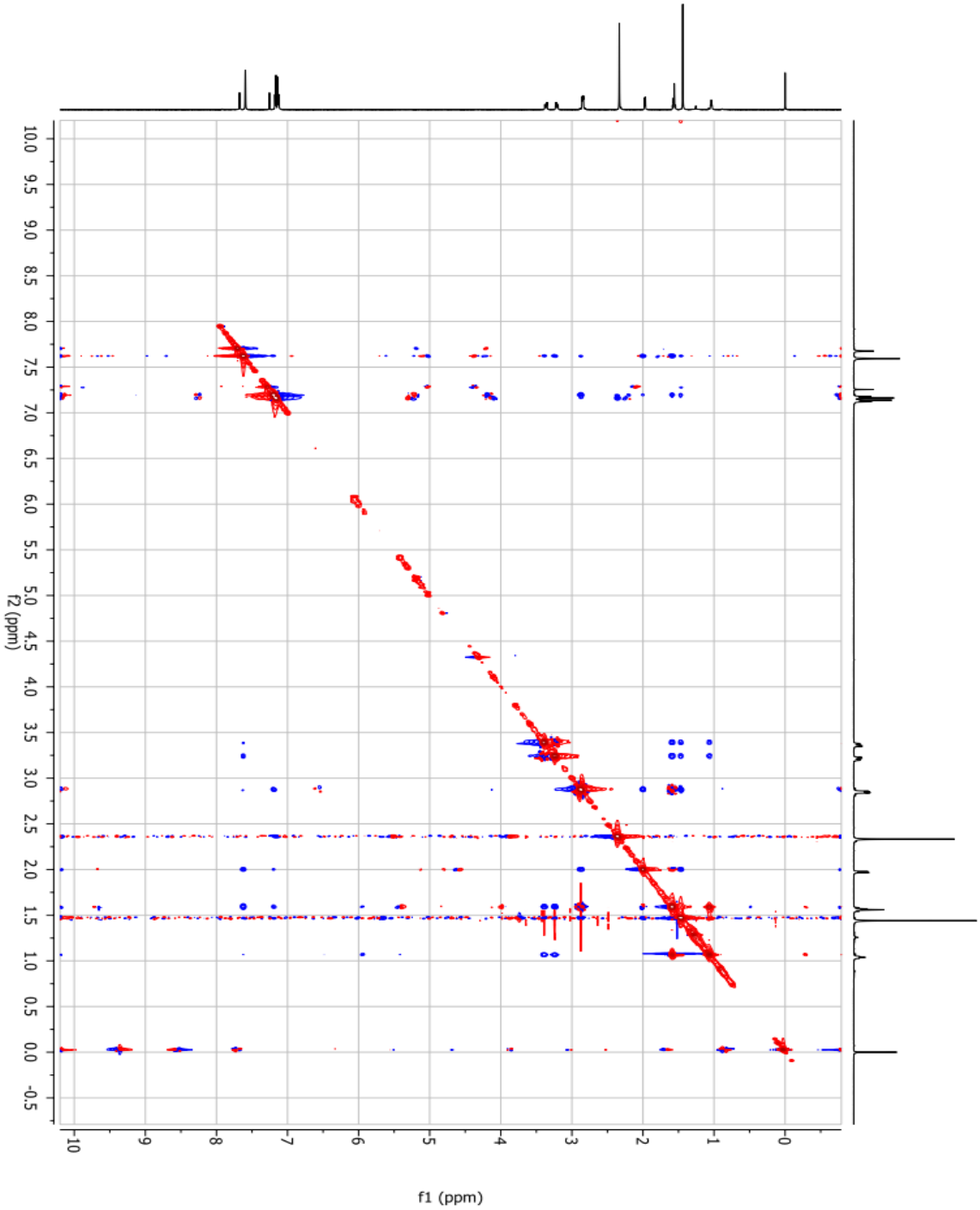
$[\alpha]_D^{32}$: +23.0 (*c* = 1.0, $CHCl_3$).

FTIR (neat): 3360, 2923, 1515, 1374, 1275, 1169, 1127, 1021, 894, 682 cm^{-1}.

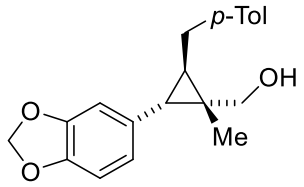

7.68
7.59
7.18
7.16
7.14
7.12
3.38
3.37
3.36
3.35
3.23
3.22
3.21
3.20
2.86
2.85
2.84
2.84
2.33
1.98
1.97
1.58
1.57
1.56
1.56
1.54
1.44
p-Tol
OH
F3C
Me
CF3
0.95
1.97
4.02
1.00
1.00
2.01
2.99
0.98
1.05
3.02
1.02
f1 (ppm)


141.86
137.97
135.82
131.75
131.49
131.22
130.96
129.33
128.98
128.95
127.85
124.42
122.24
120.08
120.05
120.02
67.51
34.91
33.86
30.59
28.69
20.99
17.06
p-Tol
OH
F3C
Me
CF3
f1 (ppm)


H
p-Tol
H
H
H
F3C
OH
Me
CF3


f2 (ppm)
f1 (ppm)

((1*S*,2*S*,3*R*)-2-(benzo[*d*][1,3]dioxol-5-yl)-1-methyl-3-(4-methylbenzyl)cyclopropyl)methanol (2.3d)



Detailed Procedures

An oven-dried sealed tube equipped with a magnetic stir bar was charged with vinyl-dioxanone **2.1a** (26.2 mg, 0.1 mmol, 100 mol%), tri(*p*-tolyl)boroxine (30.1 mg, 0.085 mmol, 85 mol%) **2.2a**, dicyclohexylphenylphosphine (5.8 mg, 0.02 mmol, 20 mol%, 95%wt) and potassium phosphate (42.4 mg, 0.2 mmol, 200 mol%). This tube was transferred into an argon-atmosphere glovebox. $Ni(cod)_2$ (2.8 mg, 0.01 mmol, 10 mol%) and toluene (0.5 mL, 0.2 M) were added. After sealing the tube with cap, the tube was removed from the glovebox and the reaction mixture was stirred at 55 ˚C for 48 h. The reaction was cooled to ambient temperature, diluted with Et_2O (1 mL) and filtered through a plug of silica gel, which was rinsed with Et_2O (2 mL). The combined organic solution was concentrated *in vacuo*. The residue was subjected to flash column chromatography (SiO_2, hexanes: ethyl acetate = 5:1) to furnish the title compound as a white solid (21.6 mg, 0.07 mmol) in 70% yield.

TLC (SiO_2) R_f = 0.25 (hexanes/ethyl acetate = 3:1).

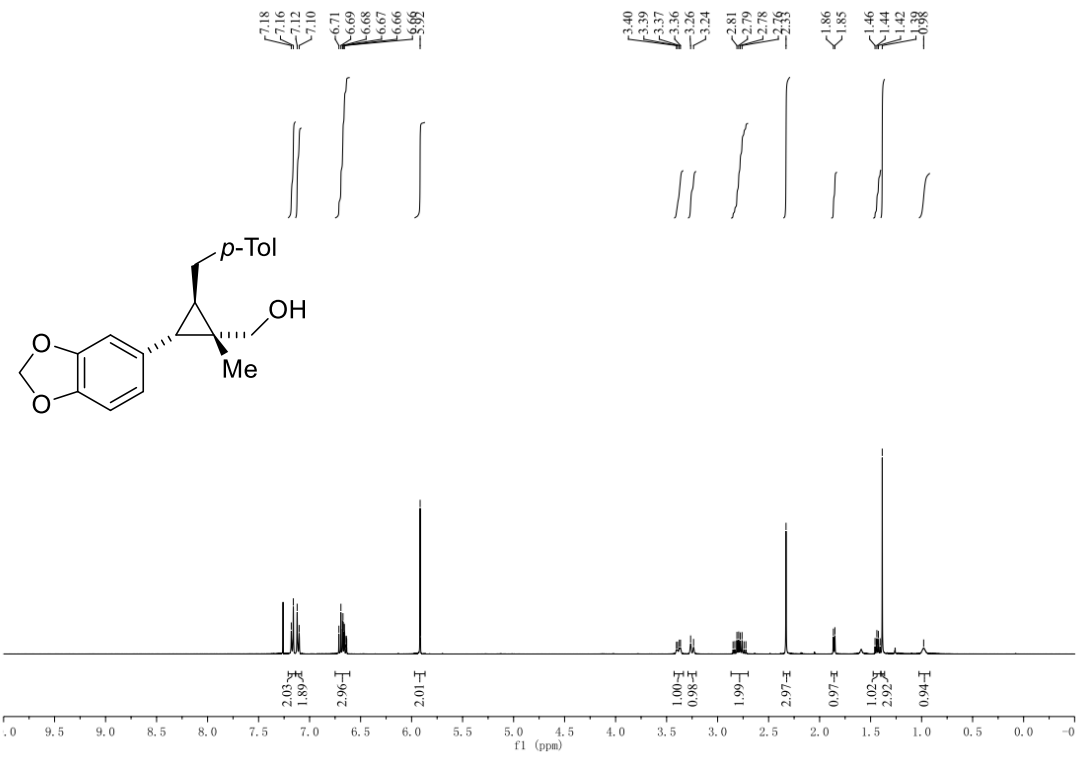
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.21 – 7.07 (m, 4H), 6.74 – 6.62 (m, 3H), 5.92 (s, 2H), 3.38 (dd, *J* = 11.5, 4.4 Hz, 1H), 3.25 (d, *J* = 11.5 Hz, 1H), 2.88 – 2.70 (m, 2H), 2.33 (s, 3H), 1.86 (d, *J* = 5.9 Hz, 1H), 1.46 – 1.40 (m, 1H), 1.39 (s, 3H), 0.98 (brs, 1H).

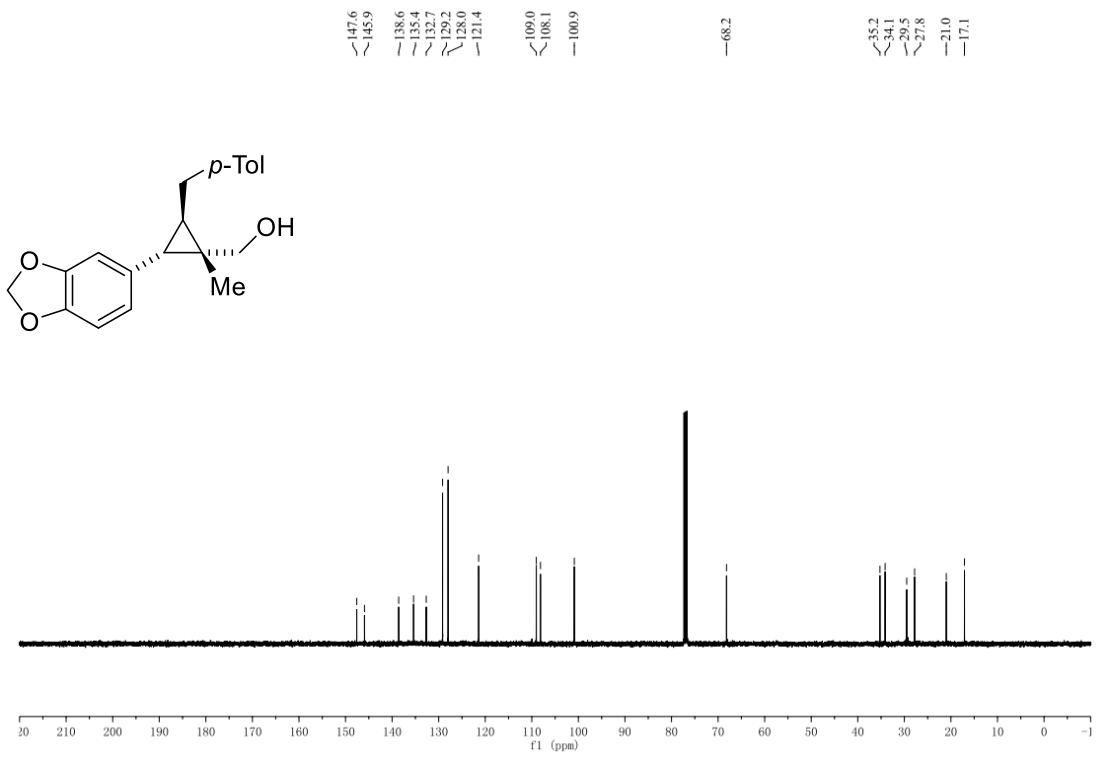
^{13}C NMR (100 MHz, $CDCl_3$) δ 147.6, 145.9, 138.6, 135.4, 132.7, 129.2, 128.0, 121.4, 109.0, 108.1, 100.9, 68.2, 35.2, 34.1, 29.5, 27.8, 21.0, 17.1.

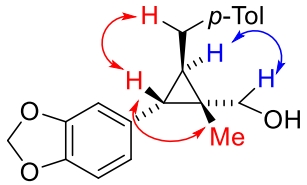
HRMS (CI) Calcd. for $C_{20}H_{22}O_3^+$ $[M]^+$: 310.1563, Found: 310.1567.

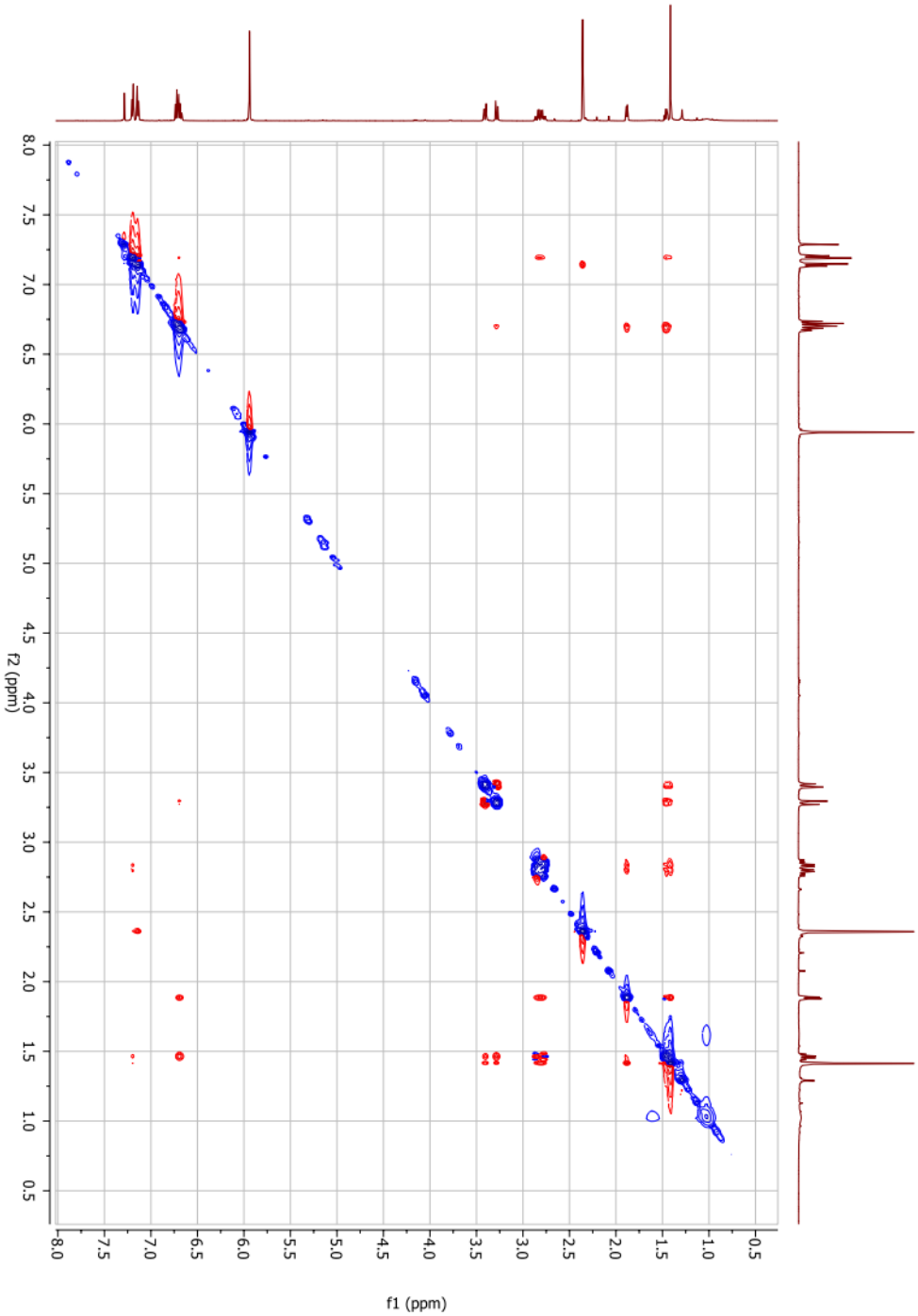
$[\alpha]_D^{33}$: +25.7 (*c* = 1.0, $CHCl_3$).

FTIR (neat): 3430, 2919, 1608 1503, 1490, 1441, 1234, 1189, 1039, 935, 808 cm^{-1}

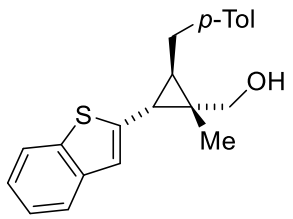

7.18
7.16
7.12
7.10
6.71
6.69
6.68
6.67
6.66
5.92
3.40
3.39
3.37
3.36
3.26
3.24
2.81
2.79
2.78
2.76
2.33
1.86
1.85
1.46
1.44
1.42
1.39
0.98
p-Tol
OH
Me
O
O
2.03
1.89
2.96
2.01
1.00
0.98
1.99
2.97
0.97
1.02
2.92
0.94
f1 (ppm)


147.6
145.9
138.6
135.4
132.7
129.2
128.0
121.4
109.0
108.1
100.9
68.2
35.2
34.1
29.5
27.8
21.0
17.1
p-Tol
OH
Me
O
O
f1 (ppm)


H
p-Tol
H
H
H
O
O
Me
OH


f2 (ppm)
f1 (ppm)

((1*S*,2*R*,3*S*)-1-methyl-2-(4-methylbenzyl)-3-(*p*-tolyl)cyclopropyl)methanol (2.3e)



Detailed Procedures

An oven-dried sealed tube equipped with a magnetic stir bar was charged with vinyl-dioxanone **2.1a** (27.4 mg, 0.1 mmol, 100 mol%), tri(p-tolyl)boroxine (30.1 mg, 0.085 mmol, 85 mol%) **2.2a**, dicyclohexylphenylphosphine (5.8 mg, 0.02 mmol, 20 mol%, 95%wt) and potassium phosphate (42.4 mg, 0.2 mmol, 200 mol%). This tube was transferred into an argon-atmosphere glovebox. $Ni(cod)_2$ (2.8 mg, 0.01 mmol, 10 mol%) and toluene (0.5 mL, 0.2 M) were added. After sealing the tube with cap, the tube was removed from the glovebox and the reaction mixture was stirred at 45 ˚C for 48 h. The reaction was cooled to ambient temperature, diluted with Et_2O (1 mL) and filtered through a plug of silica gel, which was rinsed with Et_2O (2 mL). The combined organic solution was concentrated *in vacuo*. The residue was subjected to flash column chromatography (SiO_2, hexanes: ethyl acetate = 20:1) to furnish the title compound as a colorless oil (15.7 mg, 0.068 mmol) in 68% yield.

TLC (SiO_2) R_f = 0.26 (hexanes/ethyl acetate = 5:1).

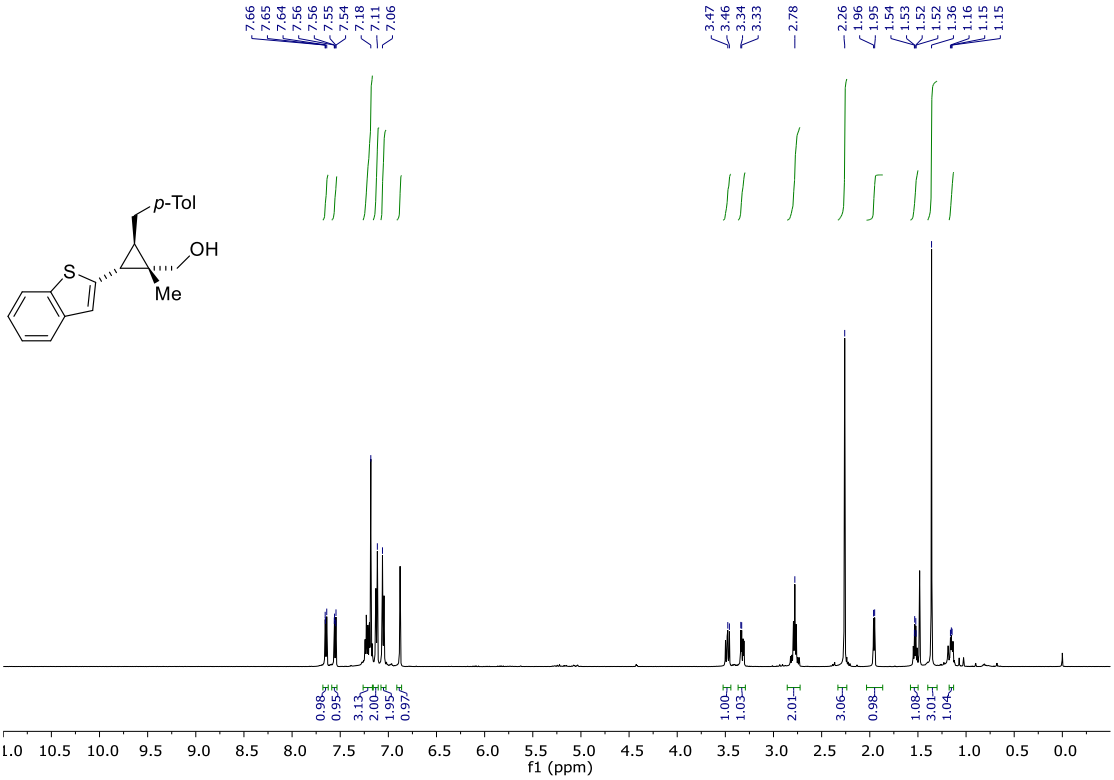
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.75 – 7.69 (m, 1H), 7.66 – 7.60 (m, 1H), 7.36 – 7.27 (m, 2H), 7.20 (d, *J* = 8.0 Hz, 2H), 7.13 (d, *J* = 8.0 Hz, 2H), 6.96 (t, *J* = 1.0 Hz, 1H), 3.56 (d, *J* = 11.8 Hz, 1H), 3.40 (d, *J* = 11.8 Hz, 1H), 2.91 – 2.80 (m, 2H), 2.34 (s, 3H), 2.03 (d, *J* = 5.7 Hz, 1H), 1.61 (td, *J* = 7.1, 5.7 Hz, 1H), 1.44 (s, 3H).

^{13}C NMR (125 MHz, $CDCl_3$) δ 143.9, 140.0, 139.2, 138.0, 135.6, 129.2, 128.0, 124.3, 123.8, 122.9, 122.0, 121.5, 67.9, 33.8, 31.3, 30.4 (d, *J* = 7.9 Hz), 21.0, 16.6.

HRMS (ESI) Calcd. for $C_{21}H_{22}NaOS^+$ $[M+Na]^+$: 345.1284, Found: 345.1295.

$[\alpha]_D^{33}$: +17.0 (*c* = 1.0, $CHCl_3$).

FTIR (neat): 2285, 2922, 2359, 2340, 1514, 1457, 1436, 1068, 1020, 805, 746, 668 cm^{-1}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Me
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7.56
7.56
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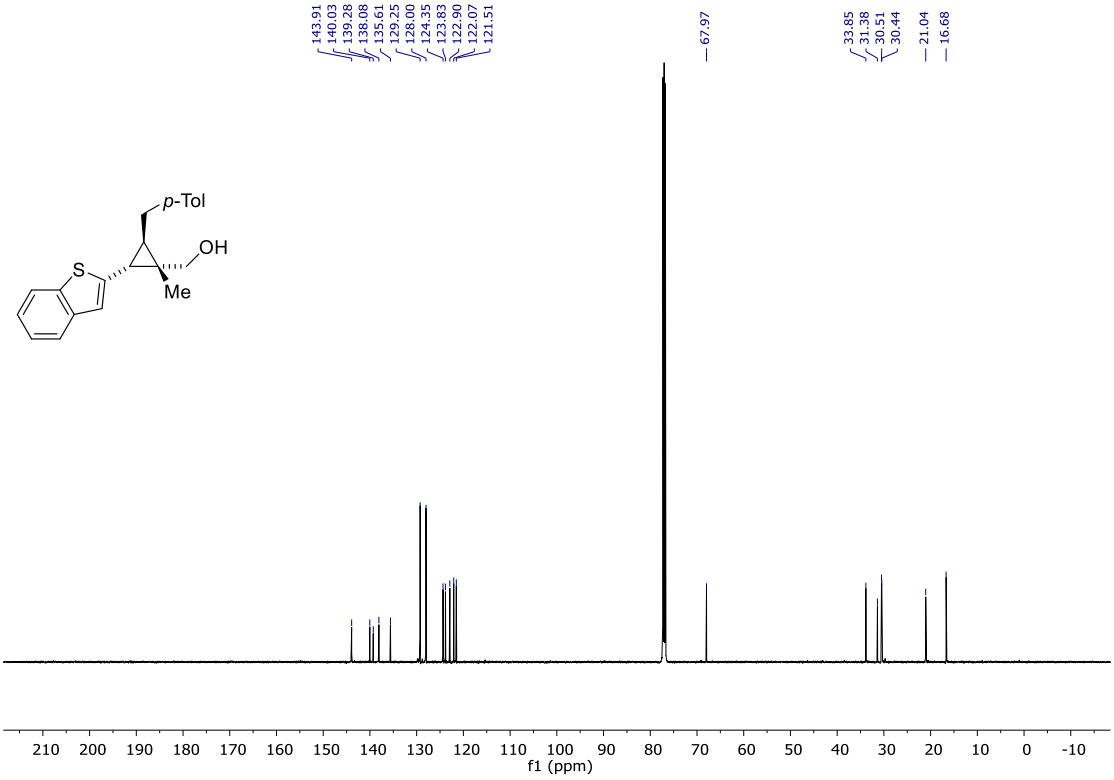
2.26
1.96
1.95
1.54
1.53
1.52
1.52
1.36
1.16
1.15
1.15
0.98
0.95
3.13
2.00
1.95
0.97
1.00
1.03
2.01
3.06
0.98
1.08
3.01
1.04
f1 (ppm)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OH
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Me
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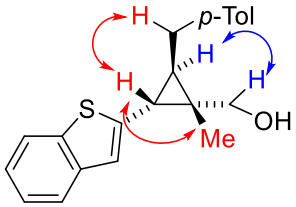
30.51
30.44
21.04
16.68
f1 (ppm)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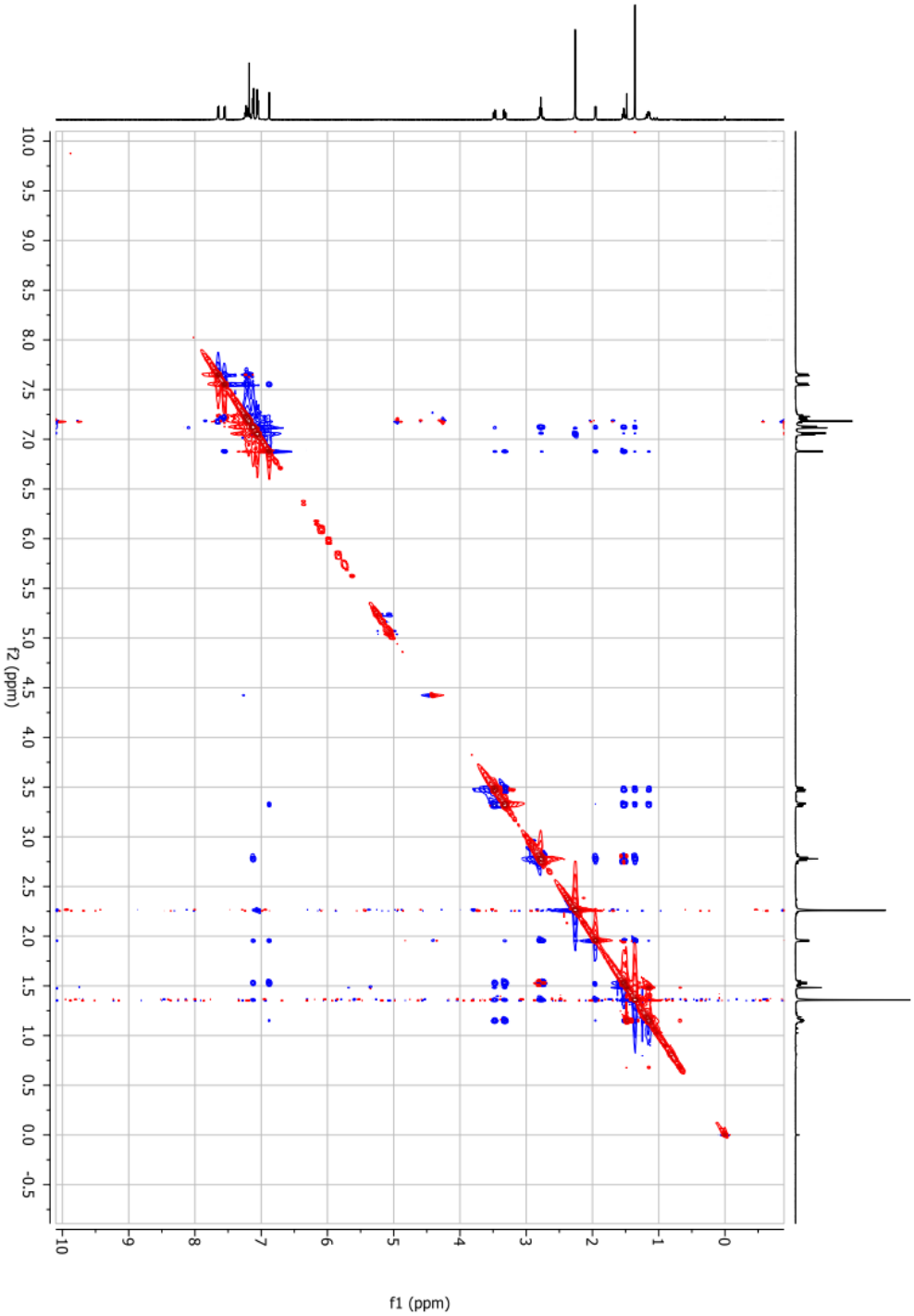
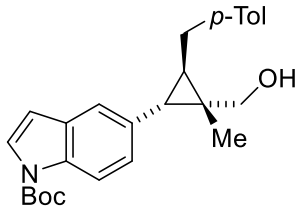
p-Tol
H
H
H
S
OH
Me


f2 (ppm)
f1 (ppm)

***tert*-butyl 5-((1*S*,2*S*,3*R*)-2-(hydroxymethyl)-2-methyl-3-(4-methylbenzyl)cyclopropyl)-1H-indole-1-carboxylate (2.3f)**



Detailed Procedures

An oven-dried sealed tube equipped with a magnetic stir bar was charged with vinyl-dioxanone **2.1e** (35.7 mg, 0.1 mmol, 100 mol%), tri(p-tolyl)boroxizne (30.1 mg, 0.085 mmol, 85 mol%) **2.2a**, dicyclohexylphenylphosphine (5.8 mg, 0.02 mmol, 20 mol%, 95%wt) and potassium phosphate (42.4 mg, 0.2 mmol, 200 mol%). This tube was transferred into an argon-atmosphere glovebox. $Ni(cod)_2$ (2.8 mg, 0.01 mmol, 10 mol%) and toluene (0.5 mL, 0.2 M) were added. After sealing the tube with cap, the tube was removed from the glovebox and the reaction mixture was stirred at 70 ˚C for 48 h. The reaction was cooled to ambient temperature, diluted with Et_2O (1 mL) and filtered through a plug of silica gel, which was rinsed with Et_2O (2 mL). The combined organic solution was concentrated *in vacuo*. The residue was subjected to flash column chromatography (SiO_2, hexanes: ethyl acetate = 12:1) to furnish the title compound as a colorless oil (28.4 mg, 0.07 mmol) in 70% yield.

TLC (SiO_2) R_f = 0.43 (hexanes/ethyl acetate = 4:1).

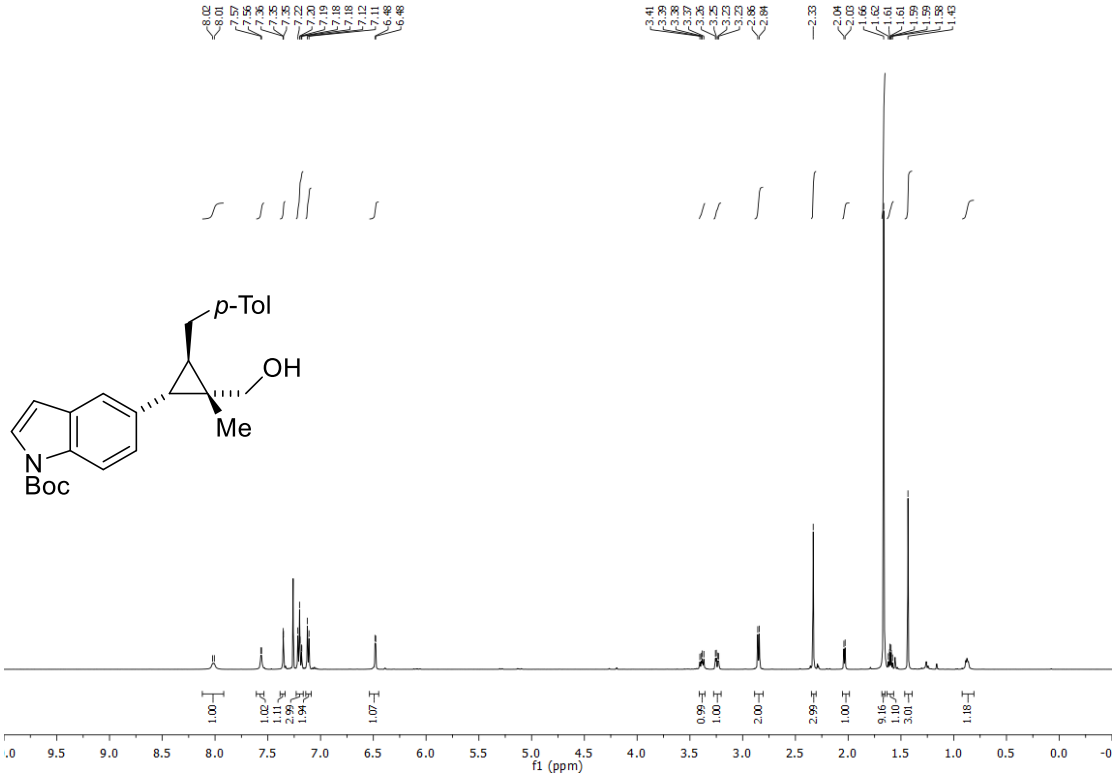
^{1}H NMR (500 MHz, $CDCl_3$) δ 8.02 (d, *J* = 8.5 Hz, 1H), 7.56 (d, *J* = 3.7 Hz, 1H), 7.38 – 7.34 (m, 1H), 7.23 – 7.16 (m, 3H), 7.12 (d, *J* = 7.7 Hz, 2H), 6.48 (d, *J* = 3.7 Hz, 1H), 3.39 (dd, *J* = 11.6, 7.5 Hz, 1H), 3.24 (dd, *J* = 11.6, 4.2 Hz, 1H), 2.85 (d, *J* = 7.0 Hz, 2H), 2.33 (s, 3H), 2.03 (d, *J* = 5.8 Hz, 1H),tbs 1.66 (s, 9H), 1.60 (td, *J* = 7.1, 5.8 Hz, 1H), 1.43 (s, 3H), 0.87 (dd, *J* = 7.8, 5.0 Hz, 1H).

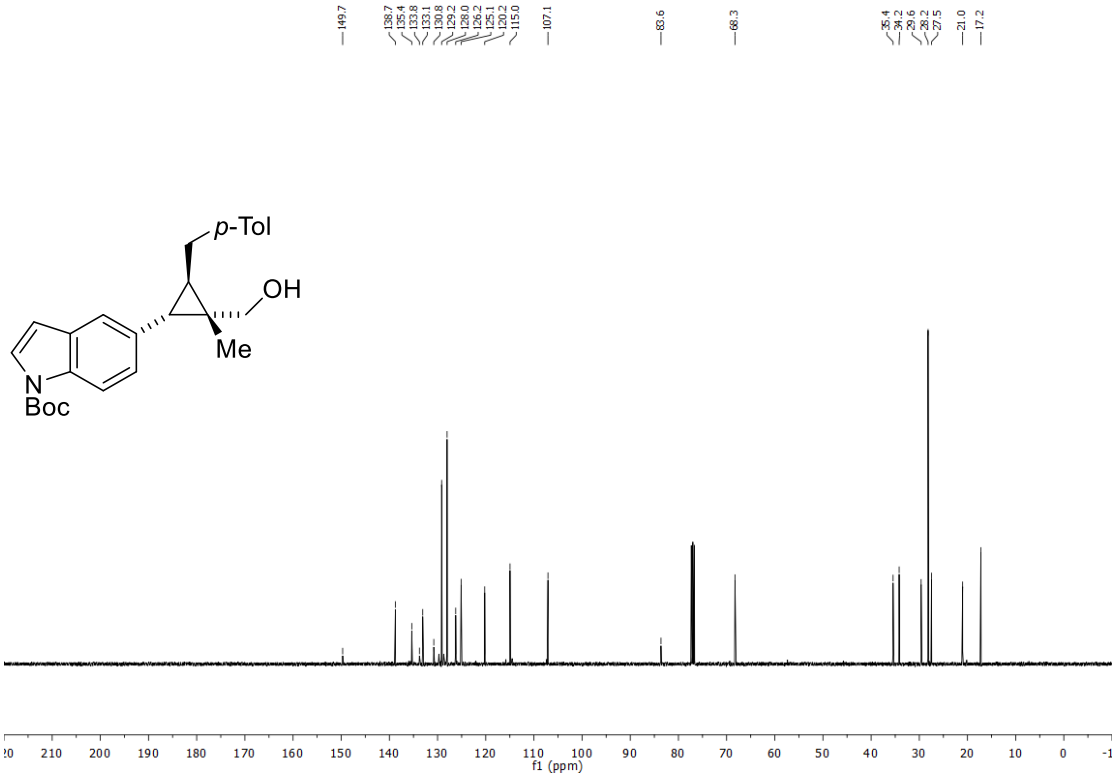
^{13}C NMR (100 MHz, $CDCl_3$) δ 149.7, 138.8, 135.4, 133.8, 133.1, 130.8, 129.2, 128.0, 126.2, 125.1, 120.2, 115.0, 107.1, 83.6, 68.3, 35.5, 34.2, 29.6, 28.2, 27.5, 21.0, 17.2.

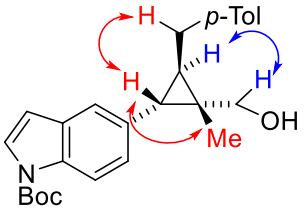
HRMS (ESI) Calcd. for $C_{26}H_{31}NO_3^+$ $[M+Na]^+$: 428.2196, Found: 428.2200.

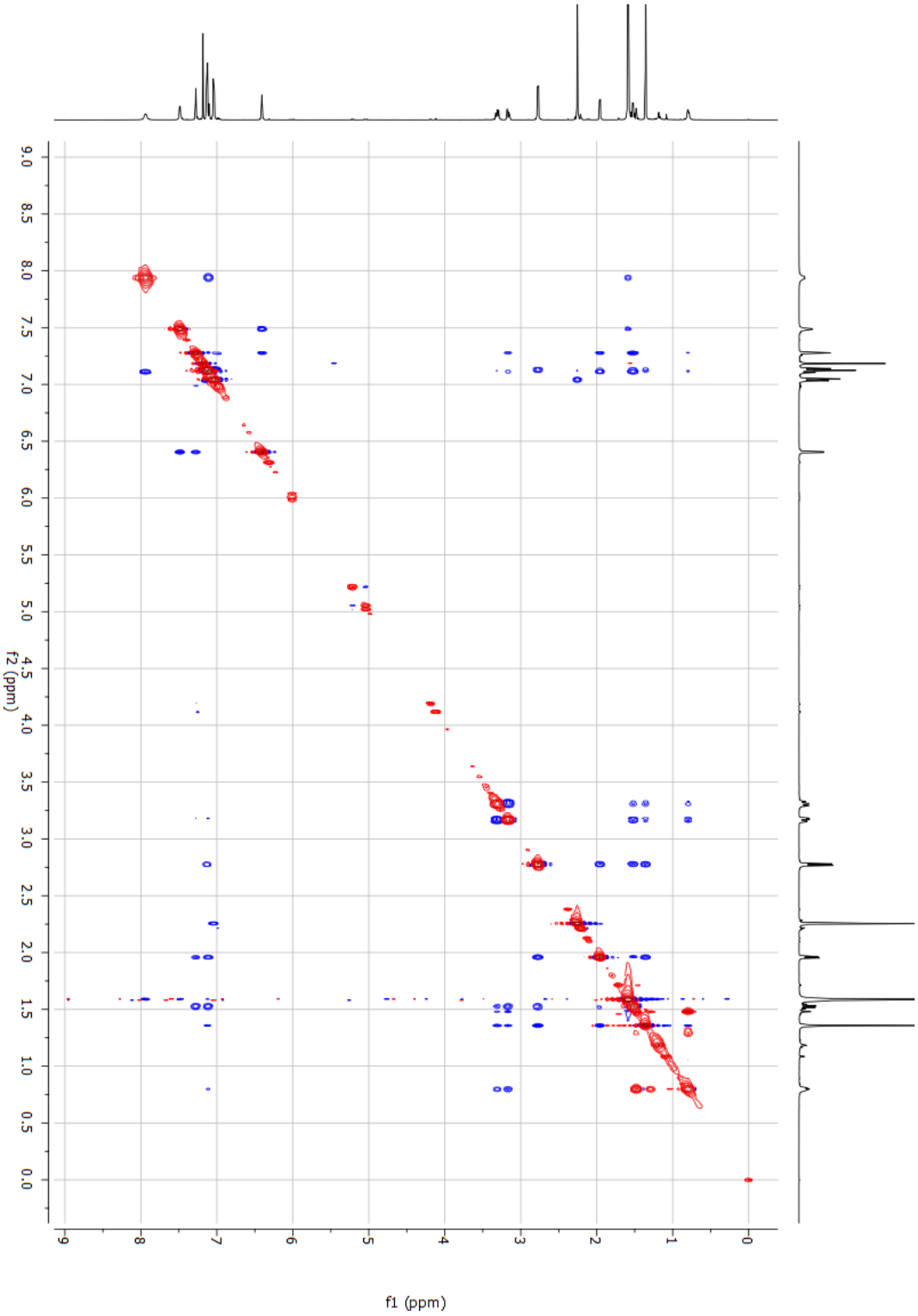
$[\alpha]_D^{25}$: +33.2 (*c* = 1.0, $CHCl_3$).

FTIR (neat): 3394, 2976, 1731, 1473, 1369, 1251, 1163, 1132, 1022, 746 cm^{-1}

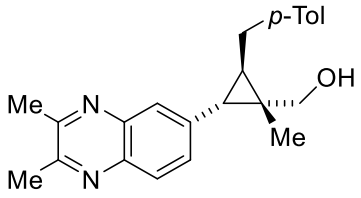





H
p-Tol
H
H
H
OH
Me
N
Boc


f2 (ppm)
f1 (ppm)

((1*S*,2*S*,3*R*)-2-(2,3-dimethylquinoxalin-6-yl)-1-methyl-3-(4-methylbenzyl)cyclopropyl)methanol (2.3g)



Detailed Procedures

An oven-dried sealed tube equipped with a magnetic stir bar was charged with vinyl-dioxanone **2.1g** (29.8 mg, 0.1 mmol, 100 mol%), tri(*p*-tolyl)boroxine (30.1 mg, 0.085 mmol, 85 mol%) **2.2a**, dicyclohexylphenylphosphine (5.8 mg, 0.02 mmol, 20 mol%, 95%wt) and potassium phosphate (42.4 mg, 0.2 mmol, 200 mol%). This tube was transferred into an argon-atmosphere glovebox. $Ni(cod)_2$ (2.8 mg, 0.01 mmol, 10 mol%) and toluene (0.5 mL, 0.2 M) were added. After sealing the tube with cap, the tube was removed from the glovebox and the reaction mixture was stirred at 55 ˚C for 48 h. The reaction was cooled to ambient temperature, diluted with Et_2O (1 mL) and filtered through a plug of silica gel, which was rinsed with Et_2O (2 mL). The combined organic solution was concentrated *in vacuo*. The residue was subjected to flash column chromatography (SiO_2, hexanes: ethyl acetate = 1:1) to furnish the title compound as a yellow solid (21.4 mg, 0.06 mmol) in 62% yield.

TLC (SiO_2) R_f = 0.29 (hexanes/ethyl acetate = 1:1).

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.84 (d, *J* = 8.6 Hz, 1H), 7.69 (s, 1H), 7.56 (dd, *J* = 8.5, 1.3 Hz, 1H), 7.20 – 7.07 (m, 4H), 3.40 (d, *J* = 11.3 Hz, 1H), 3.29 (d, *J* = 11.5 Hz, 1H), 2.92 – 2.81 (m, 2H), 2.69 (s, 3H), 2.69 (s, 3H), 2.32 (s, 3H), 2.09 (d, *J* = 5.9 Hz, 1H), 1.75 – 1.71 (m, 1H), 1.47 (s, 3H), 1.13 (brs, 1H).

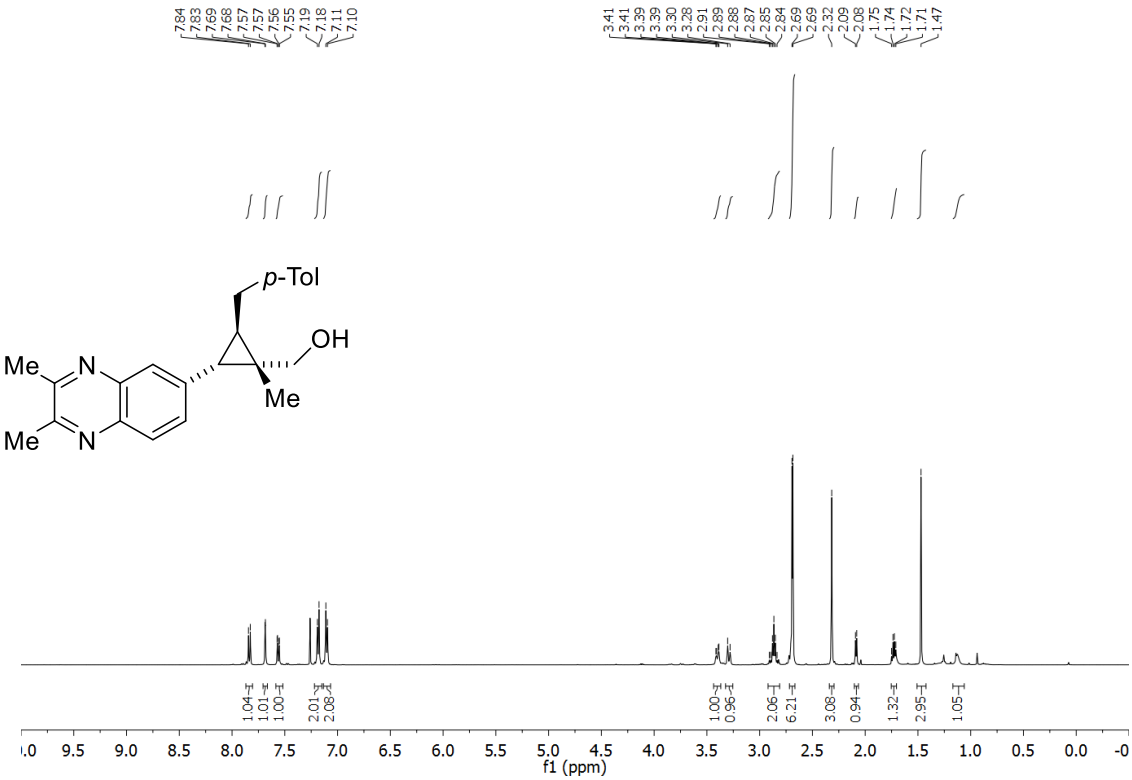
^{13}C NMR (125 MHz, $CDCl_3$) δ 153.5, 152.8, 140.9, 140.4, 139.8, 138.3, 135.5, 130.7, 129.2, 128.0, 127.9, 126.1, 67.6, 35.7, 34.1, 31.0, 28.1, 23.1, 23.0, 21.0, 17.2.

HRMS (ESI) Calcd. for $C_{23}H_{27}N_2O^+$ $[M+H]^+$: 347.2118, Found: 347.2120.

$[\alpha]_D^{33}$: +25.0 (*c* = 1.0, $CHCl_3$).

m.p. : 152-153 ˚C

FTIR (neat): 3350, 2920, 2866, 2360, 2343, 1619, 1556, 1514, 1498, 1449, 1379, 1334, 1185, 1157, 1041, 1022, 837, 806, 669 cm^{-1}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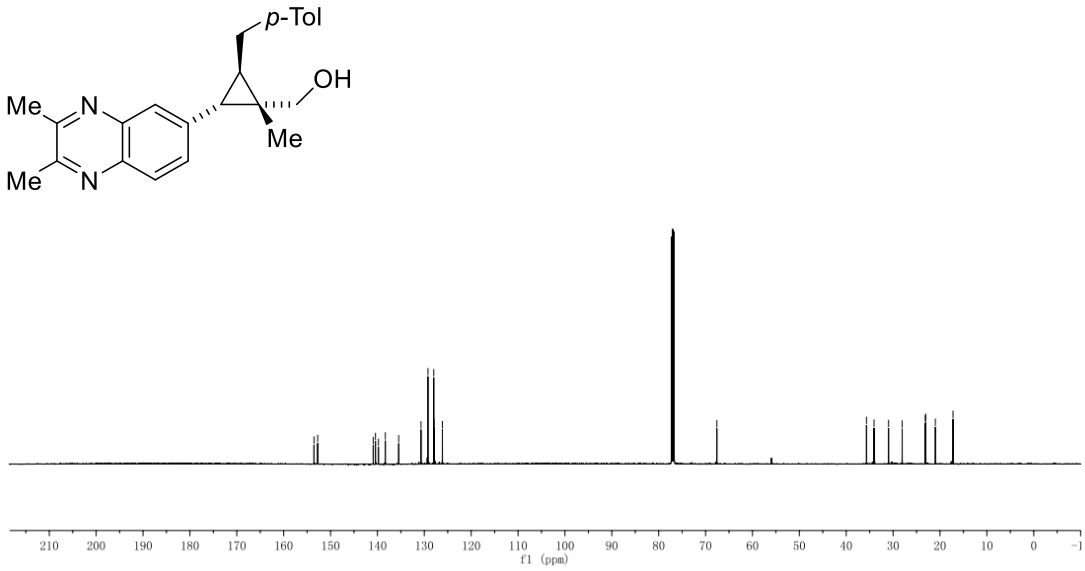
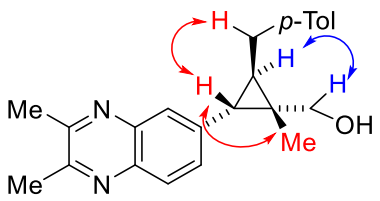
OH
Me
Me
Me
N
N
f1 (ppm)


p-Tol
OH
Me
Me
Me
N
N
f1 (ppm)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OH
Me
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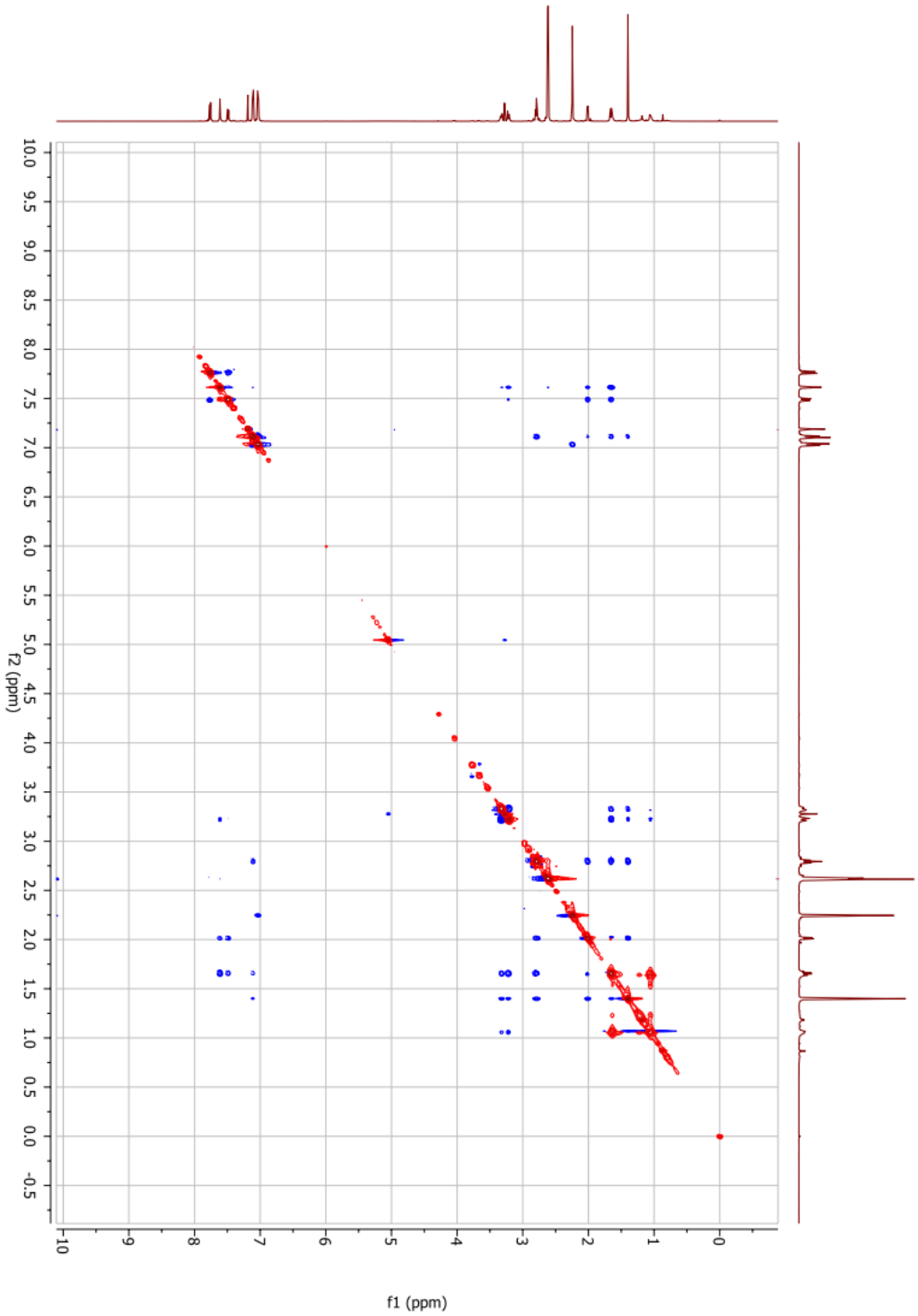
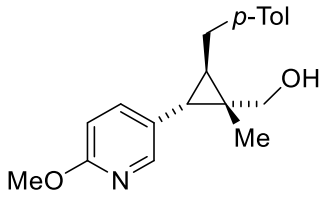
N


f1 (ppm)
f2 (ppm)

((*1S,2S,3R*)-2-(6-methoxypyridin-3-yl)-1-methyl-3-(4-methylbenzyl)cyclopropyl)methanol (2.3h)



Detailed Procedures

An oven-dried sealed tube equipped with a magnetic stir bar was charged with vinyl-dioxanone **2.1h** (24.9 mg, 0.1 mmol, 100 mol%), tri(p-tolyl)boroxine (30.1 mg, 0.085 mmol, 85 mol%) **2.2a**, dicyclohexylphenylphosphine (5.8 mg, 0.02 mmol, 20 mol%, 95%wt) and potassium phosphate (42.4 mg, 0.2 mmol, 200 mol%). This tube was transferred into an argon-atmosphere glovebox. $Ni(cod)_2$ (2.8 mg, 0.01 mmol, 10 mol%) and toluene (0.5 mL, 0.2 M) were added. After sealing the tube with cap, the tube was removed from the glovebox and the reaction mixture was stirred at 45 ˚C for 48 h. The reaction was cooled to ambient temperature, diluted with Et_2O (1 mL) and filtered through a plug of silica gel, which was rinsed with Et_2O (2 mL). The combined organic solution was concentrated in *vacuo*. The residue was subjected to flash column chromatography (SiO_2, hexanes: ethyl acetate = 4:1) to furnish the title compound as oil (27.2 mg, 0.92 mmol) in 92% yield.

TLC (SiO_2) R_f = 0.10 (hexanes/ethyl acetate = 4:1).

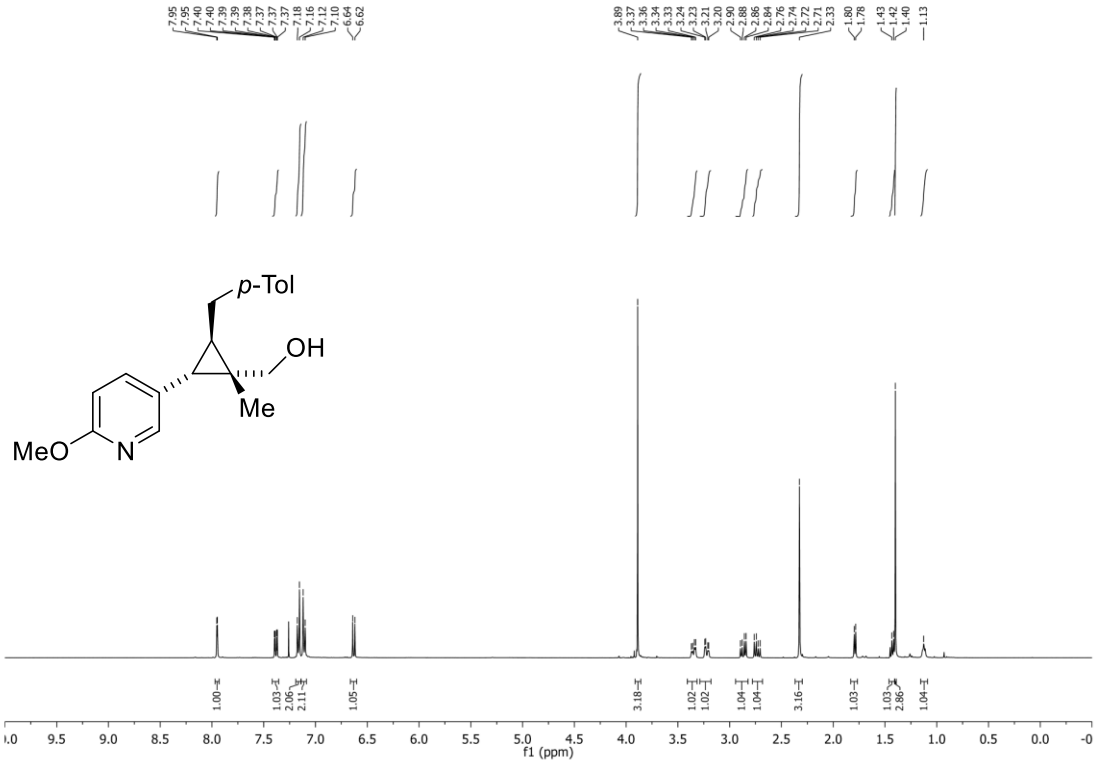
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.95 (d, *J* = 2.5 Hz, 1H), 7.38 (ddd, *J* = 8.5, 2.5, 0.7 Hz, 1H), 7.17 (d, *J* = 8.0 Hz, 2H), 7.11 (d, *J* = 8.0 Hz, 2H), 6.63 (dd, *J* = 8.5, 0.7 Hz, 1H), 3.89 (s, 3H), 3.35 (dd, *J* = 11.6, 4.7 Hz, 1H), 3.22 (dd, *J* = 11.5, 3.8 Hz, 1H), 2.87 (dd, *J* = 15.0, 6.6 Hz, 1H), 2.73 (dd, *J* = 15.0, 7.6 Hz, 1H), 2.33 (s, 3H), 1.79 (d, *J* = 5.9 Hz, 1H), 1.46 – 1.41 (m, 1H), 1.40 (s, 3H), 1.13 (t, *J* = 5.4 Hz, 1H).

^{13}C NMR (100 MHz, $CDCl_3$) δ 162.8, 146.6, 139.4, 138.4, 135.5, 129.2, 128.0, 127.1, 110.2, 68.0, 53.3, 34.2, 32.0, 29.0, 27.8, 21.0, 17.0.

HRMS (ESI) Calcd. for $C_{19}H_{23}NNaO_2^+$ $[M+Na]^+$: 320.1621, Found: 320.1625

$[\alpha]_D^{31}$: +100.6 (c = 1.3, $CHCl_3$)

FTIR (neat): 1607, 1494, 1408, 1373, 1316, 1283, 1258, 1109, 1022, 814, 726 cm^{-1}.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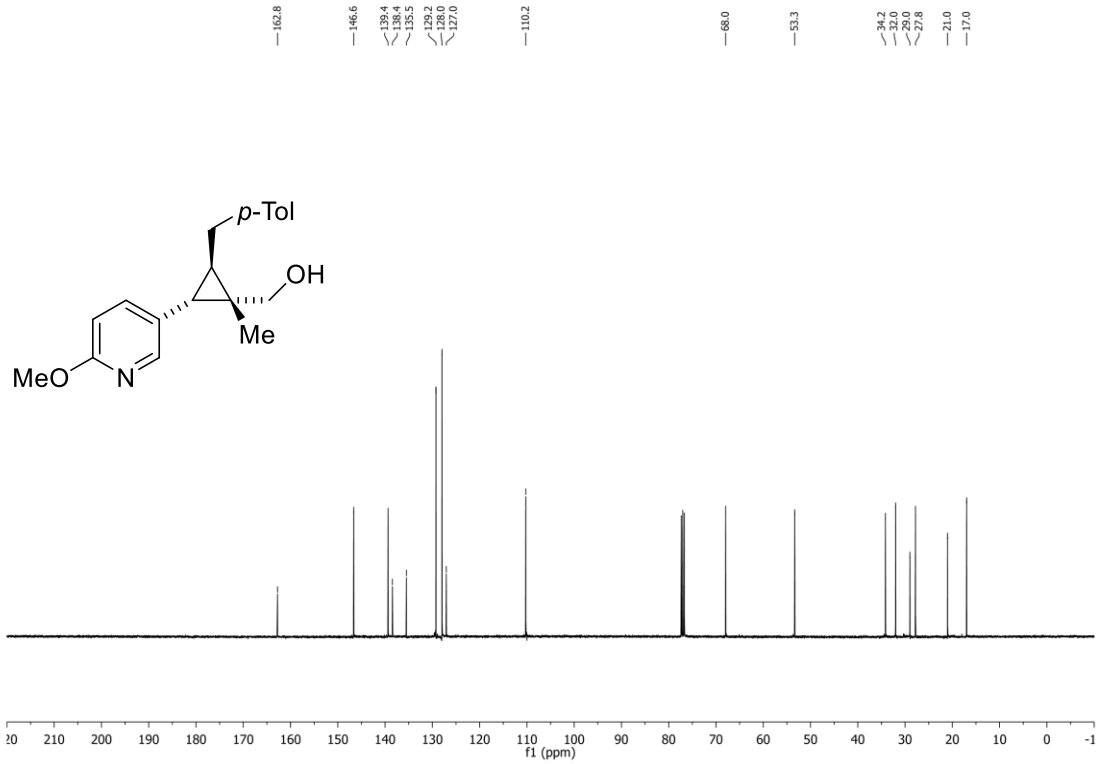
Me
MeO
N
f1 (ppm)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OH
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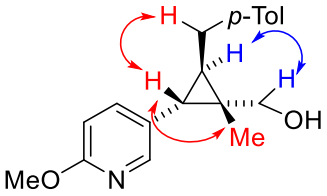
MeO
N
f1 (ppm)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OH
Me
MeO
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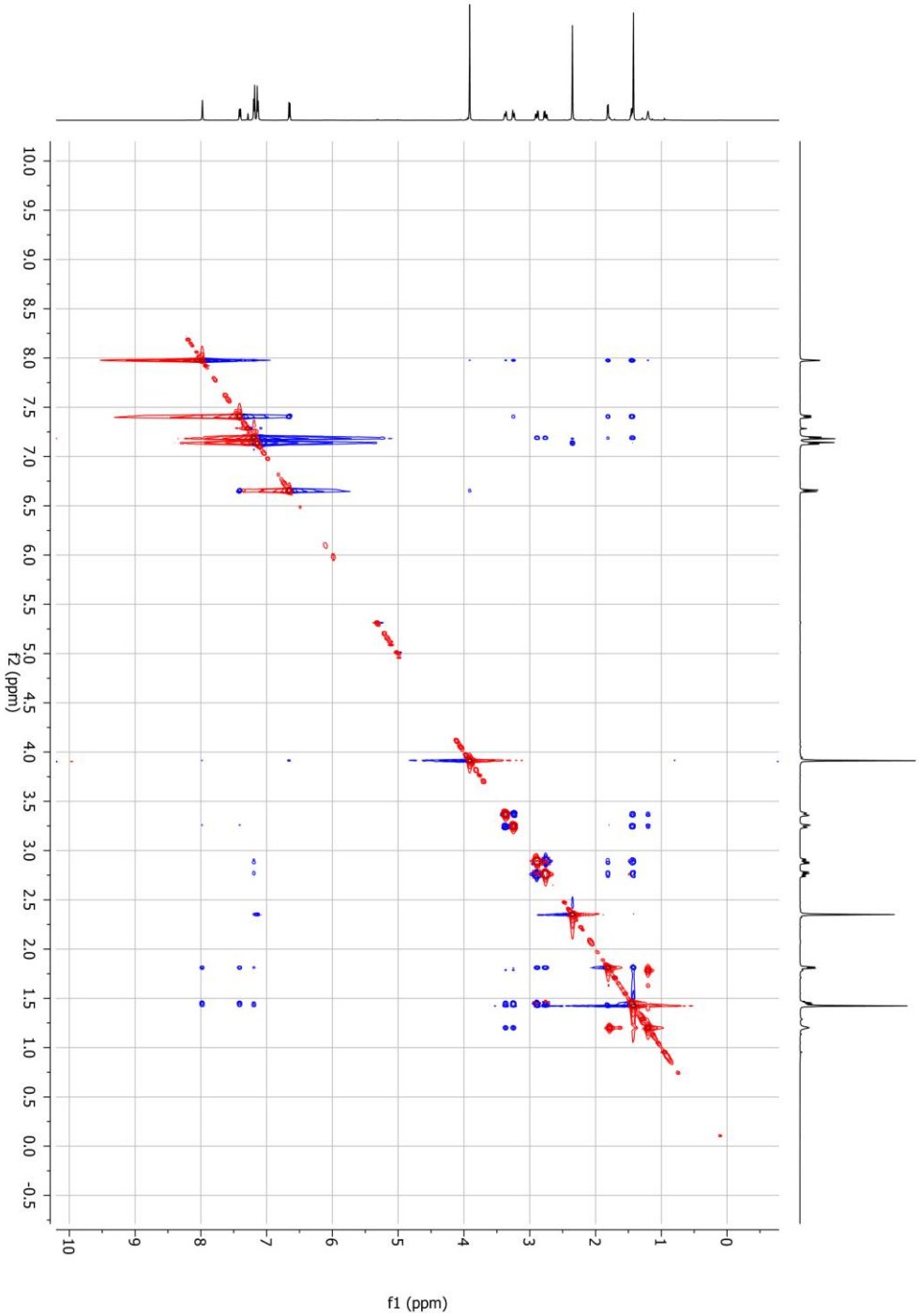
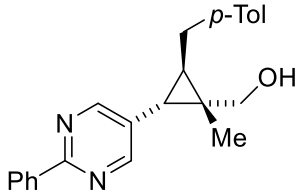

f2 (ppm)
f1 (ppm)

((*1S,2R,3S*)-1-methyl-2-(4-methylbenzyl)-3-(2-phenylpyrimidin-5-yl)cyclopropyl)methanol (2.3i)



Detailed Procedures

An oven-dried sealed tube equipped with a magnetic stir bar was charged with vinyl-dioxanone **2.1i** (29.6 mg, 0.1 mmol, 100 mol%), tri(p-tolyl)boroxine (30.1 mg, 0.085 mmol, 85 mol%) **2.2a**, dicyclohexylphenylphosphine (5.8 mg, 0.02 mmol, 20 mol%, 95%wt) and potassium phosphate (42.4 mg, 0.2 mmol, 200 mol%). This tube was transferred into an argon-atmosphere glovebox. $Ni(cod)_2$ (2.8 mg, 0.01 mmol, 10 mol%) and toluene (0.5 mL, 0.2 M) were added. After sealing the tube with cap, the tube was removed from the glovebox and the reaction mixture was stirred at 45 ˚C for 48 h. The reaction was cooled to ambient temperature, diluted with Et_2O (1 mL) and filtered through a plug of silica gel, which was rinsed with Et_2O (2 mL). The combined organic solution was concentrated in *vacuo*. The residue was subjected to flash column chromatography (SiO_2, hexanes: ethyl acetate = 4:1) to furnish the title compound (29.2 mg, 0.85 mmol) in 85% yield.

TLC (SiO_2) R_f = 0.10 (hexanes/ethyl acetate = 4:1).

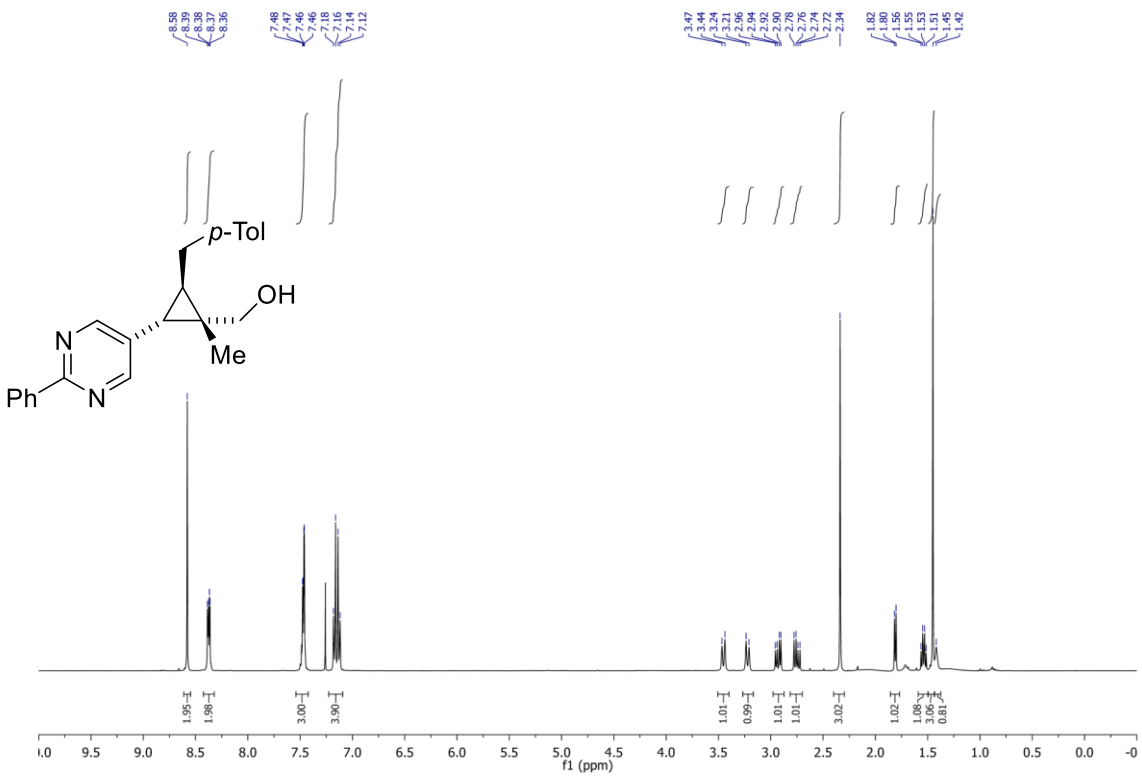
^{1}H NMR (400 MHz, $CDCl_3$) δ 8.58 (s, 2H), 8.41 – 8.33 (m, 2H), 7.47 (s, 3H), 7.15 (s, 4H), 3.45 (d, *J* = 11.3 Hz, 1H), 3.22 (d, *J* = 11.3 Hz, 1H), 2.93 (dd, *J* = 14.9, 6.5 Hz, 1H), 2.75 (dd, *J* = 14.9, 7.8 Hz, 1H), 2.34 (s, 3H), 1.81 (d, *J* = 5.9 Hz, 1H), 1.54 (dt, *J* = 7.9, 6.3 Hz, 1H), 1.45 (s, 3H), 1.42 (s, 1H).

^{13}C NMR (100 MHz, $CDCl_3$) δ 162.5, 157.6, 138.0, 137.4, 135.7, 130.5, 130.2, 129.4, 128.6, 127.9, 127.9, 67.4, 34.0, 30.0, 29.8, 28.1, 21.0, 17.0.

HRMS (ESI) Calcd. for $C_{23}H_{24}N_2NaO^+$ $[M+Na]^+$: 367.1781, Found: 367.1784

$[\alpha]_D^{31}$: +120.3 (c = 1.1, $CHCl_3$)

FTIR (neat): 2361, 2343, 2331, 1515, 1438, 1421, 1024, 748, 693, 669 cm^{-1}.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8.36
7.48
7.47
7.46
7.46
7.18
7.16
7.14
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3.47
3.44
3.24
3.21
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2.94
2.92
2.90
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1.51
1.45
1.42
p-Tol
OH
Me
N
N
Ph
1.95
1.98
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0.99
1.01
1.01
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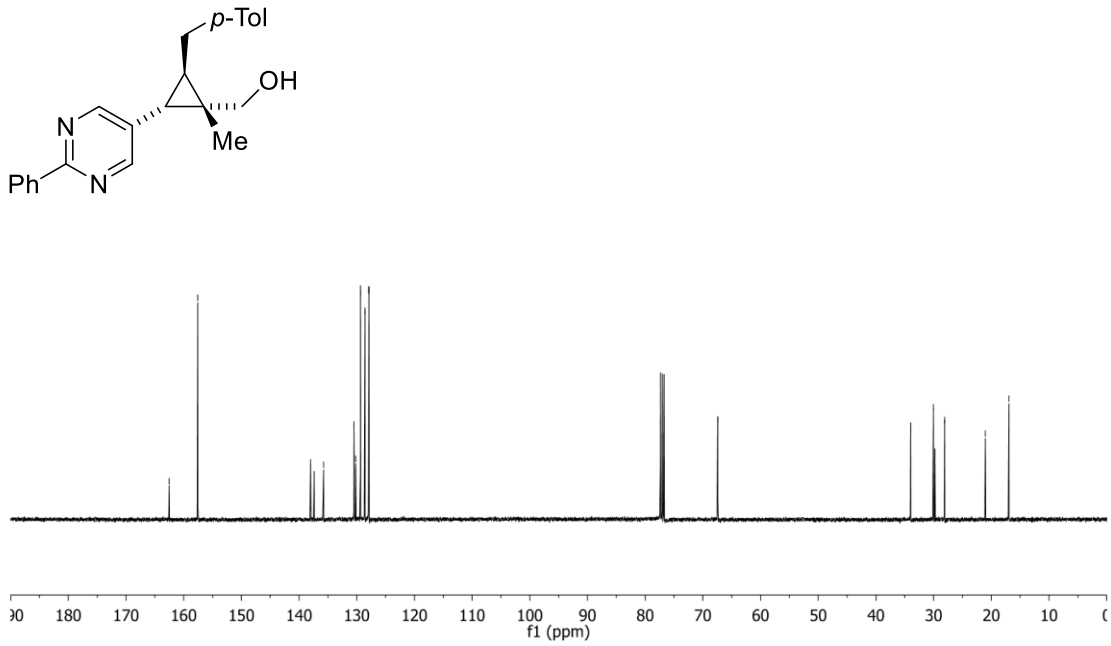
1.02
1.08
3.06
0.81
f1 (ppm)


162.5
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137.4
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129.4
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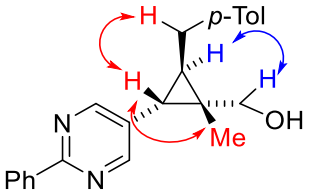
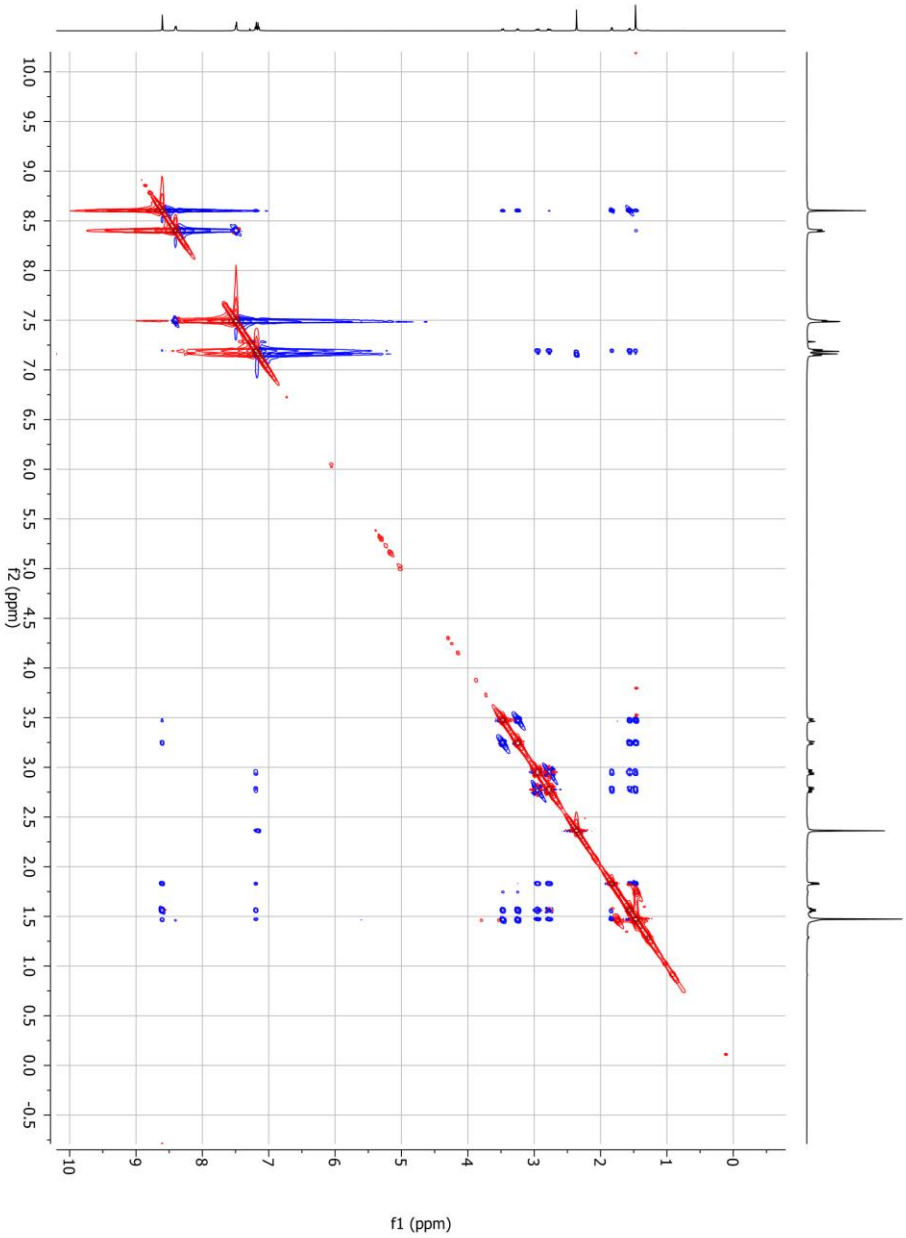
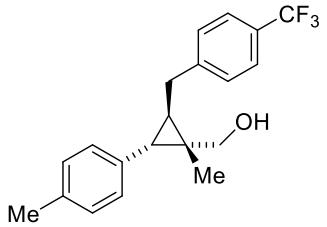
127.9
127.9
67.4
34.0
30.0
29.8
28.1
21.0
17.0
p-Tol
OH
Me
N
N
Ph
f1 (ppm)


H
p-Tol
H
H
H
N
OH
Me
Ph
N


f2 (ppm)
f1 (ppm)

((*1S,2S,3R*)-1-methyl-2-(p-tolyl)-3-(4-(trifluoromethyl)benzyl)cyclopropyl)methanol (2.3j)



Detailed Procedures

An oven-dried sealed tube equipped with a magnetic stir bar was charged with vinyl-dioxanone **2.1a** (23.3 mg, 0.1 mmol, 100 mol%), tri(p-tolyl)boroxine (43.9 mg, 0.085 mmol, 85 mol%) **2.2b**, dicyclohexylphenylphosphine (5.8 mg, 0.02 mmol, 20 mol%, 95%wt) and potassium phosphate (42.4 mg, 0.2 mmol, 200 mol%). This tube was transferred into an argon-atmosphere glovebox. $Ni(cod)_2$ (2.8 mg, 0.01 mmol, 10 mol%) and toluene (0.5 mL, 0.2 M) were added. After sealing the tube with cap, the tube was removed from the glovebox and the reaction mixture was stirred at 45 ˚C for 48 h. The reaction was cooled to ambient temperature, diluted with Et_2O (1 mL) and filtered through a plug of silica gel, which was rinsed with Et_2O (2 mL). The combined organic solution was concentrated in *vacuo*. The residue was subjected to flash column chromatography (SiO_2, hexanes: ethyl acetate = 4:1) to furnish the title compound as oil (24.7 mg, 0.74 mmol) in 74% yield.

TLC (SiO_2) R_f = 0.30 (hexanes/ethyl acetate = 4:1).

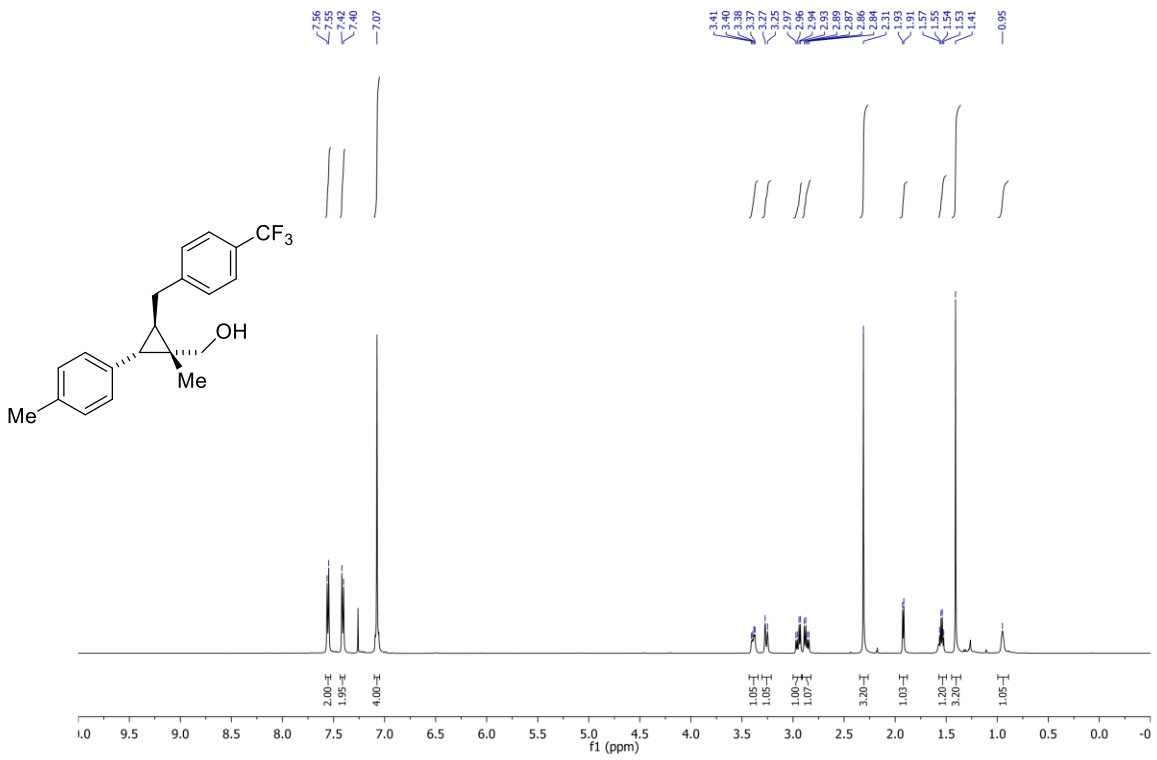
^{1}H NMR (500 MHz, $CDCl_3$) δ 7.55 (d, *J* = 7.9 Hz, 2H), 7.41 (d, *J* = 7.9 Hz, 2H), 7.11 – 7.03 (m, 4H), 3.39 (dd, *J* = 11.9, 5.6 Hz, 1H), 3.26 (d, *J* = 11.4 Hz, 1H), 2.95 (dd, *J* = 15.4, 6.8 Hz, 1H), 2.87 (dd, *J* = 15.4, 7.5 Hz, 1H), 2.31 (s, 3H), 1.92 (d, *J* = 5.8 Hz, 1H), 1.55 (q, *J* = 6.8 Hz, 1H), 1.41 (s, 3H), 0.95 (s, 1H).

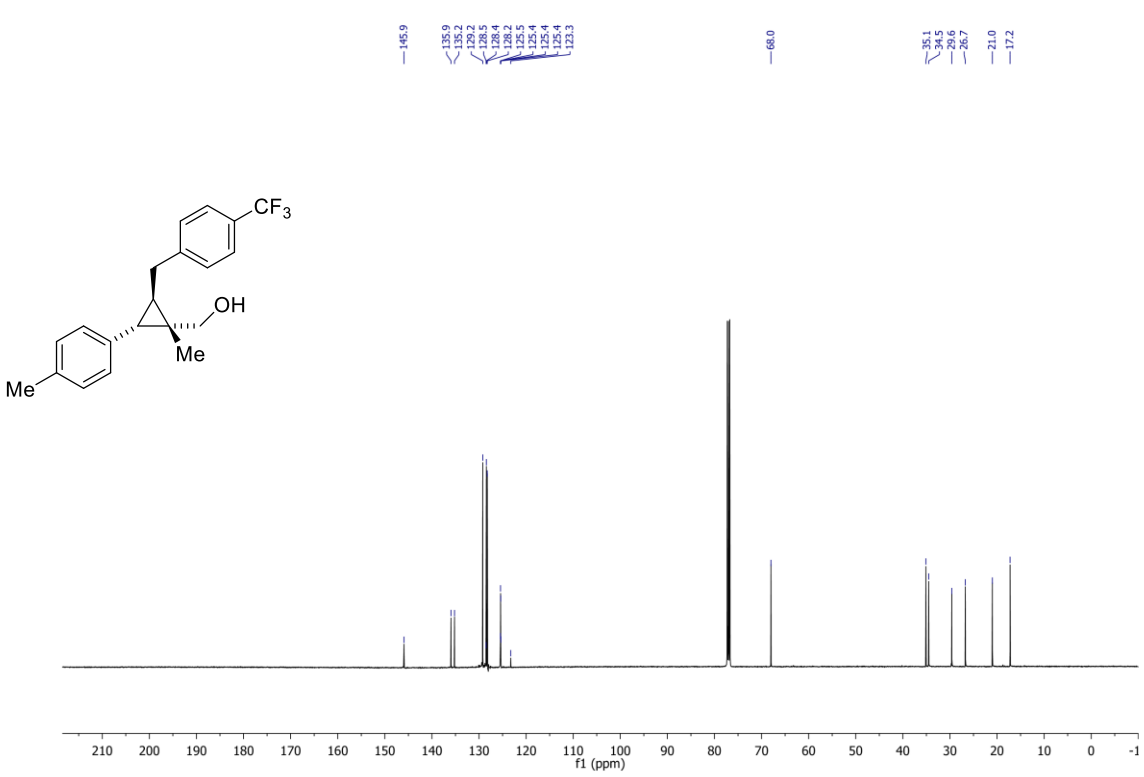
^{13}C NMR (125 MHz, $CDCl_3$) δ 145.9, 136.0, 135.2, 129.2, 128.5, 128.5, 128.2, 125.5, 125.4, 125.4, 125.4, 123.3, 68.0, 35.1, 34.5, 29.6, 26.7, 21.0, 17.2.

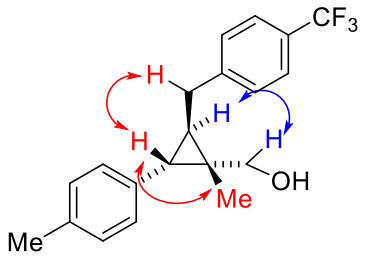
HRMS (ESI) Calcd. for $C_{20}H_{21}F_3NaO^+$ $[M+Na]^+$: 357.1437, Found: 357.1442

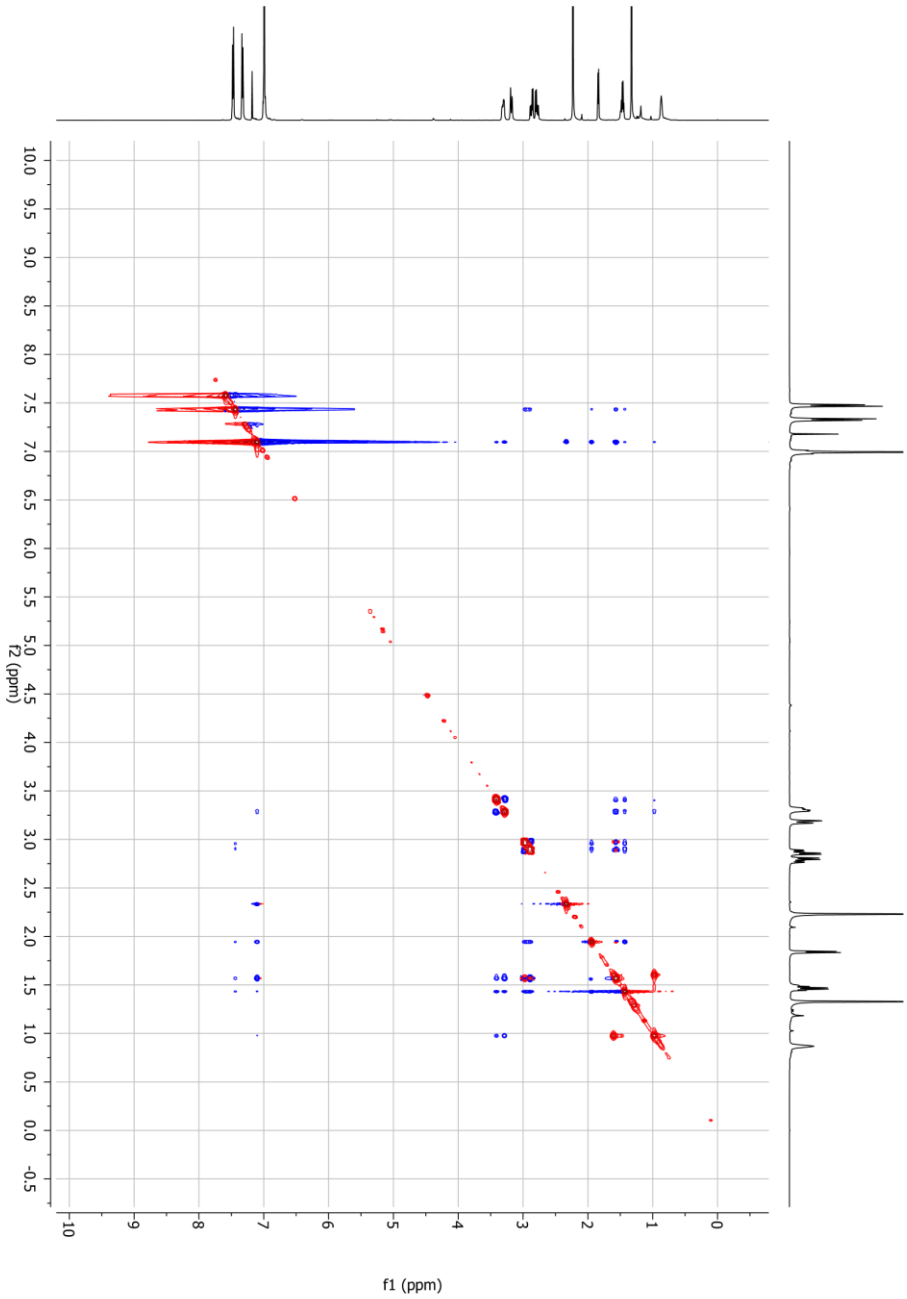
$[\alpha]_D^{29}$: +19.7 (c = 0.76, $CHCl_3$)

FTIR (neat): 1515, 1324, 1275, 1161, 1121, 1067, 1018, 913, 819, 749 cm^{-1}.

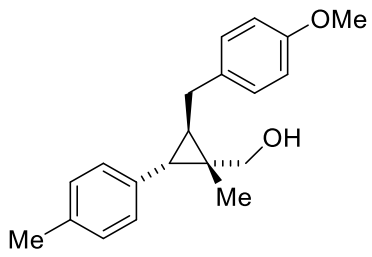

CF3
OH
Me
Me
f1 (ppm)


CF3
OH
Me
Me
f1 (ppm)


CF3
H
H
H
H
OH
Me
Me


f2 (ppm)
f1 (ppm)

((1*S*,2*R*,3*S*)-2-(4-methoxybenzyl)-1-methyl-3-(*p*-tolyl)cyclopropyl)methanol (2.3k)



Detailed Procedures

An oven-dried sealed tube equipped with a magnetic stir bar was charged with vinyl-dioxanone **2.1a** (29.8 mg, 0.1 mmol, 100 mol%), tri(*p*-methoxyphenyl)boroxine (34.2 mg, 0.085 mmol, 85 mol%) **2.2c**, dicyclohexylphenylphosphine (5.8 mg, 0.02 mmol, 20 mol%, 95%wt) and potassium phosphate (42.4 mg, 0.2 mmol, 200 mol%). This tube was transferred into an argon-atmosphere glovebox. $Ni(cod)_2$ (2.8 mg, 0.01 mmol, 10 mol%) and toluene (0.5 mL, 0.2 M) were added. After sealing the tube with cap, the tube was removed from the glovebox and the reaction mixture was stirred at 55 ˚C for 48 h. The reaction was cooled to ambient temperature, diluted with Et_2O (1 mL) and filtered through a plug of silica gel, which was rinsed with Et_2O (2 mL). The combined organic solution was concentrated *in vacuo*. The residue was subjected to flash column chromatography (SiO_2, hexanes: ethyl acetate = 8:1) to furnish the title compound as a yellow solid (22.5 mg, 0.08 mmol) in 76% yield.

TLC (SiO_2) R_f = 0.30 (hexanes/ethyl acetate = 4:1).

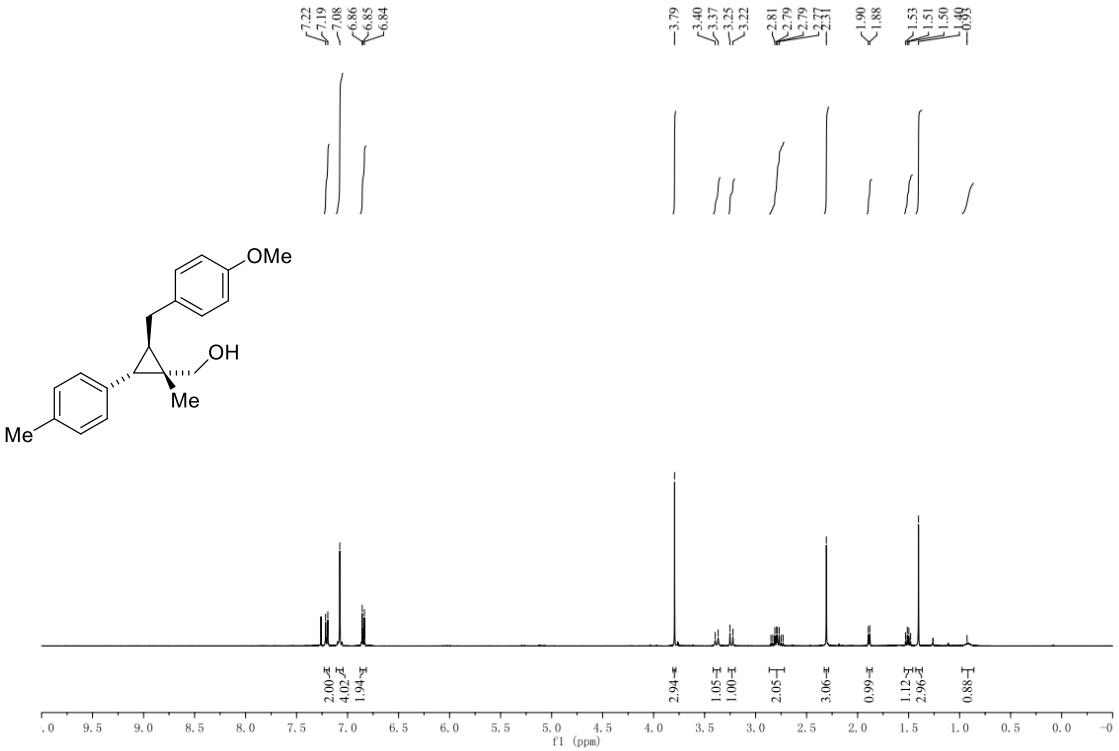
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.23 – 7.18 (m, 2H), 7.10 – 7.04 (m, 4H), 6.87 – 6.82 (m, 2H), 3.79 (s, 3H), 3.38 (d, *J* = 11.6 Hz, 1H), 3.24 (d, *J* = 11.6 Hz, 1H), 2.82 (dd, *J* = 15.1, 6.9 Hz, 1H), 2.76 (dd, *J* = 15.1, 7.3 Hz, 1H), 2.31 (s, 3H), 1.89 (d, *J* = 5.9 Hz, 1H), 1.51 (dd, *J* = 13.1, 7.1 Hz, 1H), 1.40 (s, 3H), 0.93 (brs, 1H).

^{13}C NMR (100 MHz, $CDCl_3$) δ 157.8, 135.7, 135.7, 133.9, 129.1, 129.0, 128.3, 113.9, 68.2, 55.2, 35.1, 33.7, 29.6, 27.5, 21.0, 17.2.

HRMS (CI) Calcd. for$C_{20}H_{24}O_2^+$ $[M]^+$: 296.1771, Found: 296.1771.

$[\alpha]_D^{33}$: +29.0 (*c* = 1.0, $CHCl_3$).

FTIR (neat): 3414, 2921, 1611, 1511, 1463, 1301, 1244, 1177, 1035, 824, 744 cm^{-1}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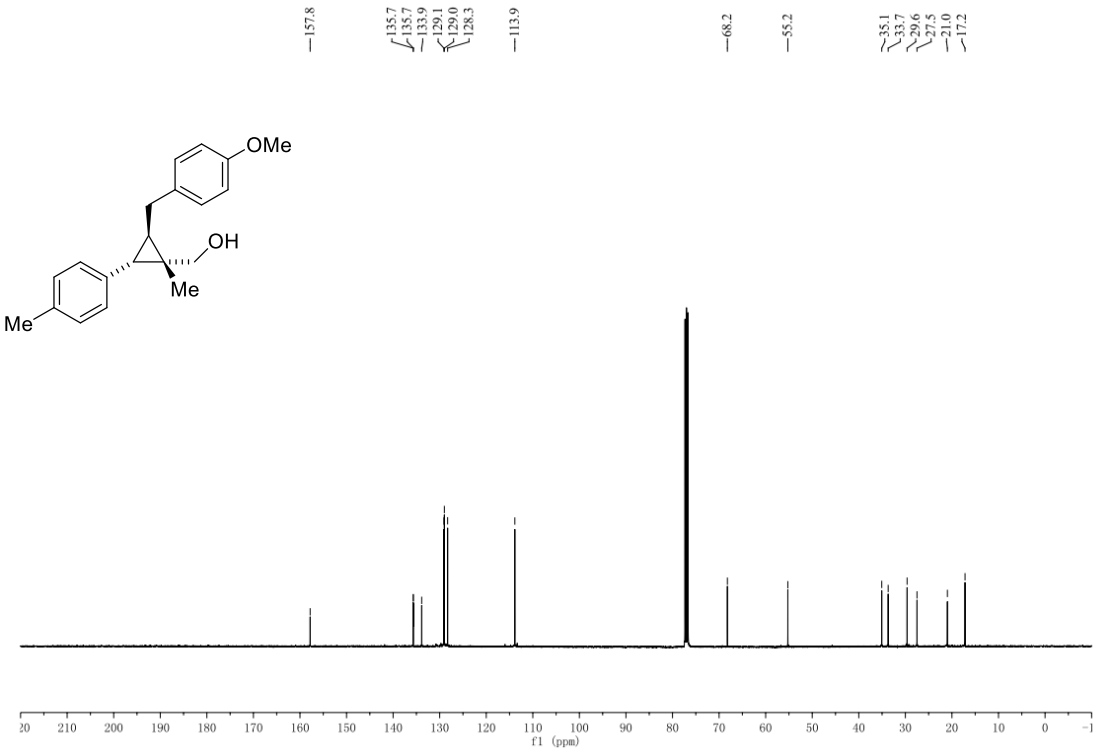
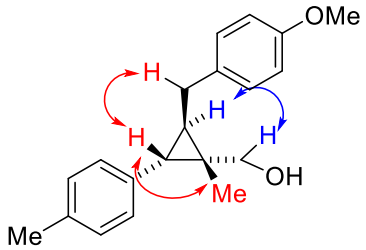
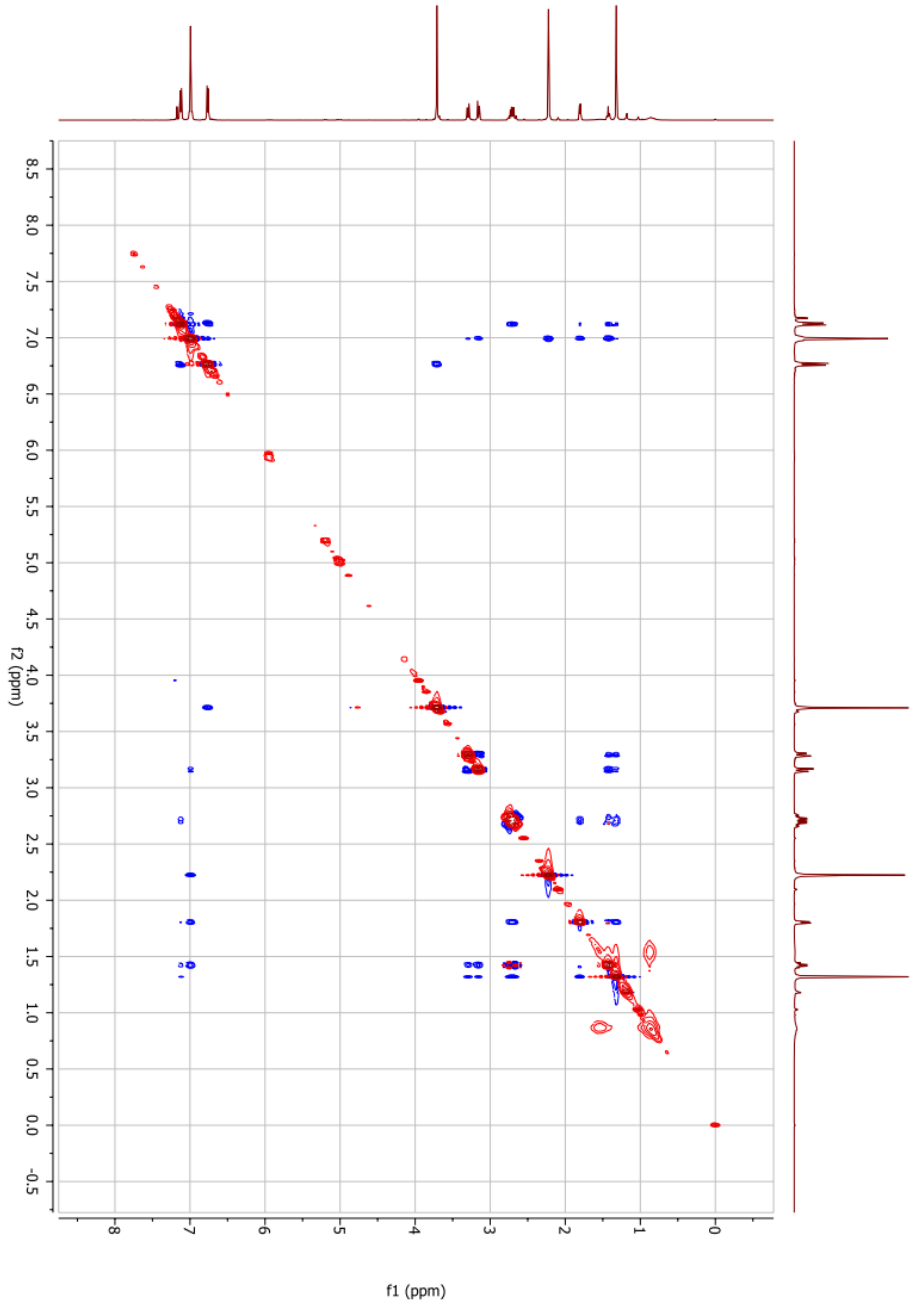
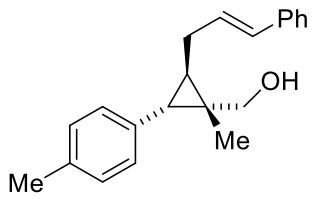
OH
Me
Me
7.22
7.19
7.08
6.86
6.85
6.84
3.79
3.40
3.37
3.25
3.22
2.81
2.79
2.79
2.77
2.31
1.90
1.88
1.53
1.51
1.50
1.40
0.99
2.00
4.02
1.94
2.94
1.05
1.00
2.05
3.06
0.99
1.12
2.96
0.88
f1 (ppm)


OMe
OH
Me
Me
157.8
135.7
135.7
133.9
129.1
129.0
128.3
113.9
68.2
55.2
35.1
33.7
29.6
27.5
21.0
17.2
f1 (ppm)


OMe
H
H
H
H
OH
Me
Me


f2 (ppm)
f1 (ppm)

((1S,2R,3S)-2-cinnamyl-1-methyl-3-(p-tolyl)cyclopropyl)methanol (2.3l)



Detailed Procedures

An oven-dried sealed tube equipped with a magnetic stir bar was charged with vinyl-dioxanone **2.1a** (23.2 mg, 0.1 mmol, 100 mol%), tri(phenylvinyl)boroxine **2.2d** (33.2 mg, 0.085 mmol, 85 mol%), dicyclohexylphenylphosphine (5.8 mg, 0.02 mmol, 20 mol%, 95%wt) and potassium phosphate (42.4 mg, 0.2 mmol, 200 mol%). This tube was transferred into an argon-atmosphere glovebox. $Ni(cod)_2$ (2.8 mg, 0.01 mmol, 10 mol%) and toluene (0.5 mL, 0.2 M) were added. After sealing the tube with cap, the tube was removed from the glovebox and the reaction mixture was stirred at 65 ˚C for 48 h. The reaction was cooled to ambient temperature, diluted with Et_2O (1 mL) and filtered through a plug of silica gel, which was rinsed with Et_2O (2 mL). The combined organic solution was concentrated *in vacuo*. The residue was subjected to flash column chromatography (SiO_2, hexanes: ethyl acetate = 20:1) to furnish the title compound as a colorless oil (18.7 mg, 0.064 mmol) in 64% yield.

TLC (SiO_2) R_f = 0.35 (hexanes/ethyl acetate = 4:1).

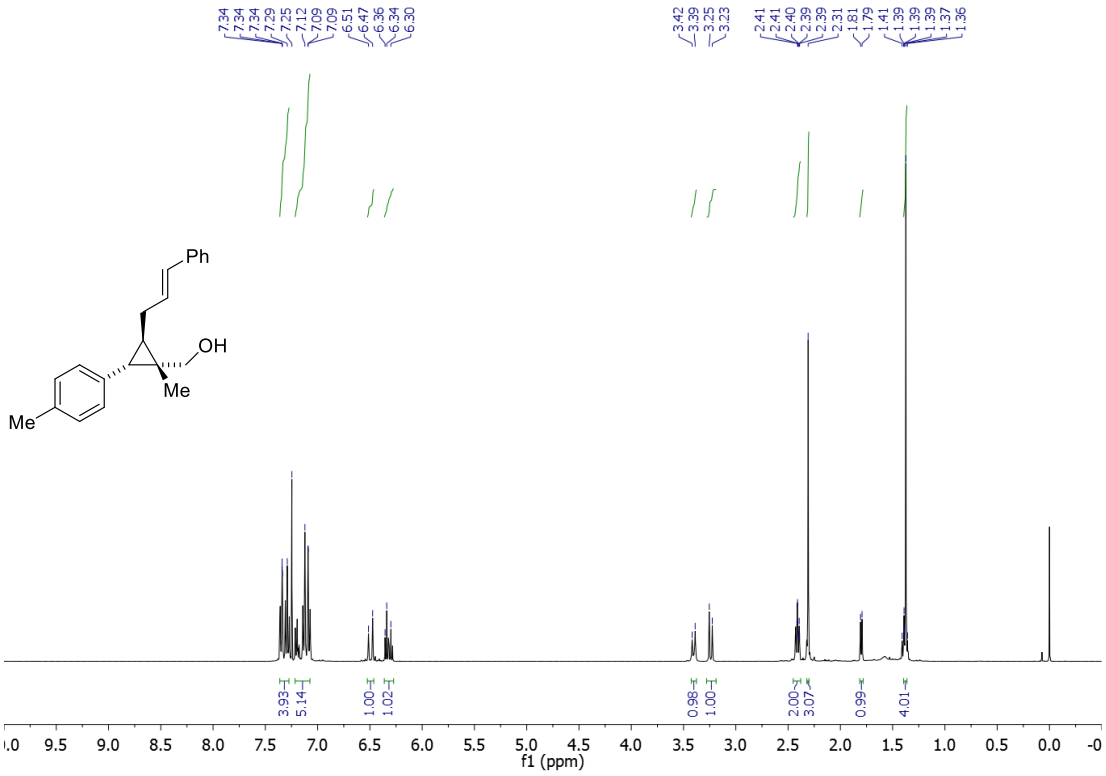
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.37 – 7.26 (m, 4H), 7.22 – 7.05 (m, 5H), 6.54 – 6.43 (m, 1H), 6.32 (dt, *J* = 15.8, 6.5 Hz, 1H), 3.40 (d, *J* = 11.6 Hz, 1H), 3.24 (d, *J* = 11.6 Hz, 1H), 2.41-2.39 (m, 2H), 2.31 (s, 3H), 1.80 (d, *J* = 5.9 Hz, 1H), 1.41-1.36(m, 1H), 1.37 (s, 3H)

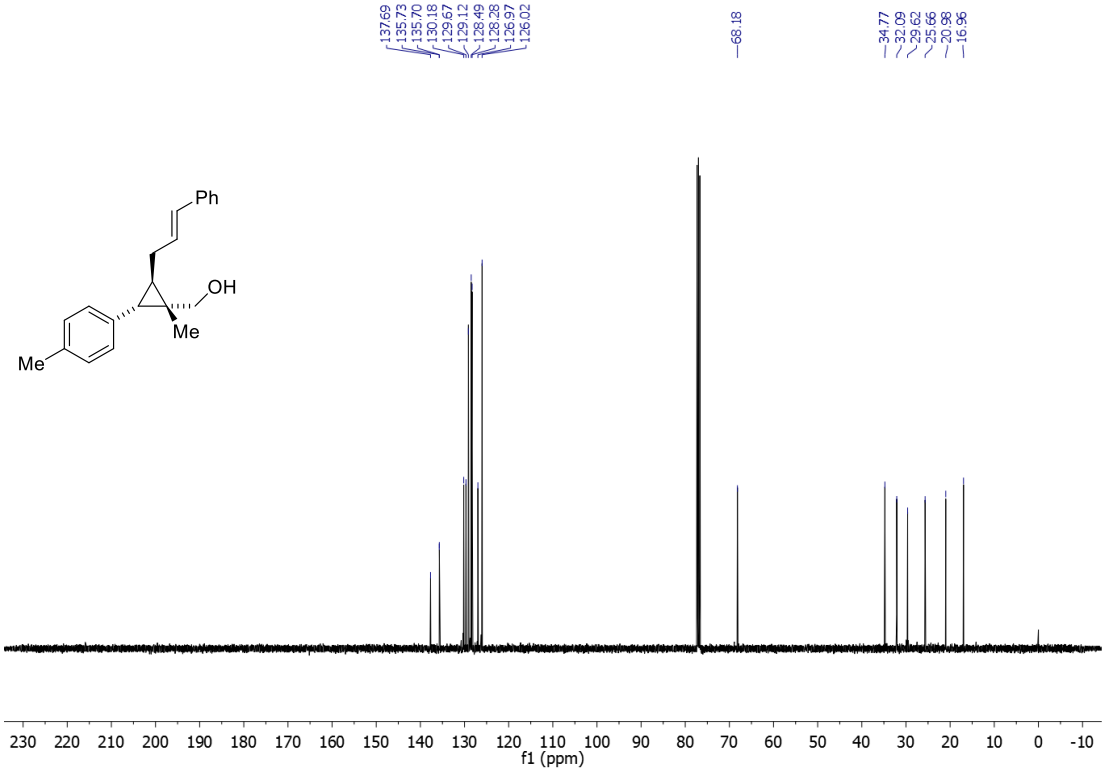
^{13}C NMR (100 MHz, $CDCl_3$) δ 137.6, 135.7 (d, *J* = 2.3 Hz), 130.1, 129.6, 129.1, 128.4, 128.2, 126.9, 126.0, 68.1, 34.7, 32.0, 29.6, 25.6, 20.9, 16.9.

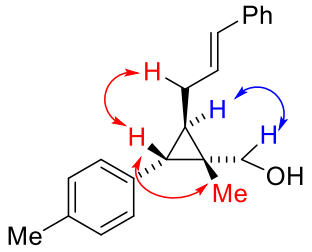
HRMS (ESI) Calcd. for $C_{21}H_{24}NaO^+$ $[M+Na]^+$: 315.1719, Found: 315.1729.

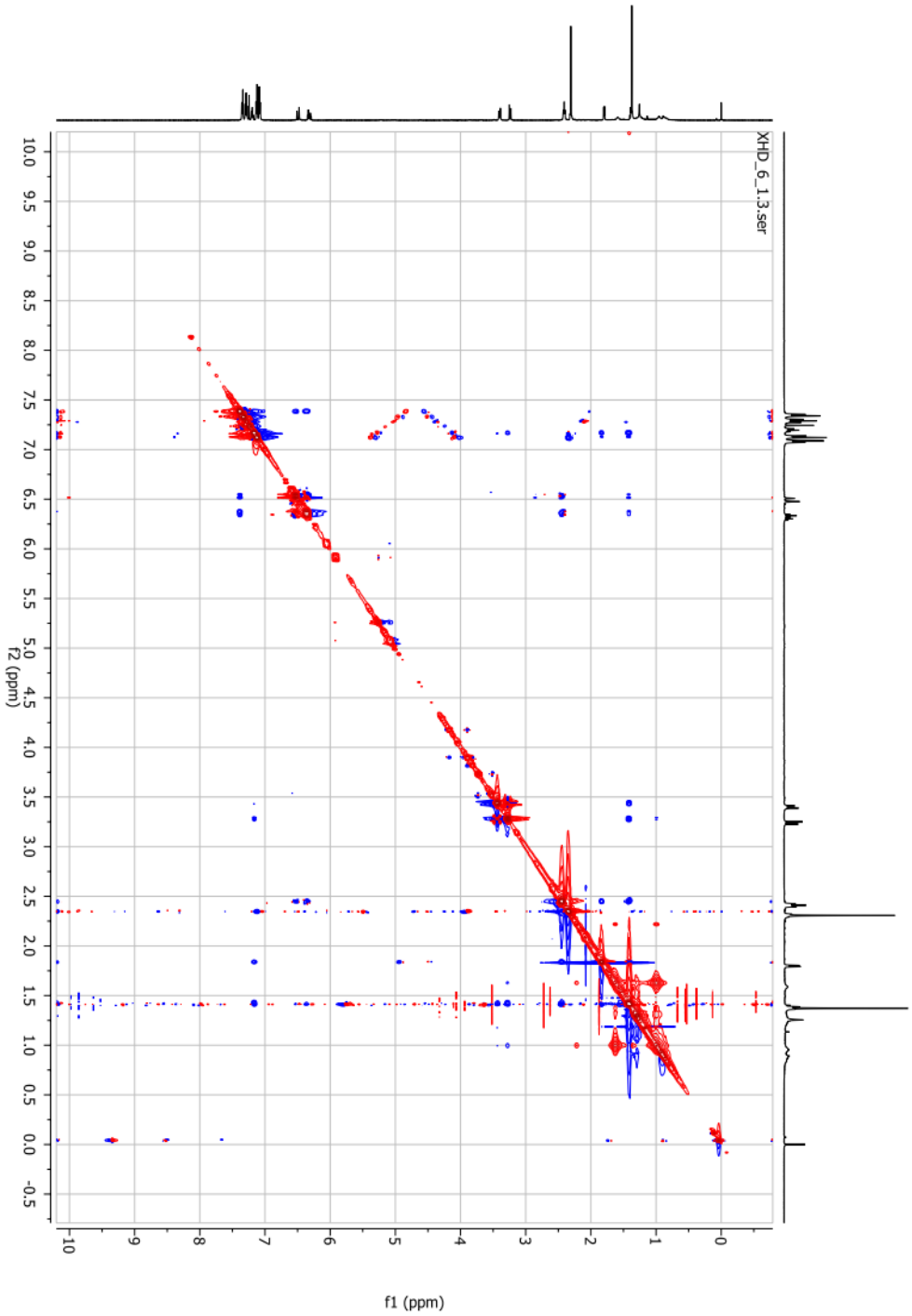
$[\alpha]_D^{33}$: +9.7 (*c* = 1.0, $CHCl_3$).

FTIR (neat): 3406, 2922, 1514, 1448, 1378, 1019, 963, 825, 803, 741, 692 cm^{-1}.

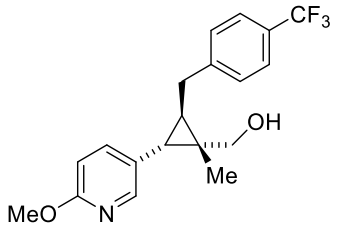

Ph
OH
Me
Me
f1 (ppm)


Ph
OH
Me
Me
f1 (ppm)


Ph
H
H
H
H
OH
Me
Me


XHD_6_1.3.ser
f2 (ppm)
f1 (ppm)

((*1S,2S,3R*)-2-(6-methoxypyridin-3-yl)-1-methyl-3-(4-(trifluoromethyl)benzyl)cyclopropyl)methanol (2.3m)



Detailed Procedures

An oven-dried sealed tube equipped with a magnetic stir bar was charged with vinyl-dioxanone **2.1h** (24.9 mg, 0.1 mmol, 100 mol%), tri(p-tolyl)boroxine (43.9 mg, 0.085 mmol, 85 mol%) **2.2b**, dicyclohexylphenylphosphine (5.8 mg, 0.02 mmol, 20 mol%, 95%wt) and potassium phosphate (42.4 mg, 0.2 mmol, 200 mol%). This tube was transferred into an argon-atmosphere glovebox. $Ni(cod)_2$ (2.8 mg, 0.01 mmol, 10 mol%) and toluene (0.5 mL, 0.2 M) were added. After sealing the tube with cap, the tube was removed from the glovebox and the reaction mixture was stirred at 55 ˚C for 48 h. The reaction was cooled to ambient temperature, diluted with Et_2O (1 mL) and filtered through a plug of silica gel, which was rinsed with Et_2O (2 mL). The combined organic solution was concentrated in *vacuo*. The residue was subjected to flash column chromatography (SiO_2, hexanes: ethyl acetate = 3:1,) to furnish the title compound as oil (25.2 mg, 0.72 mmol) in 72% yield.

TLC (SiO_2) R_f = 0.10 (hexanes/ethyl acetate = 3:1).

^{1}H NMR 1H NMR (500 MHz, $CDCl_3$) δ 7.94 (d, *J* = 2.4 Hz, 1H), 7.56 (d, *J* = 8.0 Hz, 2H), 7.40 (d, *J* = 8.6 Hz, 2H), 7.38 (dd, *J* = 6.4, 2.3 Hz, 1H), 6.64 (d, *J* = 8.4 Hz, 1H), 3.89 (s, 3H), 3.36 (d, *J* = 11.4 Hz, 1H), 3.25 (d, *J* = 11.4 Hz, 1H), 2.97 (dd, *J* = 15.2, 6.6 Hz, 1H), 2.84 (dd, *J* = 15.2, 7.7 Hz, 1H), 1.82 (d, *J* = 5.8 Hz, 1H), 1.46 (q, *J* = 6.5 Hz, 1H), 1.40 (s, 3H), 1.10 (s, 1H).

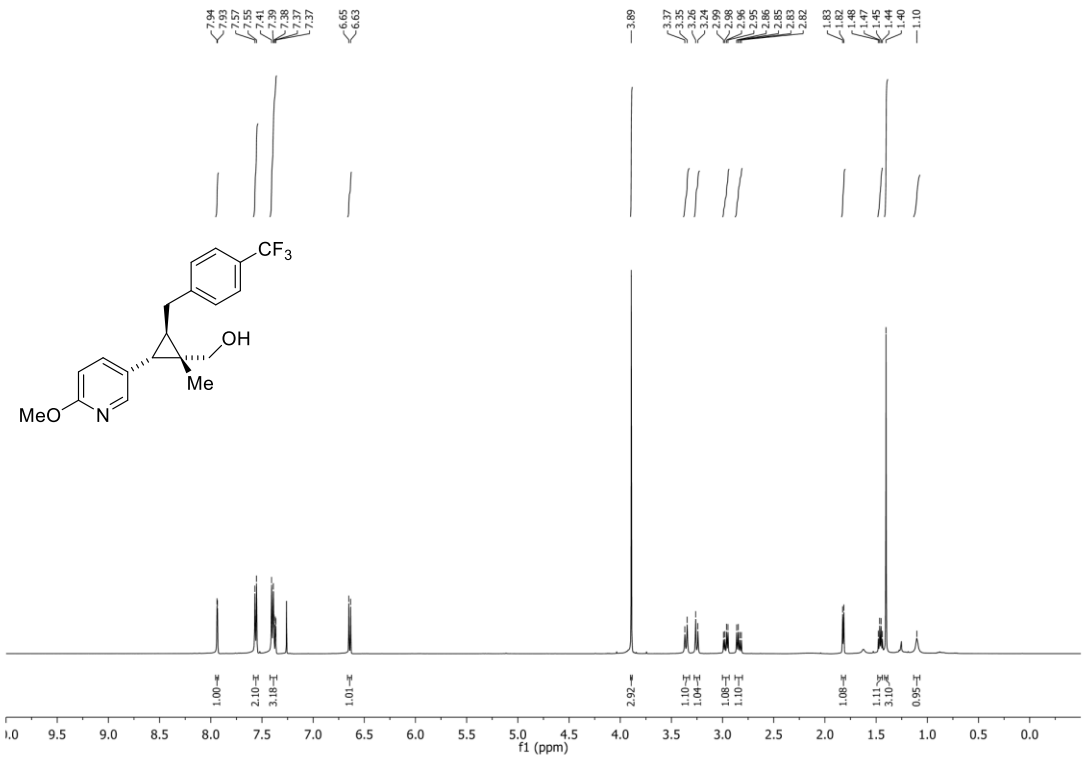
^{13}C NMR (125 MHz, $CDCl_3$) δ 163.1, 146.7, 145.8, 139.4, 128.6 (q, J^3_{CF} = 32.5 Hz), 128.6, 126.7, 125.6 (q, J^1_{CF} = 3.8 Hz), 124.4 (q, J^2_{CF} = 271 Hz, 110.5, 67.9, 53.5, 34.7, 32.2, 29.1, 27.2, 17.1.

^{19}F NMR (470 MHz, $CDCl_3$) δ -62.3.

HRMS (ESI) Calcd. for $C_{19}H_{20}F_3NNaO_2^+$ $[M+Na]^+$: 374.1339, Found: 374.1343

$[\alpha]_D^{29}$: 5.7 (c = 0.82, $CHCl_3$)

FTIR (neat): 1607, 1495, 1375, 1324, 1286, 1259, 1161, 1120, 1067, 1018, 832, 732 cm^{-1}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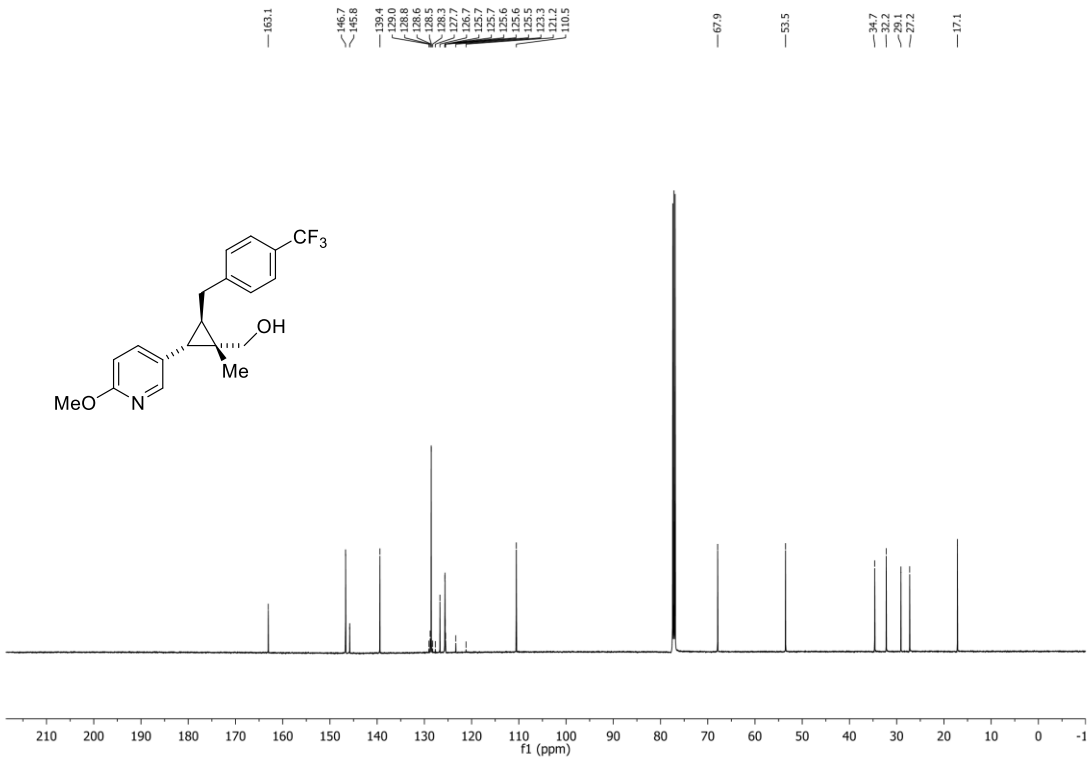
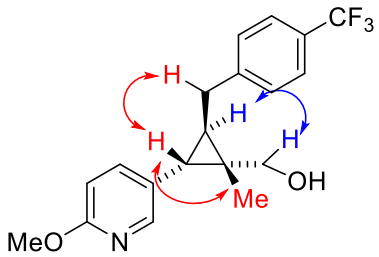
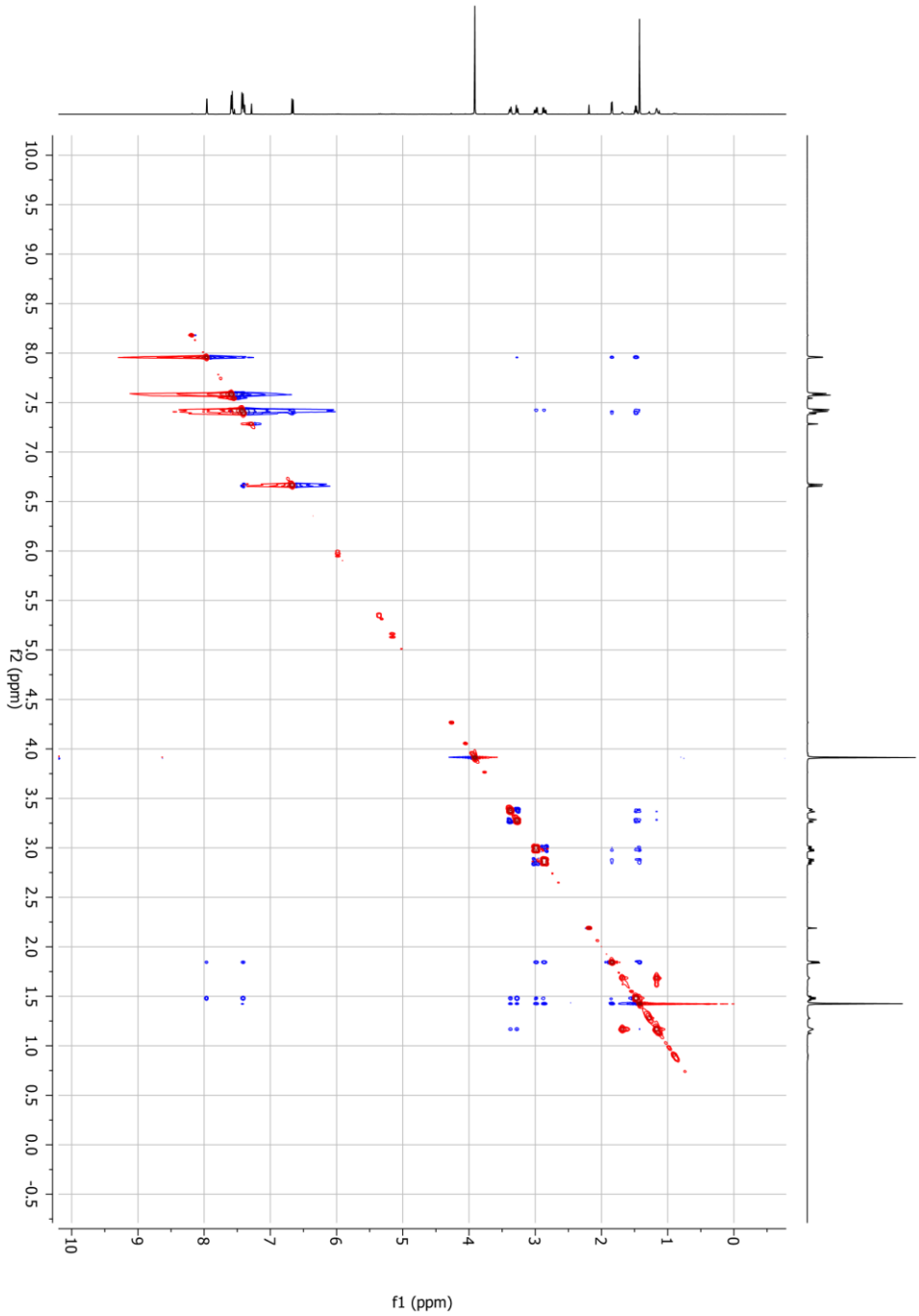
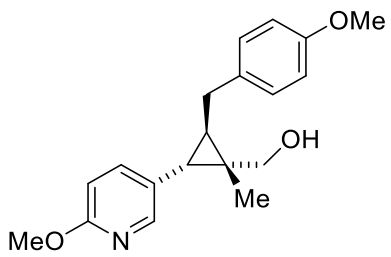
Me
MeO
N
f1 (ppm)


CF3
OH
Me
MeO
N
f1 (ppm)


CF3
H
H
H
H
OH
Me
MeO
N


f2 (ppm)
f1 (ppm)

((1*S*,2*R*,3*S*)-2-(4-methoxybenzyl)-3-(6-methoxypyridin-3-yl)-1-methylcyclopropyl)methanol (2.3n)



Detailed Procedures

An oven-dried sealed tube equipped with a magnetic stir bar was charged with vinyl-dioxanone **2.1h** (29.8 mg, 0.1 mmol, 100 mol%), tri(*p*-tolyl)boroxine **2.2d** (34.2 mg, 0.085 mmol, 85 mol%) **2.2c**, dicyclohexylphenylphosphine (5.8 mg, 0.02 mmol, 20 mol%, 95%wt) and potassium phosphate (42.4 mg, 0.2 mmol, 200 mol%). This tube was transferred into an argon-atmosphere glovebox. $Ni(cod)_2$ (2.8 mg, 0.01 mmol, 10 mol%) and toluene (0.5 mL, 0.2 M) were added. After sealing the tube with cap, the tube was removed from the glovebox and the reaction mixture was stirred at 55 ˚C for 48 h. The reaction was cooled to ambient temperature, diluted with Et_2O (1 mL) and filtered through a plug of silica gel, which was rinsed with Et_2O (2 mL). The combined organic solution was concentrated *in vacuo*. The residue was subjected to flash column chromatography (SiO_2, hexanes: ethyl acetate = 3:1) to furnish the title compound as a yellow solid (23.2 mg, 0.07 mmol) in 74% yield.

TLC (SiO_2) R_f = 0.24 (hexanes/ethyl acetate = 2:1).

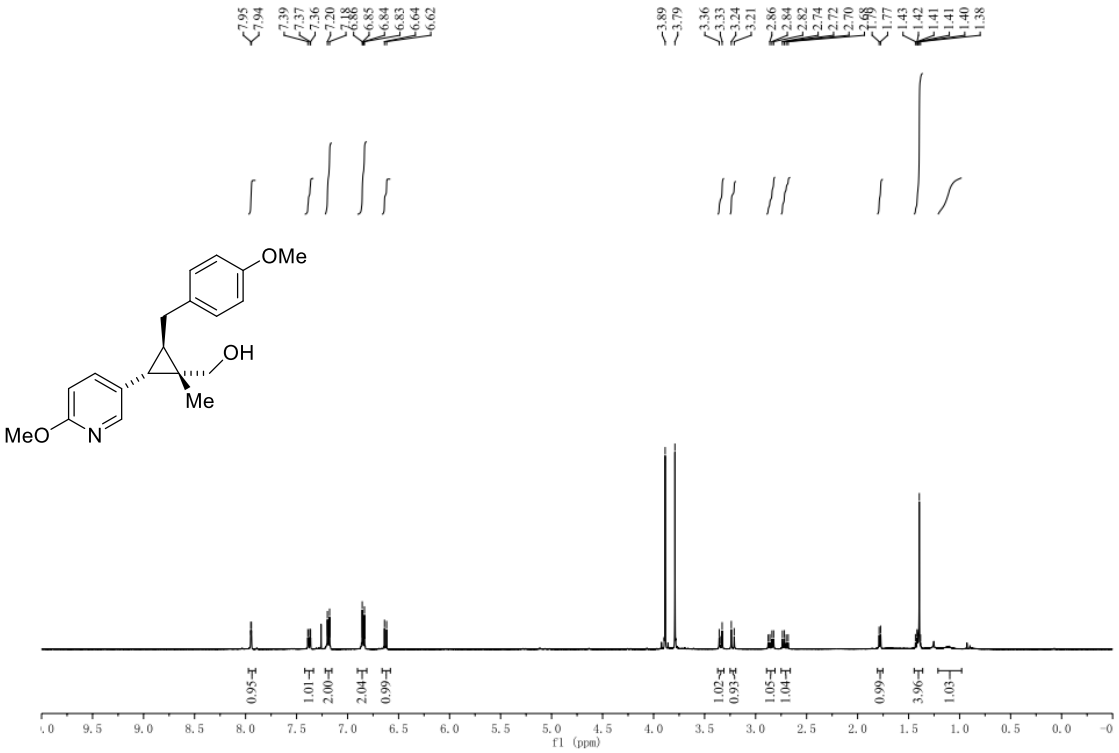
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.95 (d, *J* = 2.5 Hz, 1H), 7.38 (dd, *J* = 8.4, 2.3 Hz, 1H), 7.22 – 7.15 (m, 2H), 6.90 – 6.80 (m, 2H), 6.63 (d, *J* = 8.5 Hz, 1H), 3.89 (s, 3H), 3.79 (s, 3H), 3.34 (d, *J* = 11.4 Hz, 1H), 3.22 (d, *J* = 11.4 Hz, 1H), 2.85 (dd, *J* = 14.9, 6.6 Hz, 1H), 2.71 (dd, *J* = 15.0, 7.7 Hz, 1H), 1.78 (d, *J* = 5.8 Hz, 1H), 1.44 – 1.37 (m, 1H), 1.40 (s, 3H), 1.10 (brs, 1H).

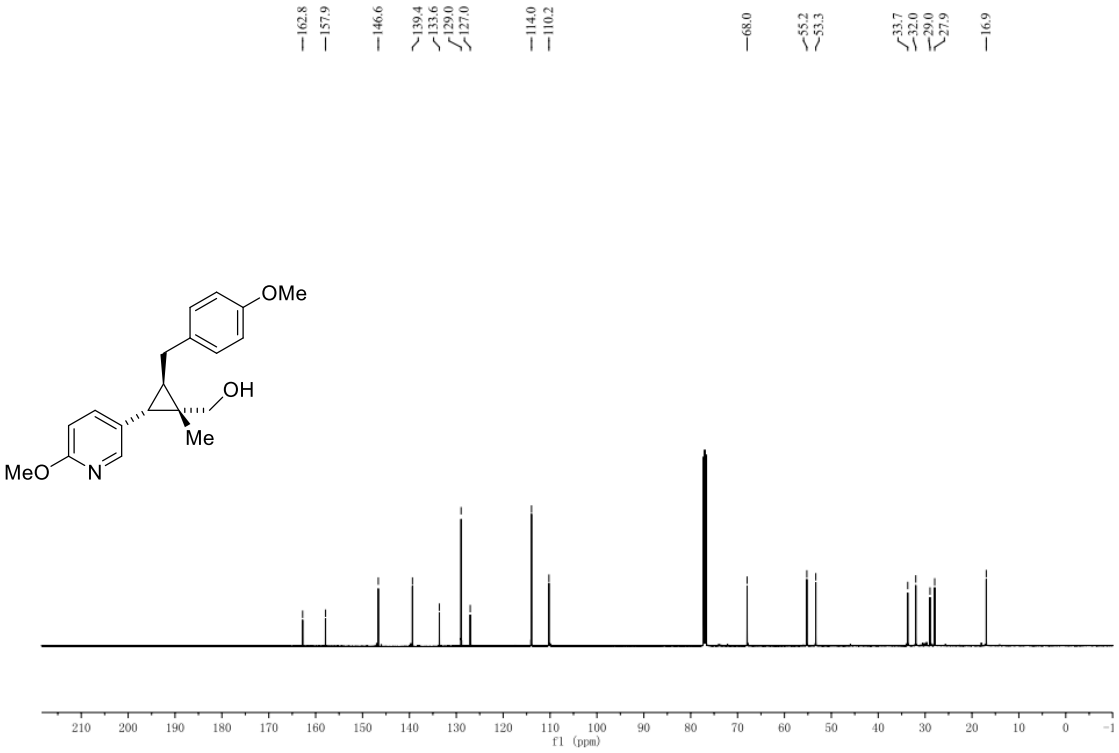
^{13}C NMR (125 MHz, $CDCl_3$) δ 162.8, 157.9, 146.6, 139.4, 133.6, 129.0, 127.0, 114.0, 110.2, 68.0, 55.2, 53.3, 33.7, 32.0, 29.0, 28.0, 16.9.

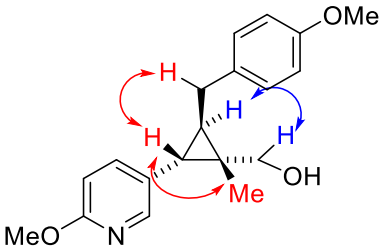
HRMS (ESI) Calcd. for $C_{19}H_{24}NO_3^+$ $[M+H]^+$: 314.1751, Found: 314.1754.

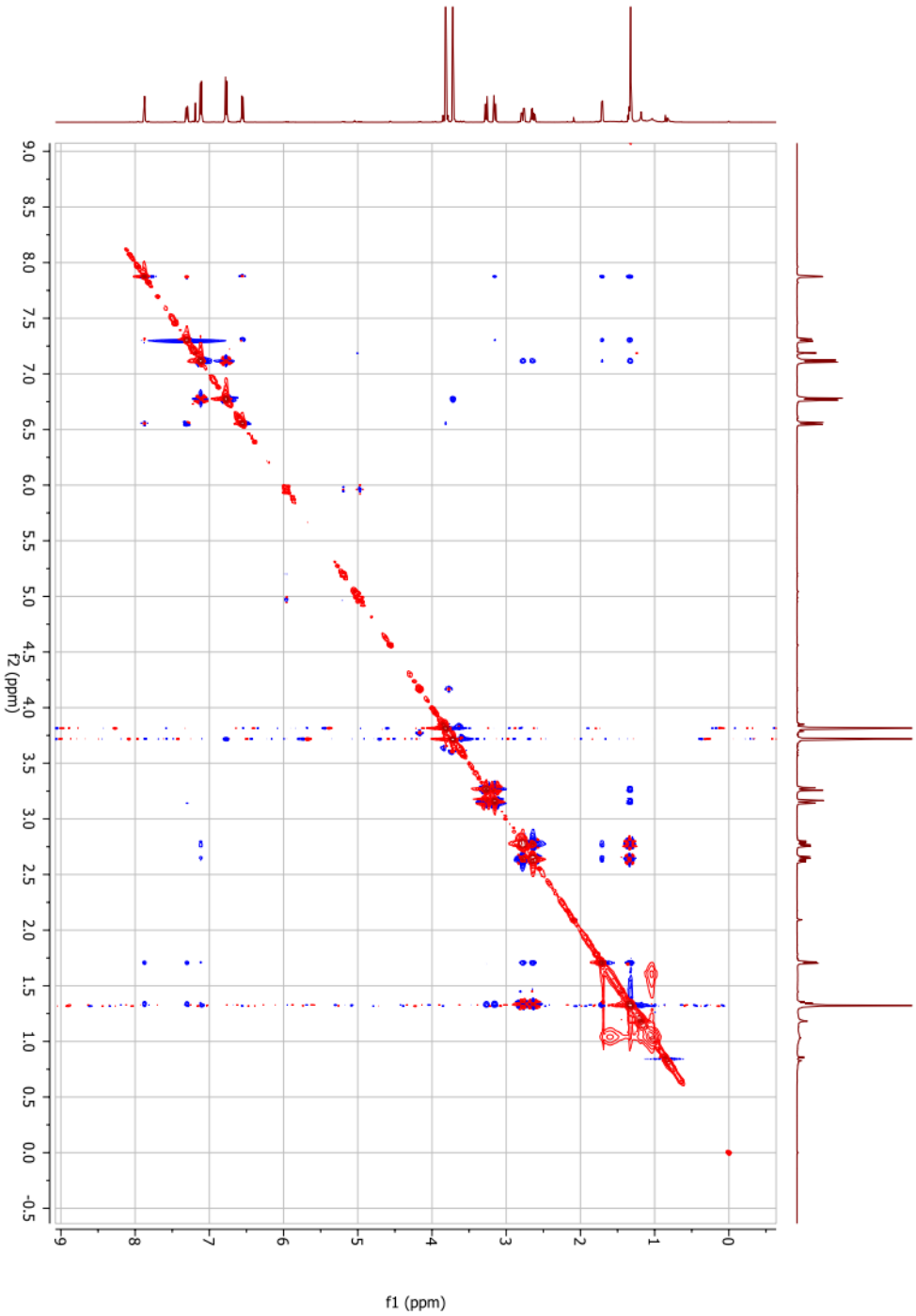
$[\alpha]_D^{33}$: +9.0 (*c* = 1.0, $CHCl_3$).

FTIR (neat): 3351, 2949, 1606, 1511, 1495, 1374, 1284, 1245, 1177, 1031, 830 cm^{-1}

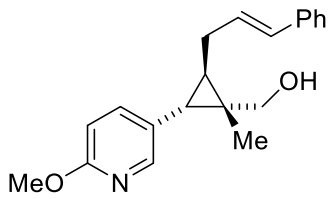

OMe
OH
Me
MeO
N
f1 (ppm)


OMe
OH
Me
MeO
N
f1 (ppm)


OMe
H
H
H
H
OH
Me
MeO
N


f2 (ppm)
f1 (ppm)

((1*S*,2*R*,3*S*)-2-cinnamyl-1-methyl-3-(*p*-tolyl)cyclopropyl)methanol (2.3o)



Detailed Procedures

An oven-dried sealed tube equipped with a magnetic stir bar was charged with vinyl-dioxanone **2.1h** (23.2 mg, 0.1 mmol, 100 mol%), tri(phenylvinyl)boroxine **2.2d** (33.2 mg, 0.085 mmol, 85 mol%), dicyclohexylphenylphosphine (5.8 mg, 0.02 mmol, 20 mol%, 95%wt) and potassium phosphate (42.4 mg, 0.2 mmol, 200 mol%). This tube was transferred into an argon-atmosphere glovebox. $Ni(cod)_2$ (2.8 mg, 0.01 mmol, 10 mol%) and toluene (0.5 mL, 0.2 M) were added. After sealing the tube with cap, the tube was removed from the glovebox and the reaction mixture was stirred at 60 ˚C for 48 h. The reaction was cooled to ambient temperature, diluted with Et_2O (1 mL) and filtered through a plug of silica gel, which was rinsed with Et_2O (2 mL). The combined organic solution was concentrated *in vacuo*. The residue was subjected to flash column chromatography (SiO_2, hexanes: ethyl acetate = 10:1) to furnish the title compound as a colorless oil (18.9 mg, 0.061 mmol) in 61% yield.

TLC (SiO_2) R_f = 0.40 (hexanes/ethyl acetate = 3:1).

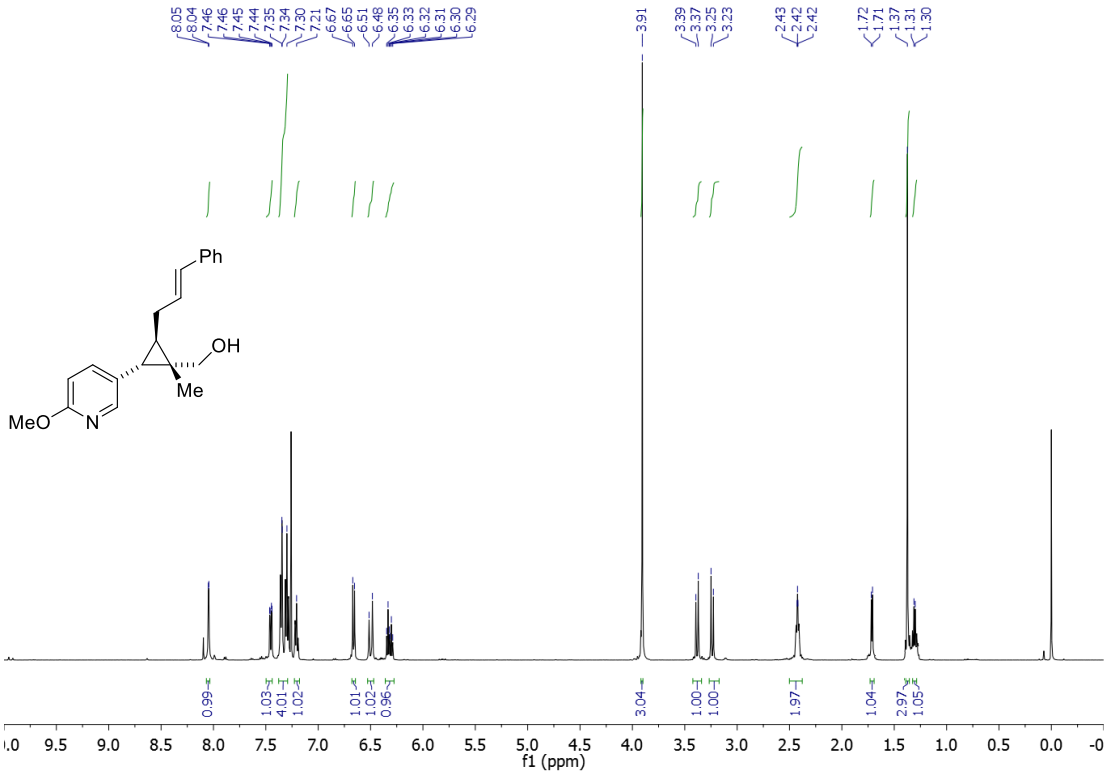
^{1}H NMR (500 MHz, $CDCl_3$) δ 8.05 (d, *J* = 2.4 Hz, 1H), 7.45 (dd, *J* = 8.6, 2.5 Hz, 1H), 7.39 – 7.27 (m, 4H), 7.24 – 7.19 (m, 1H), 6.66 (d, *J* = 8.4 Hz, 1H), 6.52 – 6.46 (m, 1H), 6.32 (dt, *J* = 15.8, 6.5 Hz, 1H), 3.38 (d, *J* = 11.4 Hz, 3H), 3.24 (d, *J* = 11.5 Hz, 1H), 2.43-2.42 (m, 2H), 1.71 (d, *J* = 5.8 Hz, 1H), 1.37 (s, 3H), 1.31 (td, *J* = 7.2, 5.9 Hz, 1H).

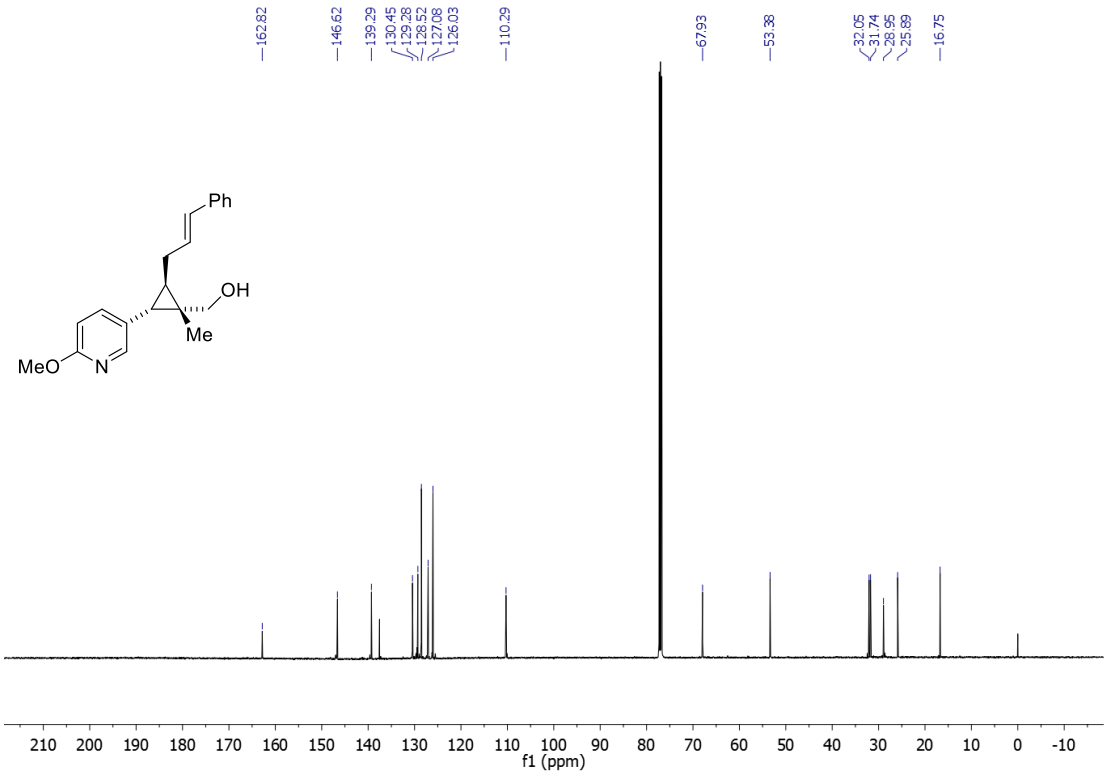
^{13}C NMR (125 MHz, $CDCl_3$) δ 162.8, 146.6, 139.2, 137.5, 130.4, 129.2, 128.5, 127.0, 126.0, 110.2, 67.9, 53.3, 32.0, 31.7, 28.9, 25.8, 16.7.

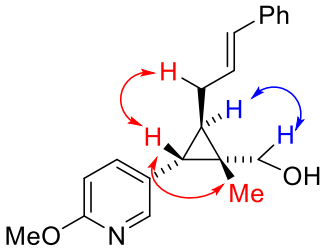
HRMS (ESI) Calcd. for $C_{20}H_{23}NaNO_2^+$ $[M+Na]^+$: 310.1802, Found: 310.1800.

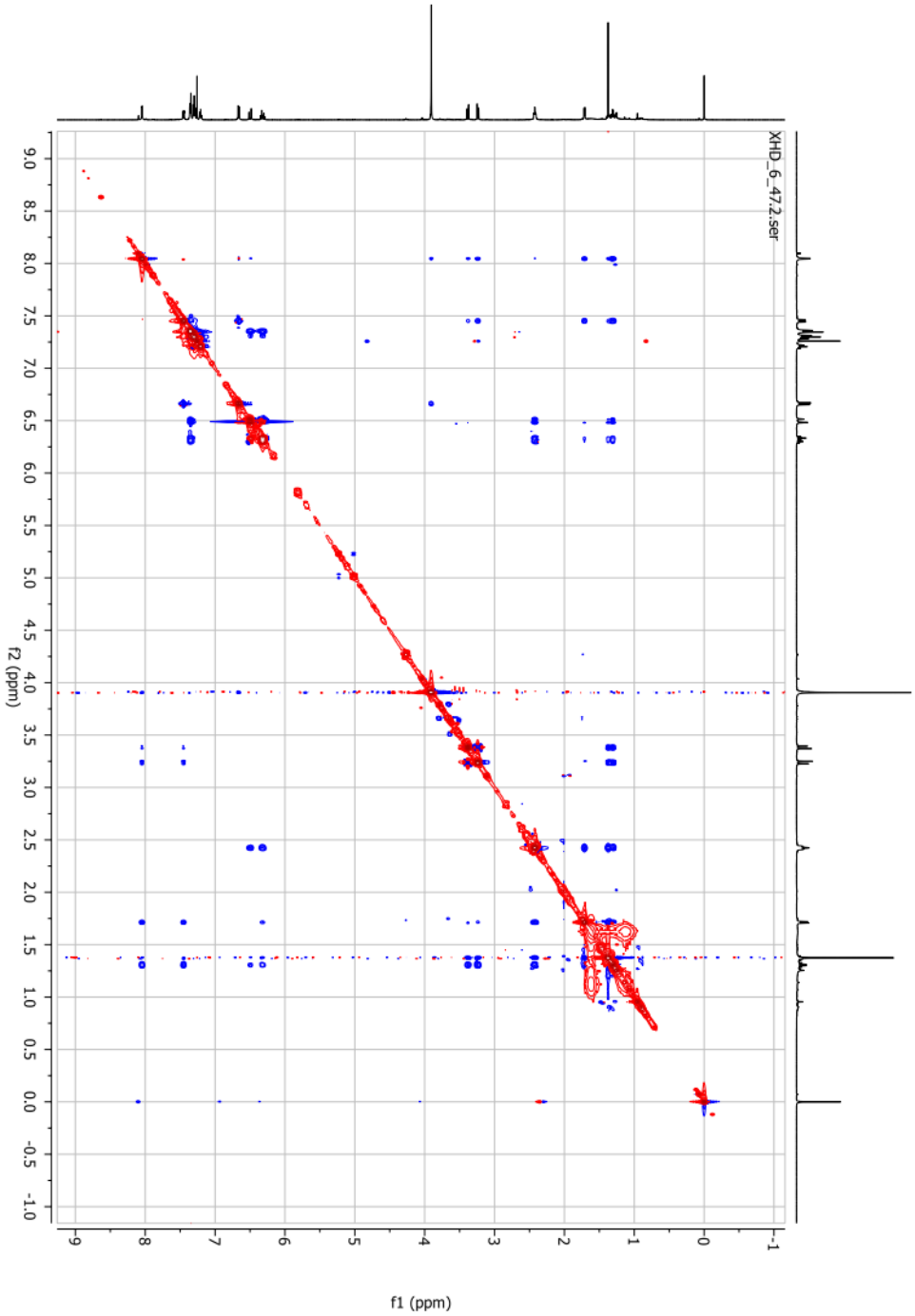
$[\alpha]_D^{33}$: +5.5 (*c* = 1.0, $CHCl_3$).

FTIR (neat): 3415, 2951, 1605, 1494, 1374, 1284, 1027, 964, 831, 742, 693 cm^{-1}.

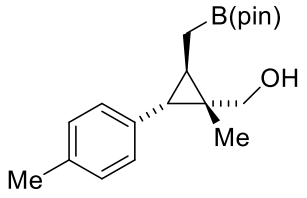

8.05
8.04
7.46
7.46
7.45
7.44
7.35
7.34
7.30
7.21
6.67
6.65
6.51
6.48
6.35
6.33
6.32
6.31
6.30
6.29
3.91
3.39
3.37
3.25
3.23
2.43
2.42
2.42
2.42
1.72
1.71
1.37
1.31
1.30
Ph
OH
Me
MeO
N
0.99
1.03
4.01
1.02
1.01
1.02
0.96
3.04
1.00
1.00
1.97
1.04
2.97
1.05
f1 (ppm)


162.82
146.62
139.29
130.45
129.28
128.52
127.08
126.03
110.29
67.93
53.38
32.05
31.74
28.95
25.89
16.75
Ph
OH
Me
MeO
N
f1 (ppm)


Ph
H
H
H
H
OH
Me
MeO
N


XHD_6_47.2.ser
f2 (ppm)
f1 (ppm)

((1*S*,2*R*,3*S*)-1-methyl-2-((4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)methyl)-3-(*p*-tolyl)cyclopropyl)methanol (2.3p)



Detailed Procedures

An oven-dried sealed tube equipped with a magnetic stir bar was charged with vinyl-dioxanone **2.1a** (29.8 mg, 0.1 mmol, 100 mol%), B_2pin_2 (50.8 mg, 0.2 mmol, 200 mol%) **2.2a**, dicyclohexylphenylphosphine (5.8 mg, 0.02 mmol, 20 mol%, 95%wt) and potassium phosphate (42.4 mg, 0.2 mmol, 200 mol%). This tube was transferred into an argon-atmosphere glovebox. $Ni(cod)_2$ (2.8 mg, 0.01 mmol, 10 mol%) and toluene (0.5 mL, 0.2 M) were added. After sealing the tube with cap, the tube was removed from the glovebox and the reaction mixture was stirred at 55 ˚C for 48 h. The reaction was cooled to ambient temperature, diluted with Et_2O (1 mL) and filtered through a plug of silica gel, which was rinsed with Et_2O (2 mL). The combined organic solution was concentrated *in vacuo*. The residue was subjected to flash column chromatography (SiO_2, hexanes: ethyl acetate = 4:1) to furnish the title compound as a yellow solid (26.8 mg, 0.08 mmol) in 85% yield.

TLC (SiO_2) R_f = 0.30 (hexanes/ethyl acetate = 4:1).

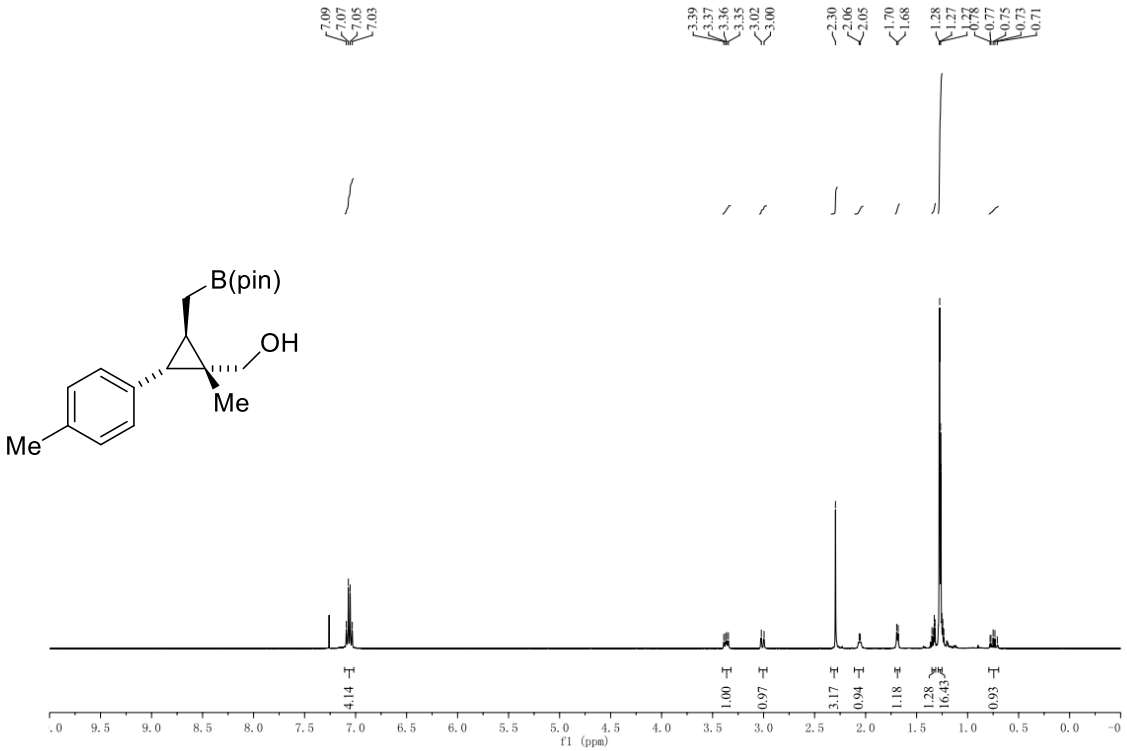
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.10 – 7.02 (m, 4H), 3.37 (dd, J = 10.9, 7.2 Hz, 1H), 3.01 (d, J = 10.9 Hz, 1H), 2.30 (s, 3H), 2.06 (brs, 1H), 1.35 – 1.31 (m, 1H), 1.29 – 1.25 (m, 16H), 0.78 – 0.71 (m, 1H).

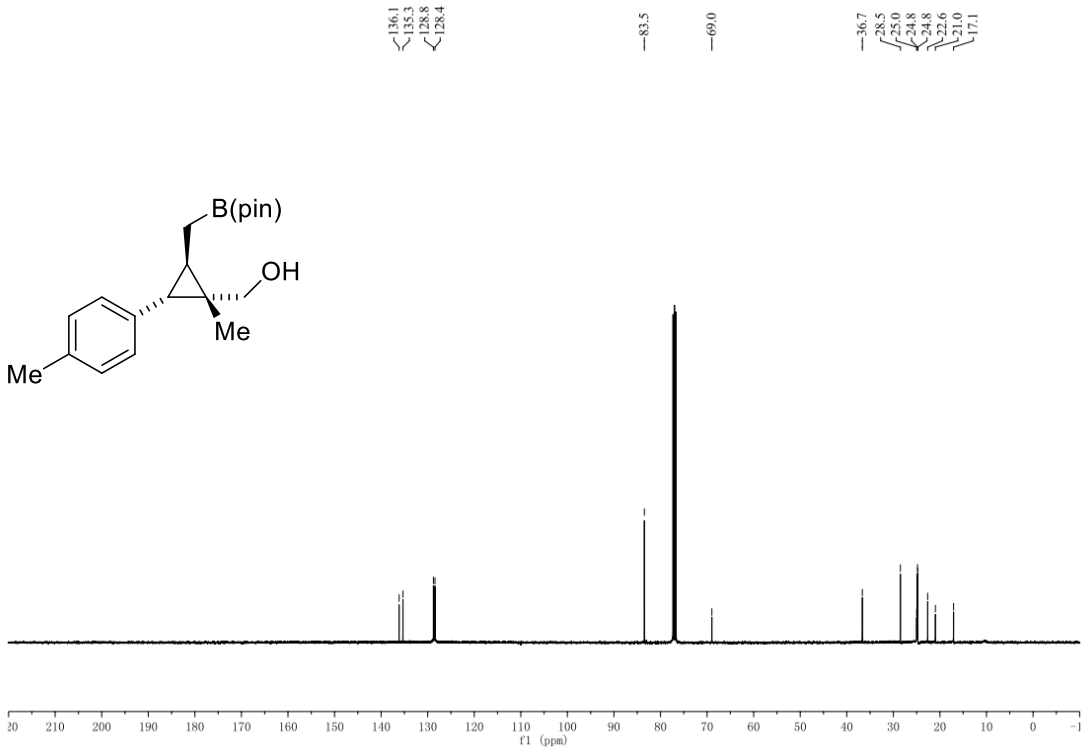
^{13}C NMR (100 MHz, $CDCl_3$) δ 136.1, 135.3, 128.8, 128.4, 83.5, 69.0, 36.6, 28.5, 25.0, 24.8, 24.8, 22.6, 21.0, 17.1.

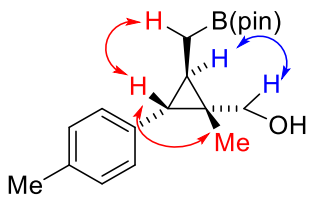
HRMS (CI) Calcd. for $C_{19}H_{29}BO_3^+$ $[M]^+$: 316.2204, Found: 316.2204.

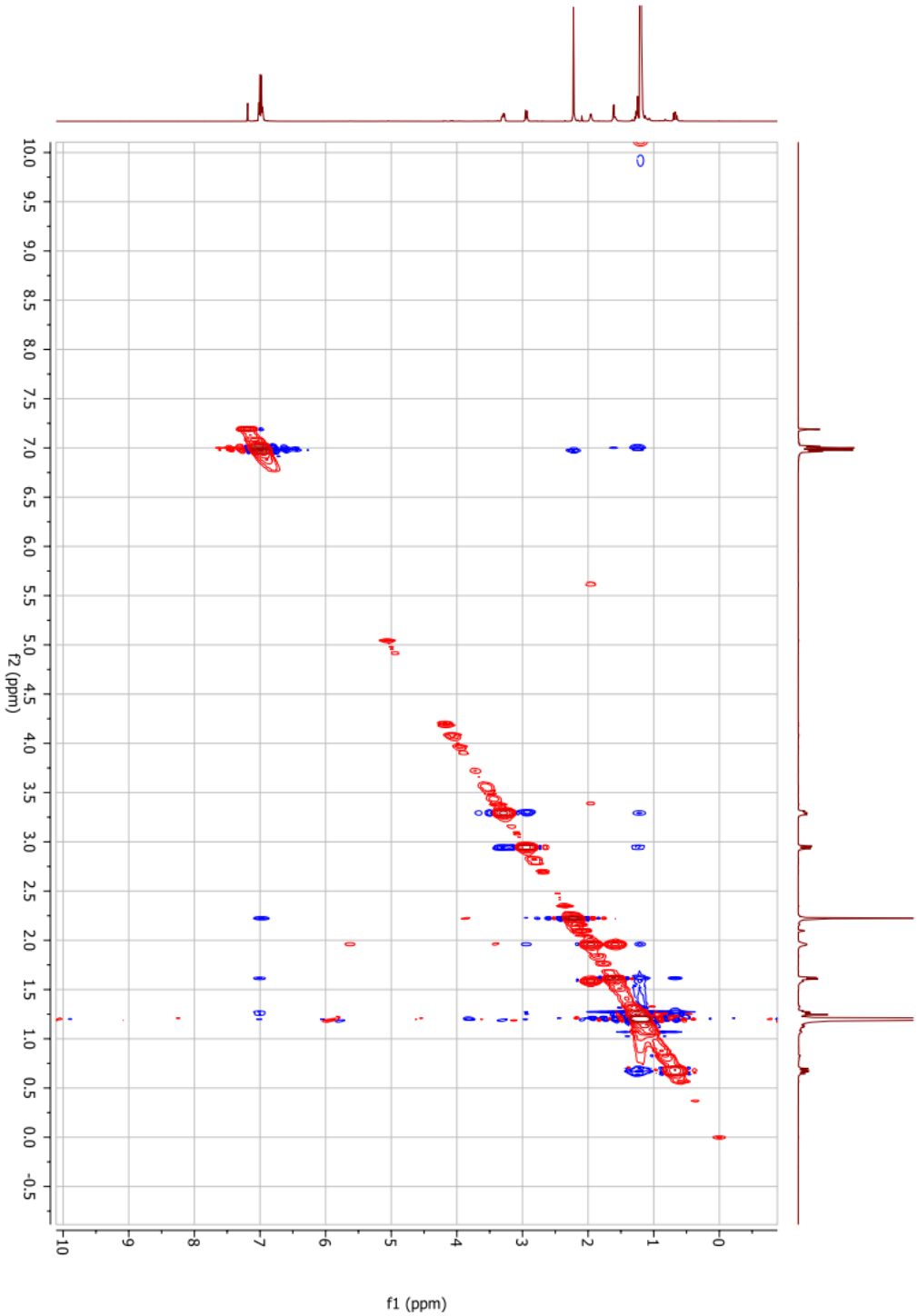
$[\alpha]_D^{33}$: +38.7 (*c* = 1.0, $CHCl_3$).

FTIR (neat): 3497, 2977, 2925, 1515, 1364, 1319, 1143, 1018, 967, 883, 848, 820, 748, 675 cm^{-1}

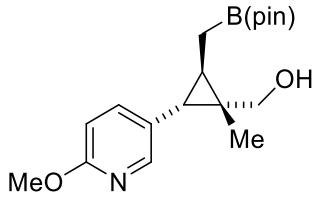

B(pin)
OH
Me
Me
7.09
7.07
7.05
7.03
3.39
3.37
3.36
3.35
3.02
3.00
2.30
2.06
2.05
1.70
1.68
1.28
1.27
0.77
0.75
0.73
0.71
4.14
1.00
0.97
3.17
0.94
1.18
1.28
16.43
0.93
f1 (ppm)


B(pin)
OH
Me
Me
136.1
135.3
128.8
128.4
83.5
69.0
36.7
28.5
25.0
24.8
24.8
22.6
21.0
17.1
f1 (ppm)


H
B(pin)
H
H
H
OH
Me
Me


f2 (ppm)
f1 (ppm)

((1*S*,2*S*,3*R*)-2-(6-methoxypyridin-3-yl)-1-methyl-3-((4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)methyl)cyclopropyl)methanol (2.3q)



Detailed Procedures

An oven-dried sealed tube equipped with a magnetic stir bar was charged with vinyl-dioxanone **2.1h** (24.9 mg, 0.1 mmol, 100 mol%), bis(pinacolato)diboron (50.8 mg, 0.2 mmol, 200 mol%), dicyclohexylphenylphosphine (5.8 mg, 0.02 mmol, 20 mol%, 95%wt) and potassium phosphate (42.4 mg, 0.2 mmol, 200 mol%). This tube was transferred into an argon-atmosphere glovebox. $Ni(cod)_2$ (2.8 mg, 0.01 mmol, 10 mol%) and toluene (0.5 mL, 0.2 M) were added. After sealing the tube with cap, the tube was removed from the glovebox and the reaction mixture was stirred at 45 ˚C for 48 h. The reaction was cooled to ambient temperature, diluted with Et_2O (1 mL) and filtered through a plug of silica gel, which was rinsed with Et_2O (2 mL). The combined organic solution was concentrated *in vacuo*. The residue was subjected to flash column chromatography (SiO_2, CH_2Cl_2: acetone = 20:1–10:1) to furnish the title compound as a colorless oil (24.0 mg, 0.07 mmol) in 72% yield.

TLC (SiO_2) R_f = 0.41 (hexanes/ethyl acetate = 1:1).

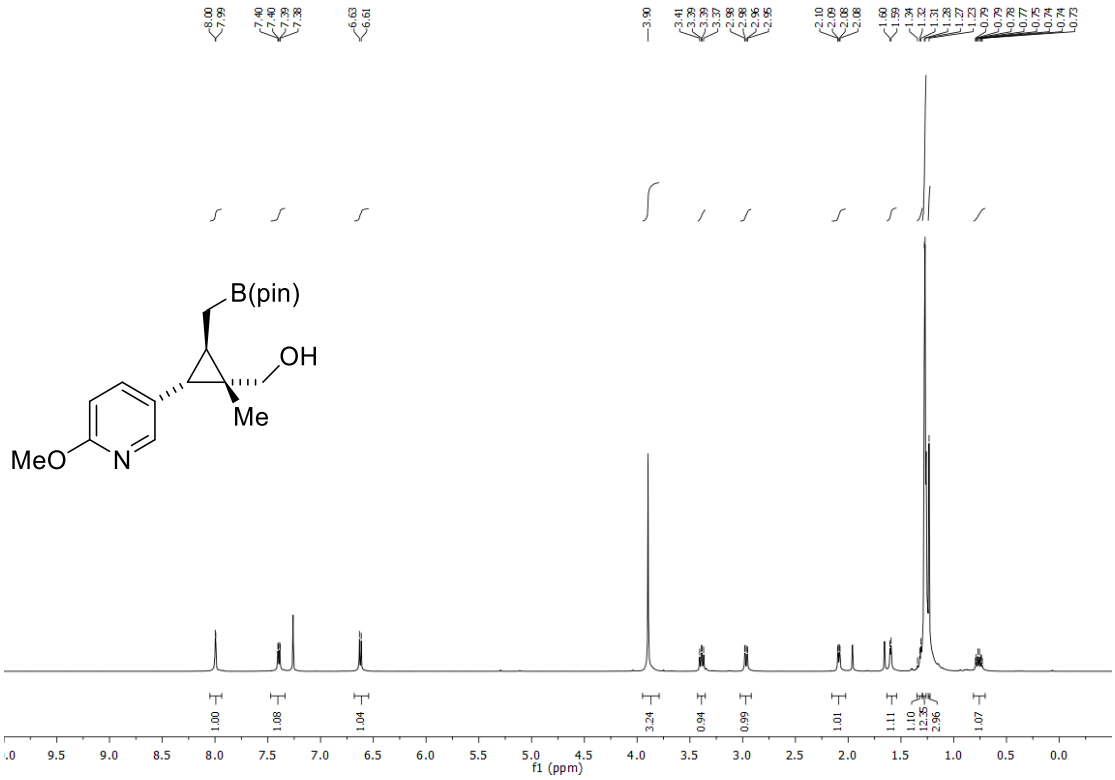
^{1}H NMR (500 MHz, $CDCl_3$) δ 8.00 (d, *J* = 2.4 Hz, 1H), 7.39 (dd, *J* = 8.5, 2.5 Hz, 1H), 6.62 (d, *J* = 8.5 Hz, 1H), 3.90 (s, 3H), 3.39 (dd, *J* = 10.9, 8.0 Hz, 1H), 2.97 (dd, *J* = 10.9, 2.9 Hz, 1H), 2.09 (dd, *J* = 8.2, 3.1 Hz, 1H), 1.60 (d, *J* = 5.4 Hz, 1H), 1.34 – 1.29 (m, *J* = 5.9 Hz, 1H), 1.27 (d, *J* = 3.2 Hz, 12H), 1.23 (s, 3H), 0.81 – 0.70 (m, 1H).

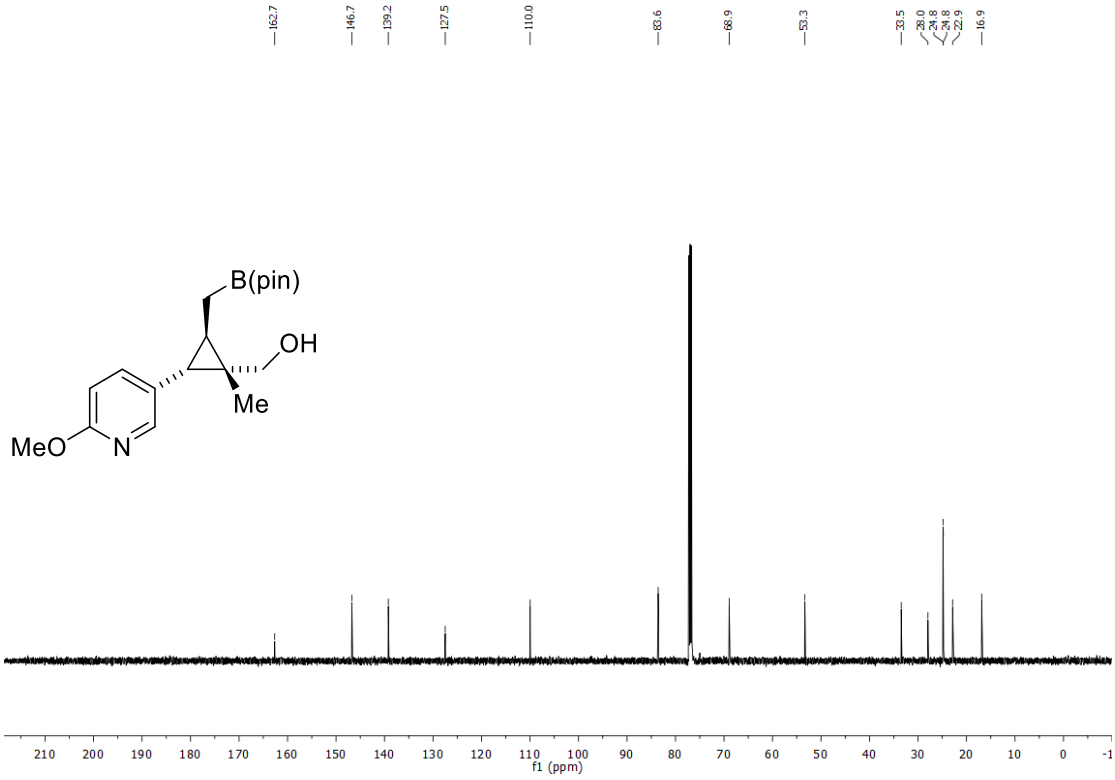
^{13}C NMR (125 MHz, $CDCl_3$) δ 162.7, 146.7, 139.2, 127.5, 110.0, 83.6, 68.9, 53.3, 33.5, 28.0, 24.8, 24.8, 22.9, 16.9.

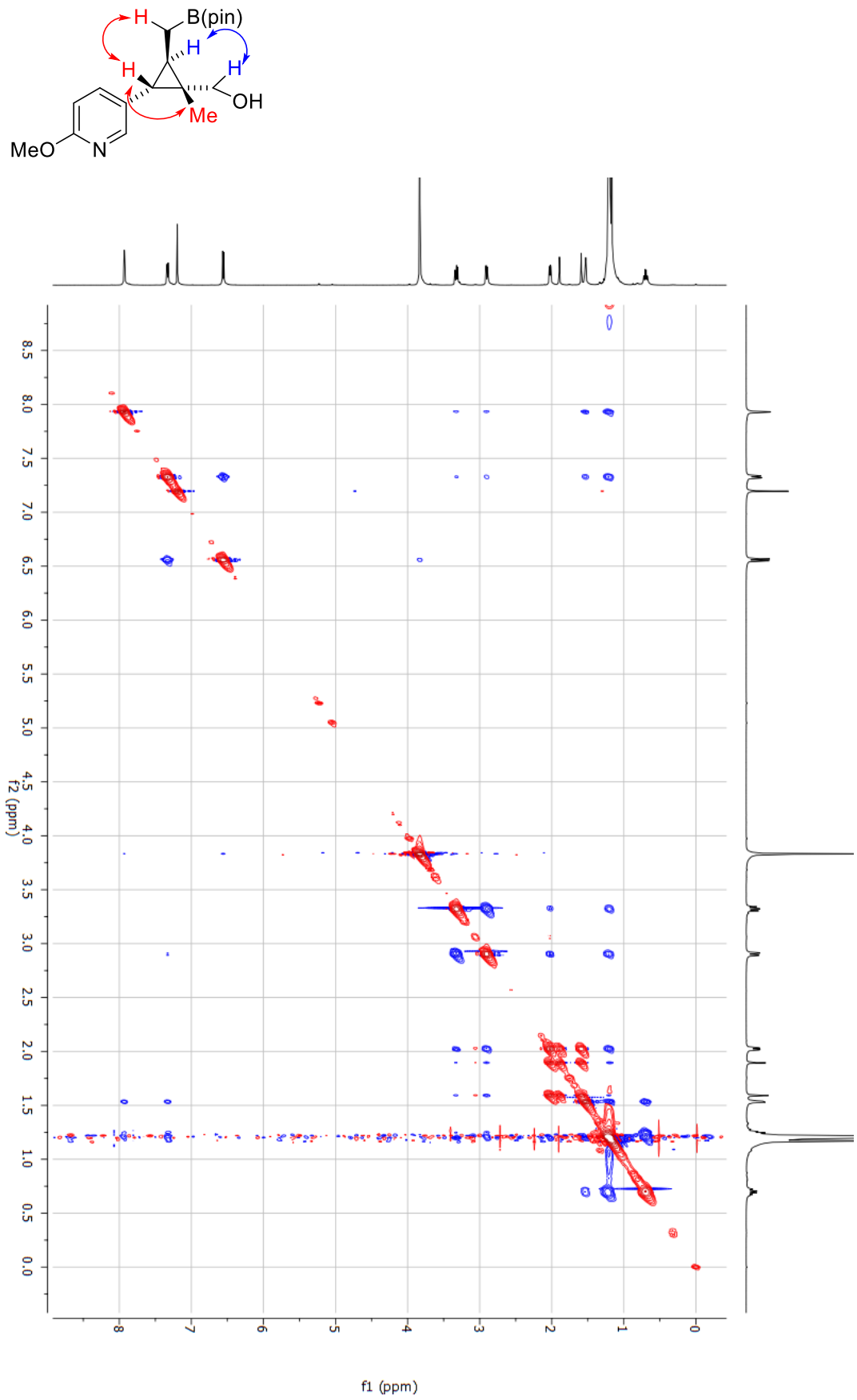
HRMS (ESI) Calcd. for $C_{18}H_{28}BNO_4$ $[M+H]^+$: 334.2187, Found: 334.2192.

$[\alpha]_D^{25}$: +33.7 (*c* = 1.0, $CHCl_3$).

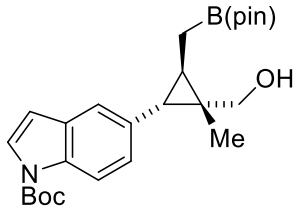
FTIR (neat): 3433, 2978, 1606, 1495, 1371, 1284, 1143, 1030, 967, 846, 755 cm^{-1}


B(pin)
OH
Me
MeO
N
f1 (ppm)


B(pin)
OH
Me
MeO
N
f1 (ppm)


H
B(pin)
H
H
H
OH
Me
MeO
N
f2 (ppm)
f1 (ppm)

***tert*-butyl 5-((1*S*,2*S*,3*R*)-2-(hydroxymethyl)-2-methyl-3-((4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)methyl)cyclopropyl)-1H-indole-1-carboxylate (2.3r)**



Detailed Procedures

An oven-dried sealed tube equipped with a magnetic stir bar was charged with vinyl-dioxanone **2.1e** (35.7 mg, 0.1 mmol, 100 mol%), bis(pinacolato)diboron (50.8 mg, 0.2 mmol, 200 mol%), dicyclohexylphenylphosphine (5.8 mg, 0.02 mmol, 20 mol%, 95%wt) and potassium phosphate (42.4 mg, 0.2 mmol, 200 mol%). This tube was transferred into an argon-atmosphere glovebox. $Ni(cod)_2$ (2.8 mg, 0.01 mmol, 10 mol%) and toluene (0.5 mL, 0.2 M) were added. After sealing the tube with cap, the tube was removed from the glovebox and the reaction mixture was stirred at 75 ˚C for 48 h. The reaction was cooled to ambient temperature, diluted with Et_2O (1 mL) and filtered through a plug of silica gel, which was rinsed with Et_2O (2 mL). The combined organic solution was concentrated *in vacuo*. The residue was subjected to flash column chromatography (SiO_2, hexanes: ethyl acetate = 15:1–10:1) to furnish the title compound as a colorless oil (33.1 mg, 0.08 mmol) in 75% yield.

TLC (SiO_2) R_f = 0.43 (hexanes/ethyl acetate = 4:1).

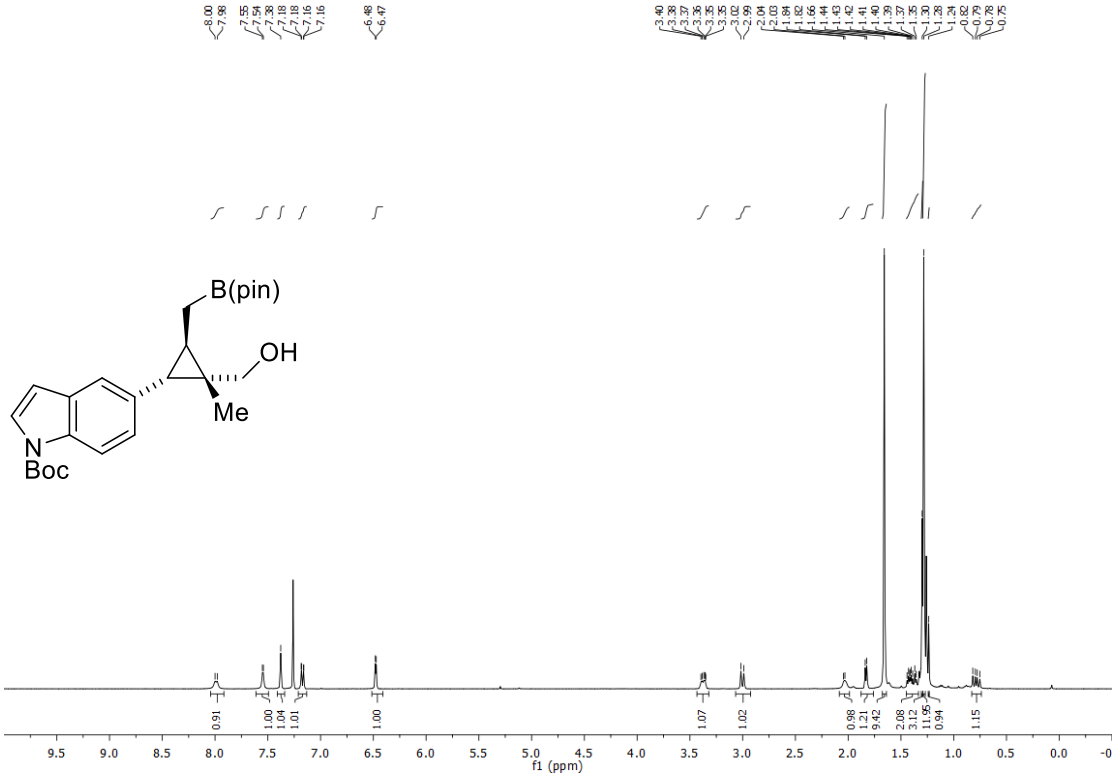
^{1}H NMR (500 MHz, $CDCl_3$) δ 7.99 (d, *J* = 8.5 Hz, 1H), 7.55 (d, *J* = 3.7 Hz, 1H), 7.38 (s, 1H), 7.17 (dd, *J* = 8.5, 1.6 Hz, 1H), 6.48 (d, *J* = 3.7 Hz, 1H), 3.43 – 3.32 (m, 1H), 3.00 (d, *J* = 11.0 Hz, 1H), 2.04 (d, *J* = 5.3 Hz, 1H), 1.83 (d, *J* = 6.0 Hz, 1H), 1.66 (s, 9H), 1.45 – 1.33 (m, 2H), 1.30 (s, 3H), 1.28 (s, 12H), 1.24 (s, 1H), 0.79 (dd, *J* = 16.9, 9.8 Hz, 1H).

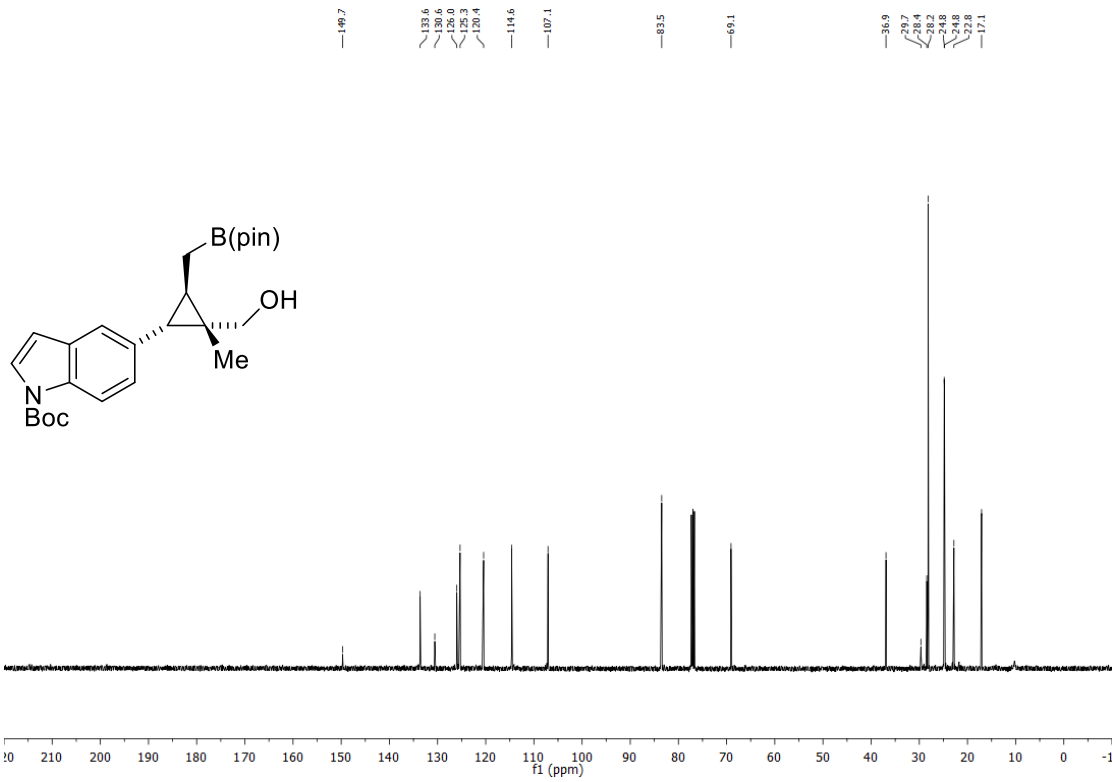
^{13}C NMR (100 MHz, $CDCl_3$) δ 149.7, 133.6, 130.6, 126.0, 125.3, 120.4, 114.6, 107.1, 83.5, 69.1, 36.9, 29.7, 28.5, 28.2, 24.8, 24.8, 22.8, 17.1.

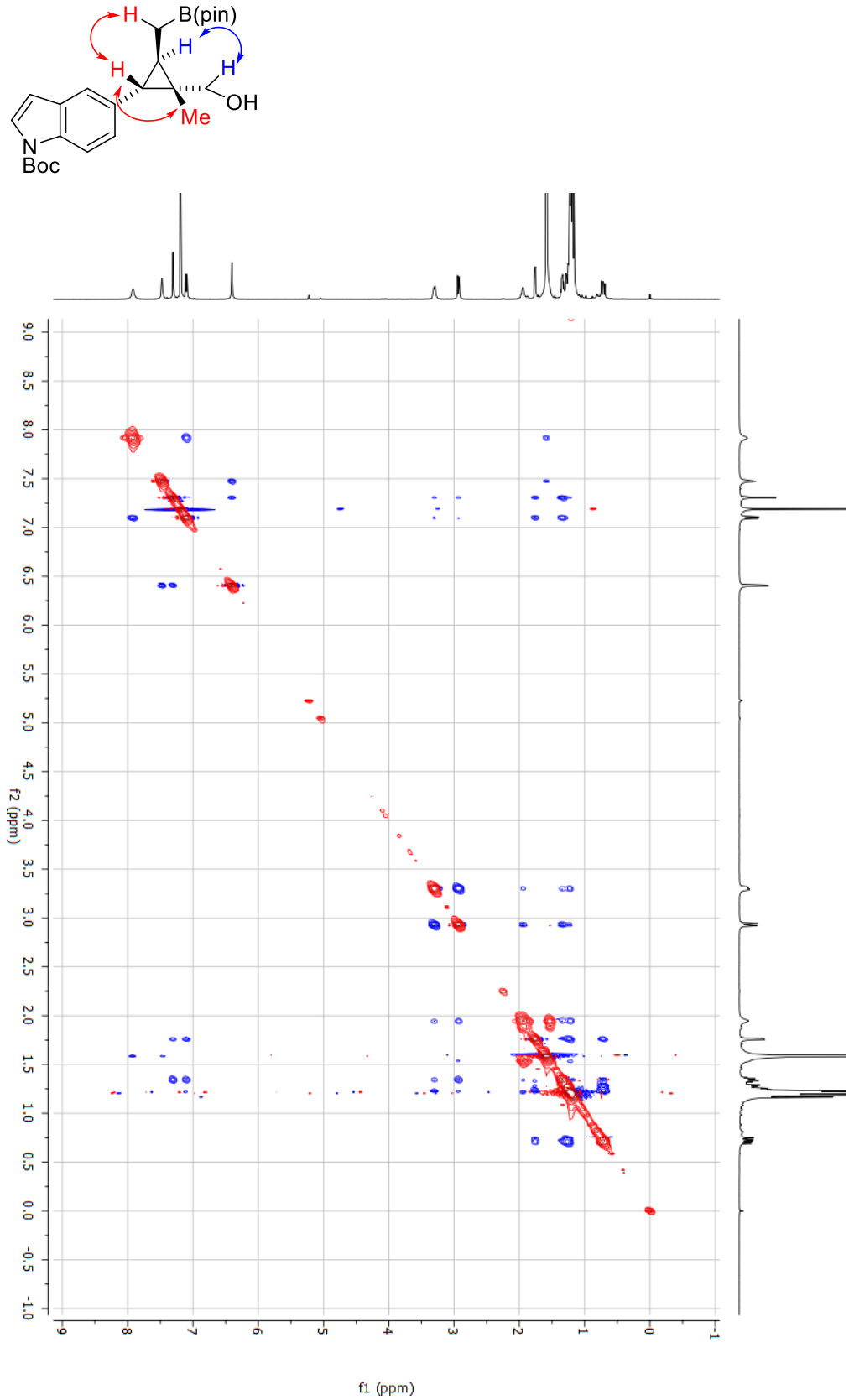
HRMS (ESI) Calcd. for $C_{25}H_{36}BNO_5$ $[M+K]^+$: 480.2323, Found: 480.2339.

$[\alpha]_D^{24}$: +31.7 (*c* = 1.0, $CHCl_3$).

FTIR (neat): 3486, 2978, 1732, 1474, 1369, 1264, 1216, 1133, 1023, 797 cm^{-1}

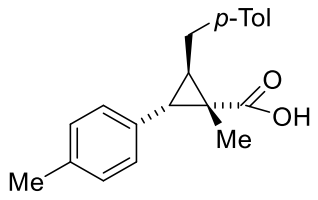





H
B(pin)
H
H
H
OH
Me
N
Boc
f2 (ppm)
f1 (ppm)

Procedures and Spectral Data for the Synthesis of 4a-4i:

(1*S*,2*R*,3*S*)-1-methyl-2-(4-methylbenzyl)-3-(p-tolyl)cyclopropane-1-carboxylic acid (2.4a)



Detailed Procedures

A vial equipped with a magnetic stir bar was charged with **2.3a** (22.4 mg, 0.08 mmol, 100 mol%). Under argon atmosphere, acetone (0.8 mL, 0.1 M) was added via syringe. The mixture was cooled to 0 °C and freshly prepared H_2CrO_4 (0.16 mL, 2.5 M, 500 mol%) was added dropwise. The reaction mixture was stirred at ambient temperature for 4 h. 2-propanol (0.5 mL) was slowly added. The mixture was filtered through a plug of sodium sulfate, which was rinsed with ethyl acetate (2 mL). The filtrate was concentrated *in vacuo*. The residue was subjected to flash column chromatography (SiO_2, hexanes: ethyl acetate = 3:1) to furnish the title compound as a colorless oil (17.8 mg, 0.06 mmol) in 76% yield.

TLC (SiO_2) R_f = 0.23 (hexanes/ethyl acetate = 3:1).

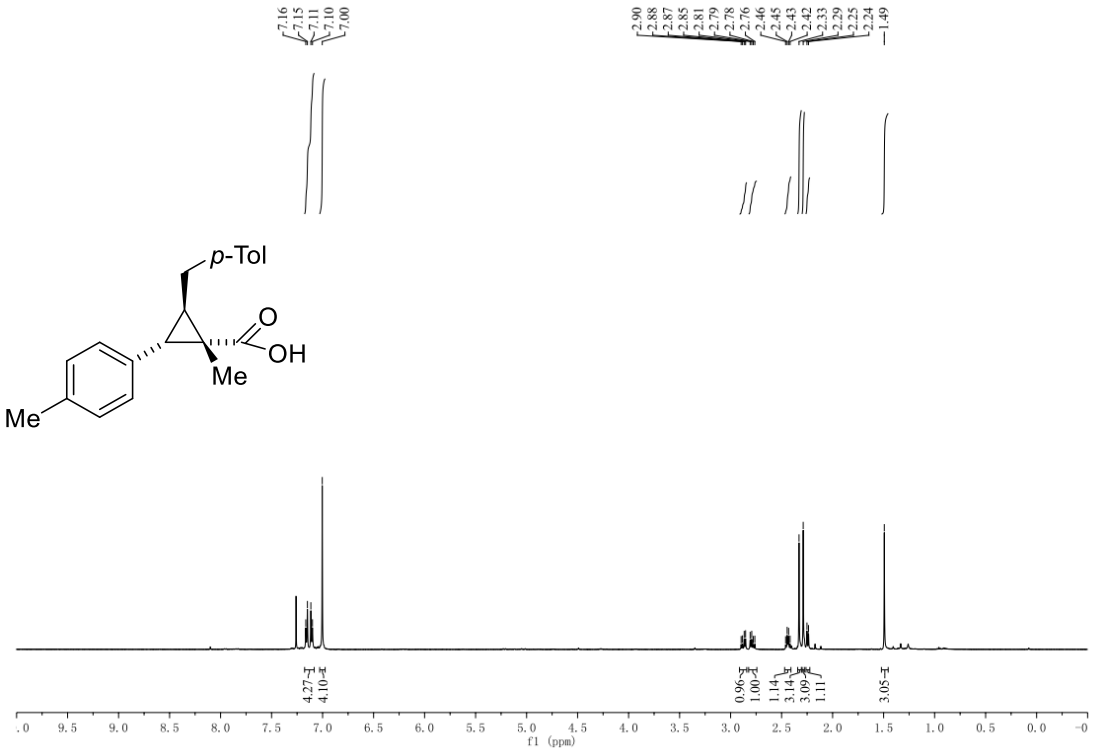
^{1}H NMR (500 MHz, $CDCl_3$) δ 7.18 – 7.08 (m, 4H), 7.00 (s, 4H), 2.87 (dd, *J* = 15.1, 6.8 Hz, 1H), 2.79 (dd, *J* = 15.1, 7.7 Hz, 1H), 2.47 – 2.40 (m, 1H), 2.33 (s, 3H), 2.29 (s, 3H), 2.24 (d, *J* = 7.5 Hz, 1H), 1.49 (s, 3H).

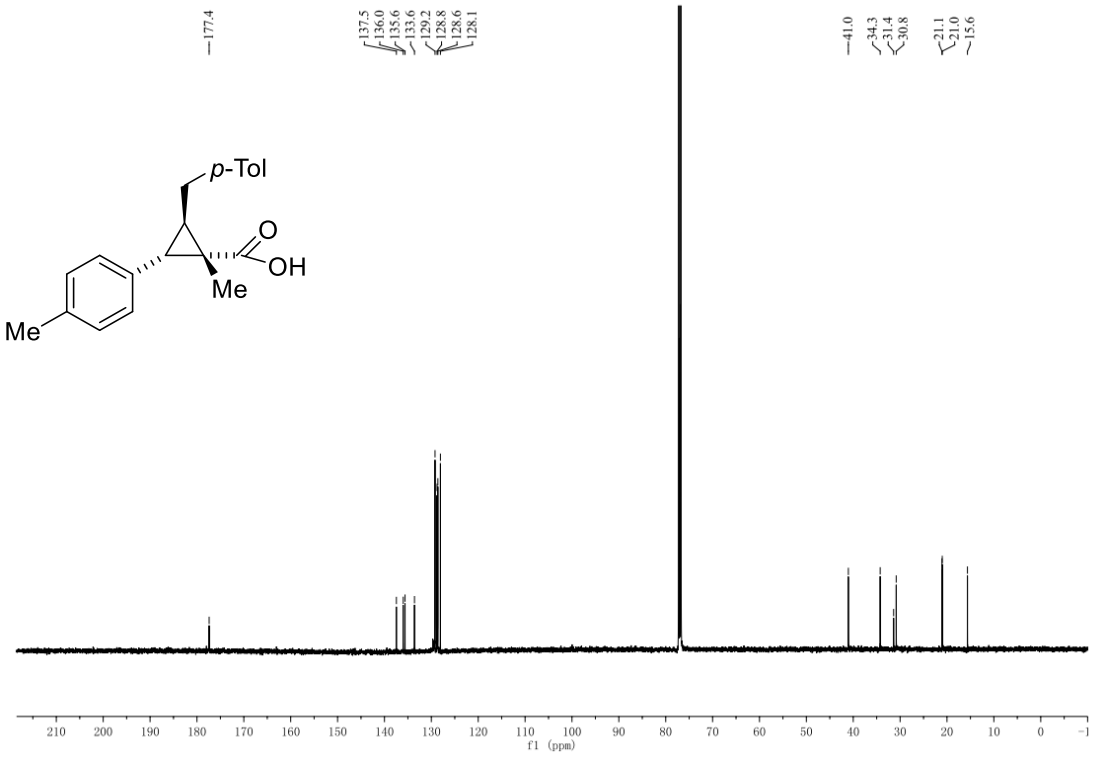
^{13}C NMR (125 MHz, $CDCl_3$) δ 177.4, 137.4, 136.0, 135.6, 133.6, 129.2, 128.8, 128.6, 128.1, 41.0, 34.2, 31.4, 30.8, 21.1, 21.0, 15.6.

HRMS (ESI) Calcd. for $C_{20}H_{22}NaO_2^+$ $[M+Na]^+$: 317.1512, Found: 317.1512.

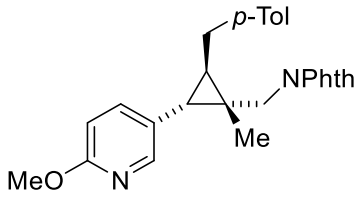
$[\alpha]_D^{34}$: -10.0 (*c* = 0.88, $CHCl_3$).

FTIR (neat): 2921, 2361, 1686, 1515, 1461, 1419, 1306, 1218, 1119, 1021, 915, 807 cm^{-1}


7.16
7.15
7.11
7.10
7.00
2.90
2.88
2.87
2.85
2.81
2.79
2.78
2.76
2.46
2.45
2.43
2.42
2.33
2.29
2.25
2.24
1.49
p-Tol
O
OH
Me
Me
4.27
4.10
0.96
1.00
1.14
3.14
3.09
1.11
3.05
f1 (ppm)


177.4
137.5
136.0
135.6
133.6
129.2
128.8
128.6
128.1
41.0
34.3
31.4
30.8
21.1
21.0
15.6
p-Tol
O
OH
Me
Me
f1 (ppm)

2-(((1S,2R,3R)-2-(6-methoxypyridin-3-yl)-1-methyl-3-(4-methylbenzyl)cyclopropyl)methyl) isoindoline-1,3-dione (2.4b)



Detailed Procedures

An oven-dried vial equipped with a magnetic stir bar was charged with **2.3h** (29.7 mg, 0.1 mmol, 100 mol%), triphenylphosphine (39.3 mg, 0.15 mmol, 150 mol%), phthalimide (22.1 mg, 0.15 mmol, 150 mol%). Under argon atmosphere, THF (1 mL, 0.1 M) was added via syringe. DEAD (65.3 mg, 0.15 mmol, 150 mol%, 40% w/w in toluene) was added slowly at ambient temperature. The mixture was stirred at 25 ˚C for 2 h. Saturated $NaHCO_3$ was added and the mixture was extracted by EA (20 mL x 2), dried (Na_2SO_4), filtered and concentrated *in vacuo*. The residue was subjected to flash column chromatography (SiO_2, hexanes: ethyl acetate = 4:1) to furnish the title compounds as oil (37.4 mg, 0.88 mmol) in 88% yield.

TLC (SiO_2) R_f = 0.20 (hexanes/ethyl acetate = 4:1).

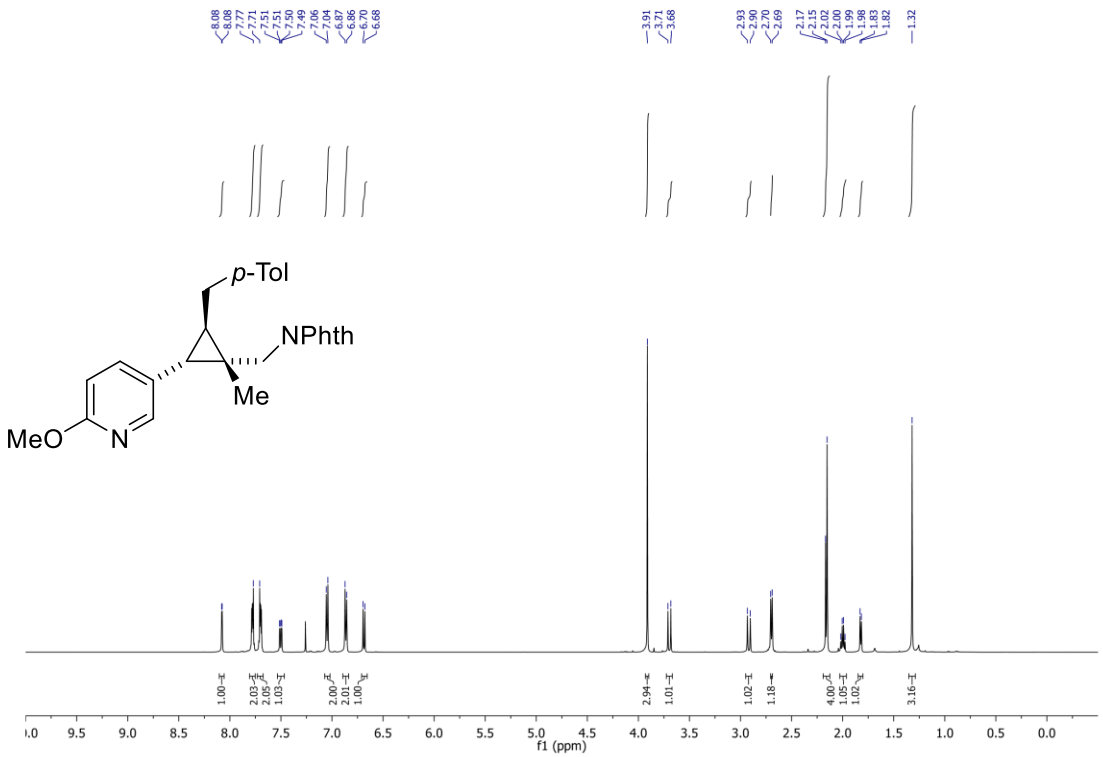
^{1}H NMR (500 MHz, $CDCl_3$) δ 8.08 (d, *J* = 2.5 Hz, 1H), 7.77 (s, 2H), 7.71 (s, 2H), 7.50 (dd, *J* = 8.5, 2.4 Hz, 1H), 7.05 (d, *J* = 7.7 Hz, 2H), 6.86 (d, *J* = 7.7 Hz, 2H), 6.69 (d, *J* = 8.5 Hz, 1H), 3.91 (s, 3H), 3.70 (d, *J* = 14.2 Hz, 1H), 2.92 (d, *J* = 14.2 Hz, 1H), 2.70 (d, *J* = 7.3 Hz, 1H), 2.17 – 2.14 (m, 4H), 2.00 (q, *J* = 7.1 Hz, 1H), 1.82 (d, *J* = 6.3 Hz, 1H), 1.32 (s, 3H).

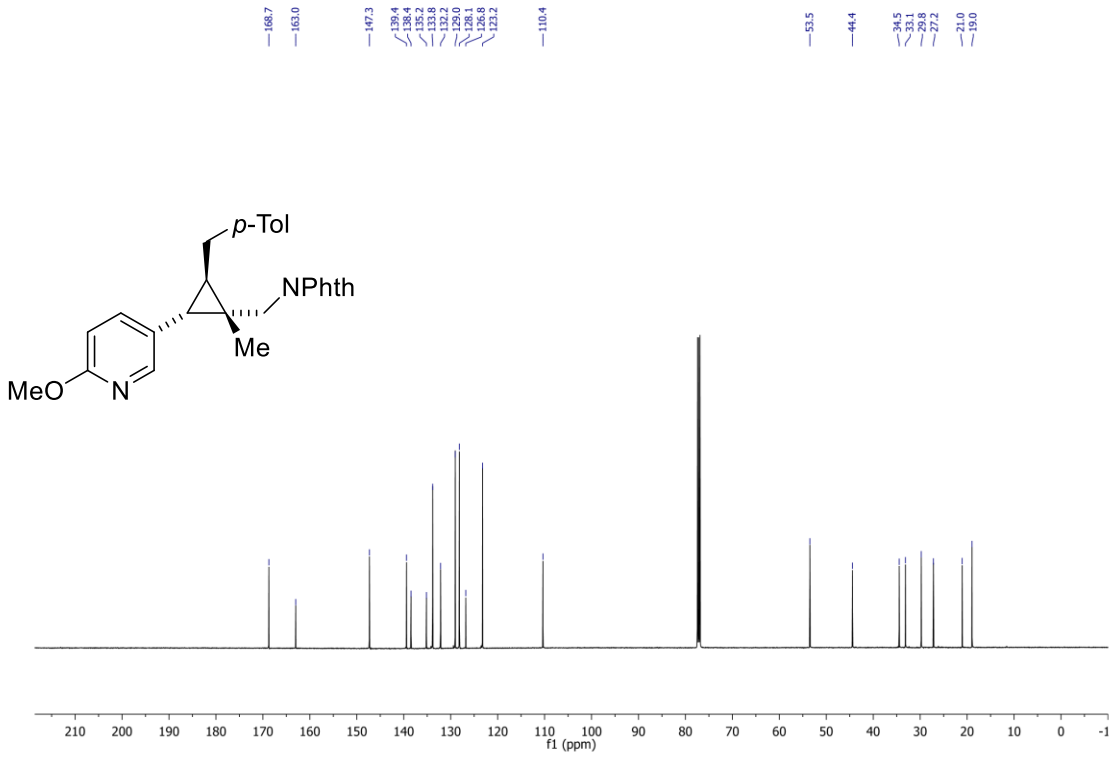
^{13}C NMR (125 MHz, $CDCl_3$) δ 168.7, 163.0, 147.3, 139.4, 138.5, 135.2, 133.8, 132.2, 129.0, 128.2, 126.8, 123.2, 110.4, 53.5, 44.4, 34.5, 33.1, 29.8, 27.2, 21.1, 19.0.

HRMS (ESI) Calcd. for $C_{27}H_{26}N_2NaO_3^+$ $[M+Na]^+$: 449.1836, Found: 449.1840

$[\alpha]_D^{30}$: +97.0 (c = 1.0, $CHCl_3$)

FTIR (neat): 1709, 1493, 1396, 1383, 1349, 1285, 1259, 1060, 1024, 927, 833, 732, 711 cm^{-1}


8.08
8.08
7.77
7.71
7.51
7.51
7.50
7.49
7.06
7.04
6.87
6.86
6.70
6.68
3.91
3.71
3.68
2.93
2.90
2.70
2.69
2.17
2.15
2.02
2.00
1.99
1.98
1.83
1.82
1.32
p-Tol
NPhth
Me
MeO
N
1.00
2.03
2.05
1.03
2.00
2.01
1.00
2.94
1.01
1.02
1.18
4.00
1.05
1.02
3.16
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)


168.7
163.0
147.3
139.4
138.4
135.2
133.8
132.2
129.0
128.1
126.8
123.2
110.4
53.5
44.4
34.5
33.1
29.8
27.2
21.0
19.0
p-Tol
NPhth
Me
MeO
N
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-1
f1 (ppm)

Crystallographic Material for 2.3a:

X-ray Experimental for $C_{20}H_{23}OH$: Crystals grew as long colorless needles by slow evaporation from DCM/pentane. The data crystal was cut from a cluster of crystals and had approximate dimensions; 0.35 x 0.035 x 0.032 mm. The data were collected on an Agilent Technologies SuperNova Dual Source diffractometer using a μ-focus Cu Kα radiation source (λ = 1.5418Å) with collimating mirror monochromators. A total of 684 frames of data were collected using -scans with a scan range of 1° and a counting time of 15 seconds per frame for frames collected with a detector offset of +/- 38.4° and 48 seconds per frame with frames collected with a detector offset of +/- 113.6°. The data were collected at 100 K using an Oxford 700 Cryostream low temperature device. Details of crystal data, data collection and structure refinement are listed in Table 1. Data collection, unit cell refinement and data reduction were performed using Agilent Technologies CrysAlisPro V 1.171.37.31.[8] The structure was solved by direct methods using SHELXT[9] and refined by full-matrix least-squares on F^2 with anisotropic displacement parameters for the non-H atoms using SHELXL-2016/6.[10] Structure analysis was aided by use of the programs PLATON98[11] and WinGX.[12] The hydrogen atoms were calculated in ideal positions with isotropic displacement parameters set to 1.2xUeq of the attached atom (1.5xUeq for methyl hydrogen atoms). The absolute structure could not be determined definitively.

The function, $\Sigma w(|F_o|^2 - |F_c|^2)^2$, was minimized, where $w = 1/[(\ (F_o))^2 + (0.1038*P)^2 + (9.9424*P)]$ and $P = (|F_o|^2 + 2|F_c|^2)/3$. $R_w(F^2)$ refined to 0.262, with R(F) equal to 0.0897 and a goodness of fit, S, = 1.12. Definitions used for calculating R(F), $R_w(F^2)$ and the goodness of fit, S, are given below.[13] The data were checked for secondary extinction effects but no correction was necessary. Neutral atom scattering factors and values used to calculate the linear absorption coefficient are from the International Tables for X-ray Crystallography (1992).[14] All figures were generated using SHELXTL/PC.[15] Tables of positional and thermal parameters, bond lengths and angles, torsion angles and figures are found elsewhere.

Table 2.4 Crystal data and structure refinement for 1.

Empirical formula	C20 H24 O	
Formula weight	280.39	
Temperature	100(2) K	
Wavelength	1.54184 Å	
Crystal system	monoclinic	
Space group	I 2	
Unit cell dimensions	a = 34.187(2) Å	= 90°.
	b = 5.8361(4) Å	= 91.395(7)°.
	c = 33.294(3) Å	= 90°.
Volume	6640.8(8) $Å^3$	
Z	16	
Density (calculated)	1.122 Mg/m^3	
Absorption coefficient	0.510 mm^{-1}	
F(000)	2432	
Crystal size	0.350 x 0.038 x 0.032 mm^3	
Theta range for data collection	2.586 to 75.298°.	
Index ranges	-42<=h<=41, -3<=k<=7, -41<=l<=41	
Reflections collected	11258	
Independent reflections	8398 [R(int) = 0.0792]	
Completeness to theta = 67.684°	98.6 %	
Absorption correction	Semi-empirical from equivalents	
Max. and min. transmission	1.00 and 0.408	
Refinement method	Full-matrix least-squares on F^2	
Data / restraints / parameters	8398 / 505 / 773	
Goodness-of-fit on F^2	1.122	
Final R indices [I>2sigma(I)]	R1 = 0.0897, wR2 = 0.2422	
R indices (all data)	R1 = 0.1131, wR2 = 0.2616	
Absolute structure parameter	-0.3(6)	
Extinction coefficient	n/a	
Largest diff. peak and hole	0.403 and -0.404 e.$Å^{-3}$	

Table 2.5 Atomic coordinates (x 10^4) and equivalent isotropic displacement parameters ($Å^2$x 10^3)

for 1. U(eq) is defined as one third of the trace of the orthogonalized U^{ij} tensor.

	x	y	z	U(eq)
C1	2148(2)	4048(11)	3445(2)	18(1)
C2	2067(2)	4115(12)	3897(2)	19(1)
C3	1846(2)	2419(12)	3628(2)	19(1)
C4	2029(2)	6025(13)	3182(2)	25(1)
C5	2535(2)	2913(13)	3341(2)	22(1)
C6	2377(2)	3446(13)	4197(2)	20(1)
C7	2370(2)	1348(12)	4401(2)	22(1)
C8	2670(2)	795(14)	4673(2)	24(1)
C9	2983(2)	2225(14)	4749(2)	25(1)
C10	2984(2)	4370(14)	4549(2)	26(1)
C11	2689(2)	4926(13)	4282(2)	24(1)
C12	3303(2)	1597(16)	5045(2)	32(2)
C13	1408(2)	2659(14)	3551(2)	25(1)
C14	1172(2)	1317(13)	3851(2)	24(1)
C15	1124(2)	2150(14)	4233(2)	26(2)
C16	916(2)	899(16)	4515(2)	31(2)
C17	753(2)	-1252(14)	4414(2)	28(2)
C18	801(2)	-2046(13)	4028(2)	27(2)
C19	1009(2)	-804(14)	3745(2)	26(1)
C20	531(2)	-2602(18)	4722(2)	39(2)
C21	3504(2)	6645(12)	2991(2)	22(1)
C22	3943(2)	6762(13)	3053(2)	23(1)
C23	3718(2)	4788(12)	3223(2)	21(1)
C24	3251(2)	8376(15)	3195(2)	30(2)
C25	3361(2)	6024(13)	2570(2)	23(1)

Table 2.5, continue.

C26	4208(2)	6578(12)	2700(2)	20(1)
C27	4430(2)	4633(13)	2630(2)	24(1)
C28	4669(2)	4498(15)	2290(2)	30(2)
C29	4681(2)	6248(15)	2021(2)	31(2)
C30	4461(2)	8197(14)	2091(2)	29(2)
C31	4226(2)	8350(13)	2428(2)	24(1)
C32	4937(2)	6100(20)	1654(2)	43(2)
C33	3684(2)	4482(13)	3673(2)	25(1)
C34	4000(2)	2960(14)	3856(2)	25(2)
C35	3912(2)	986(14)	4062(2)	26(1)
C36	4206(2)	-449(14)	4215(2)	28(2)
C37	4601(2)	116(14)	4177(2)	30(2)
C38	4688(2)	2149(16)	3978(2)	31(2)
C39	4395(2)	3562(13)	3818(2)	25(1)
C40	4921(2)	-1396(16)	4345(2)	37(2)
C41	2808(2)	8337(14)	6539(2)	24(1)
C42	2885(2)	8790(13)	6097(2)	23(1)
C43	3125(2)	7007(13)	6329(2)	24(1)
C44	2914(2)	10186(14)	6838(2)	30(2)
C45	2439(2)	7064(15)	6633(2)	26(2)
C46	2580(2)	8207(13)	5781(2)	21(1)
C47	2280(2)	9760(13)	5698(2)	25(1)
C48	1985(2)	9264(14)	5420(2)	26(2)
C49	1982(2)	7173(14)	5208(2)	25(1)
C50	2286(2)	5661(14)	5287(2)	25(1)
C51	2582(2)	6159(12)	5566(2)	22(1)
C52	1657(2)	6624(17)	4908(2)	35(2)
C53	3561(2)	7412(18)	6402(2)	34(2)
C54	3799(2)	6430(14)	6070(2)	26(2)
C55	3971(2)	4297(17)	6097(2)	35(2)
C56	4176(2)	3400(16)	5780(3)	38(2)
C57	4215(2)	4594(15)	5420(2)	32(2)
C58	4042(2)	6719(15)	5388(2)	32(2)

Table 2.5, continue.

C59	3837(2)	7652(14)	5708(2)	26(1)
C60	4431(3)	3620(20)	5072(3)	53(3)
C61	1450(2)	10176(11)	7123(2)	18(1)
C62	1026(2)	9526(12)	7053(2)	20(1)
C63	1343(2)	8495(11)	6795(2)	19(1)
C64	1579(2)	12596(12)	7024(2)	26(1)
C65	1654(2)	9197(11)	7495(2)	18(1)
C66	799(2)	8088(13)	7336(2)	22(1)
C67	711(2)	8842(13)	7720(2)	24(1)
C68	499(2)	7476(14)	7981(2)	26(1)
C69	363(2)	5331(14)	7865(2)	27(2)
C70	448(2)	4583(13)	7480(2)	23(1)
C71	660(2)	5934(13)	7217(2)	23(1)
C72	139(2)	3829(17)	8149(2)	36(2)
C73	1357(2)	8987(13)	6348(2)	24(1)
C74	1091(2)	7402(14)	6114(2)	25(1)
C75	687(2)	7754(16)	6107(2)	30(2)
C76	431(2)	6193(16)	5921(2)	32(2)
C77	572(2)	4232(15)	5734(2)	28(2)
C78	973(2)	3891(14)	5739(2)	29(2)
C79	1230(2)	5452(15)	5928(2)	28(2)
C80	292(2)	2610(16)	5527(2)	35(2)
O1	2530(1)	2124(10)	2934(1)	24(1)
O2	2973(1)	5142(11)	2573(2)	31(1)
O3	2451(1)	6003(9)	7020(1)	24(1)
O4	2064(1)	9092(10)	7439(1)	25(1)

Table 2.6 Bond lengths [Å] and angles [°] for 1.

C1-C4	1.499(9)	C14-C15	1.374(10)
C1-C5	1.525(8)	C14-C19	1.400(11)
C1-C2	1.536(8)	C15-C16	1.397(10)
C1-C3	1.541(9)	C15-H15	0.95
C2-C6	1.493(8)	C16-C17	1.410(12)
C2-C3	1.521(9)	C16-H16	0.95
C2-H2	1.00	C17-C18	1.380(10)
C3-C13	1.518(8)	C17-C20	1.511(10)
C3-H3	1.00	C18-C19	1.399(10)
C4-H4A	0.98	C18-H18	0.95
C4-H4B	0.98	C19-H19	0.95
C4-H4C	0.98	C20-H20A	0.98
C5-O1	1.433(7)	C20-H20B	0.98
C5-H5A	0.99	C20-H20C	0.98
C5-H5B	0.99	C21-C24	1.504(10)
C6-C11	1.394(9)	C21-C23	1.511(9)
C6-C7	1.400(10)	C21-C22	1.513(9)
C7-C8	1.391(9)	C21-C25	1.516(9)
C7-H7	0.95	C22-C23	1.502(10)
C8-C9	1.375(10)	C22-C26	1.508(9)
C8-H8	0.95	C22-H22	1.00
C9-C10	1.417(11)	C23-C33	1.517(9)
C9-C12	1.502(9)	C23-H23	1.00
C10-C11	1.369(10)	C24-H24A	0.98
C10-H10	0.95	C24-H24B	0.98
C11-H11	0.95	C24-H24C	0.98
C12-H12A	0.98	C25-O2	1.423(8)
C12-H12B	0.98	C25-H25A	0.99
C12-H12C	0.98	C25-H25B	0.99
C13-C14	1.518(9)	C26-C31	1.376(10)
C13-H13A	0.99	C26-C27	1.389(10)
C13-H13B	0.99	C27-C28	1.414(9)

Table 2.6, continue.

C27-H27	0.95	C42-C43	1.524(9)
C28-C29	1.360(12)	C42-H42	1.00
C28-H28	0.95	C43-C53	1.525(9)
C29-C30	1.386(12)	C43-H43	1.00
C29-C32	1.524(10)	C44-H44A	0.98
C30-C31	1.397(10)	C44-H44B	0.98
C30-H30	0.95	C44-H44C	0.98
C31-H31	0.95	C45-O3	1.432(8)
C32-H32A	0.98	C45-H45A	0.99
C32-H32B	0.98	C45-H45B	0.99
C32-H32C	0.98	C46-C47	1.391(10)
C33-C34	1.515(9)	C46-C51	1.393(10)
C33-H33A	0.99	C47-C48	1.382(10)
C33-H33B	0.99	C47-H47	0.95
C34-C35	1.378(11)	C48-C49	1.410(11)
C34-C39	1.403(9)	C48-H48	0.95
C35-C36	1.394(10)	C49-C50	1.384(10)
C35-H35	0.95	C49-C52	1.509(9)
C36-C37	1.398(10)	C50-C51	1.388(9)
C36-H36	0.95	C50-H50	0.95
C37-C38	1.394(12)	C51-H51	0.95
C37-C40	1.502(11)	C52-H52A	0.98
C38-C39	1.395(10)	C52-H52B	0.98
C38-H38	0.95	C52-H52C	0.98
C39-H39	0.95	C53-C54	1.502(10)
C40-H40A	0.98	C53-H53A	0.99
C40-H40B	0.98	C53-H53B	0.99
C40-H40C	0.98	C54-C55	1.379(12)
C41-C45	1.504(9)	C54-C59	1.409(9)
C41-C44	1.505(10)	C55-C56	1.385(12)
C41-C43	1.517(10)	C55-H55	0.95
C41-C42	1.526(8)	C56-C57	1.394(12)
C42-C46	1.501(9)	C56-H56	0.95

Table 2.6, continue.

C57-C60	1.500(11)	C69-C70	1.390(10)
C58-C59	1.399(10)	C69-C72	1.511(10)
C58-H58	0.95	C70-C71	1.396(10)
C59-H59	0.95	C70-H70	0.95
C60-H60A	0.98	C71-H71	0.95
C60-H60B	0.98	C72-H72A	0.98
C60-H60C	0.98	C72-H72B	0.98
C61-C63	1.508(8)	C72-H72C	0.98
C61-C62	1.511(9)	C73-C74	1.500(9)
C61-C65	1.518(8)	C73-H73A	0.99
C61-C64	1.518(9)	C73-H73B	0.99
C62-C66	1.493(10)	C74-C79	1.386(11)
C62-C63	1.523(8)	C74-C75	1.397(9)
C62-H62	1.00	C75-C76	1.396(11)
C63-C73	1.517(9)	C75-H75	0.95
C63-H63	1.00	C76-C77	1.395(12)
C64-H64A	0.98	C76-H76	0.95
C64-H64B	0.98	C77-C78	1.383(10)
C64-H64C	0.98	C77-C80	1.501(10)
C65-O4	1.419(7)	C78-C79	1.403(11)
C65-H65A	0.99	C78-H78	0.95
C65-H65B	0.99	C79-H79	0.95
C66-C67	1.391(9)	C80-H80A	0.98
C66-C71	1.398(10)	C80-H80B	0.98
C67-C68	1.395(10)	C80-H80C	0.98
C67-H67	0.95	O1-H1O	0.84
C68-C69	1.388(11)	O2-H2O	0.84
C68-H68	0.95	O3-H3O	0.84
		O4-H4O	0.84

C4-C1-C5	115.2(6)	C4-C1-C3	122.0(5)
C4-C1-C2	119.9(6)	C5-C1-C3	114.5(6)
C5-C1-C2	114.4(5)	C2-C1-C3	59.3(4)

Table 2.6, continue.

C6-C2-C3	123.9(6)	C8-C9-C10	117.5(6)
C6-C2-C1	120.4(5)	C8-C9-C12	121.5(7)
C3-C2-C1	60.5(4)	C10-C9-C12	120.9(7)
C6-C2-H2	113.9	C11-C10-C9	120.3(6)
C3-C2-H2	113.9	C11-C10-H10	119.9
C1-C2-H2	113.9	C9-C10-H10	119.9
C13-C3-C2	120.8(6)	C10-C11-C6	122.1(7)
C13-C3-C1	122.9(6)	C10-C11-H11	118.9
C2-C3-C1	60.2(4)	C6-C11-H11	118.9
C13-C3-H3	114.1	C9-C12-H12A	109.5
C2-C3-H3	114.1	C9-C12-H12B	109.5
C1-C3-H3	114.1	H12A-C12-H12B	109.5
C1-C4-H4A	109.5	C9-C12-H12C	109.5
C1-C4-H4B	109.5	H12A-C12-H12C	109.5
H4A-C4-H4B	109.5	H12B-C12-H12C	109.5
C1-C4-H4C	109.5	C14-C13-C3	112.2(5)
H4A-C4-H4C	109.5	C14-C13-H13A	109.2
H4B-C4-H4C	109.5	C3-C13-H13A	109.2
O1-C5-C1	111.4(5)	C14-C13-H13B	109.2
O1-C5-H5A	109.3	C3-C13-H13B	109.2
C1-C5-H5A	109.3	H13A-C13-H13B	107.9
O1-C5-H5B	109.3	C15-C14-C19	119.4(7)
C1-C5-H5B	109.3	C15-C14-C13	120.3(7)
H5A-C5-H5B	108.0	C19-C14-C13	120.3(6)
C11-C6-C7	117.8(6)	C14-C15-C16	120.8(7)
C11-C6-C2	120.0(6)	C14-C15-H15	119.6
C7-C6-C2	122.2(6)	C16-C15-H15	119.6
C8-C7-C6	119.8(6)	C15-C16-C17	120.7(7)
C8-C7-H7	120.1	C15-C16-H16	119.6
C6-C7-H7	120.1	C17-C16-H16	119.6
C9-C8-C7	122.5(7)	C18-C17-C16	117.6(7)
C9-C8-H8	118.8	C18-C17-C20	122.0(8)
C7-C8-H8	118.8	C16-C17-C20	120.4(7)

Table 2.6, continue.

C17-C18-C19	122.0(7)	C21-C24-H24C	109.5
C17-C18-H18	119.0	H24A-C24-H24C	109.5
C19-C18-H18	119.0	H24B-C24-H24C	109.5
C18-C19-C14	119.6(7)	O2-C25-C21	111.0(5)
C18-C19-H19	120.2	O2-C25-H25A	109.4
C14-C19-H19	120.2	C21-C25-H25A	109.4
C17-C20-H20A	109.5	O2-C25-H25B	109.4
C17-C20-H20B	109.5	C21-C25-H25B	109.4
H20A-C20-H20B	109.5	H25A-C25-H25B	108.0
C17-C20-H20C	109.5	C31-C26-C27	118.1(6)
H20A-C20-H20C	109.5	C31-C26-C22	119.9(6)
H20B-C20-H20C	109.5	C27-C26-C22	122.0(6)
C24-C21-C23	121.9(6)	C26-C27-C28	120.5(7)
C24-C21-C22	119.1(6)	C26-C27-H27	119.7
C23-C21-C22	59.5(4)	C28-C27-H27	119.7
C24-C21-C25	113.8(6)	C29-C28-C27	120.8(7)
C23-C21-C25	116.3(6)	C29-C28-H28	119.6
C22-C21-C25	115.8(6)	C27-C28-H28	119.6
C23-C22-C26	124.1(6)	C28-C29-C30	118.8(7)
C23-C22-C21	60.2(4)	C28-C29-C32	120.9(8)
C26-C22-C21	120.1(5)	C30-C29-C32	120.3(8)
C23-C22-H22	114.0	C29-C30-C31	120.8(7)
C26-C22-H22	114.0	C29-C30-H30	119.6
C21-C22-H22	114.0	C31-C30-H30	119.6
C22-C23-C21	60.3(4)	C26-C31-C30	121.0(7)
C22-C23-C33	121.0(6)	C26-C31-H31	119.5
C21-C23-C33	122.7(6)	C30-C31-H31	119.5
C22-C23-H23	114.2	C29-C32-H32A	109.5
C21-C23-H23	114.2	C29-C32-H32B	109.5
C33-C23-H23	114.2	H32A-C32-H32B	109.5
C21-C24-H24A	109.5	C29-C32-H32C	109.5
C21-C24-H24B	109.5	H32A-C32-H32C	109.5
H24A-C24-H24B	109.5	H32B-C32-H32C	109.5

Table 2.6, continue.

C34-C33-C23	113.2(5)	C45-C41-C42	116.7(5)
C34-C33-H33A	108.9	C44-C41-C42	118.1(7)
C23-C33-H33A	108.9	C43-C41-C42	60.1(4)
C34-C33-H33B	108.9	C46-C42-C43	123.8(6)
C23-C33-H33B	108.9	C46-C42-C41	120.3(6)
H33A-C33-H33B	107.7	C43-C42-C41	59.6(4)
C35-C34-C39	118.4(7)	C46-C42-H42	114.1
C35-C34-C33	121.9(6)	C43-C42-H42	114.1
C39-C34-C33	119.7(7)	C41-C42-H42	114.1
C34-C35-C36	121.4(6)	C41-C43-C42	60.3(4)
C34-C35-H35	119.3	C41-C43-C53	123.5(6)
C36-C35-H35	119.3	C42-C43-C53	119.2(7)
C35-C36-C37	120.9(7)	C41-C43-H43	114.4
C35-C36-H36	119.5	C42-C43-H43	114.4
C37-C36-H36	119.5	C53-C43-H43	114.4
C38-C37-C36	117.4(7)	C41-C44-H44A	109.5
C38-C37-C40	121.0(7)	C41-C44-H44B	109.5
C36-C37-C40	121.5(8)	H44A-C44-H44B	109.5
C37-C38-C39	121.7(7)	C41-C44-H44C	109.5
C37-C38-H38	119.1	H44A-C44-H44C	109.5
C39-C38-H38	119.1	H44B-C44-H44C	109.5
C38-C39-C34	120.1(7)	O3-C45-C41	113.2(5)
C38-C39-H39	120.0	O3-C45-H45A	108.9
C34-C39-H39	120.0	C41-C45-H45A	108.9
C37-C40-H40A	109.5	O3-C45-H45B	108.9
C37-C40-H40B	109.5	C41-C45-H45B	108.9
H40A-C40-H40B	109.5	H45A-C45-H45B	107.7
C37-C40-H40C	109.5	C47-C46-C51	118.0(6)
H40A-C40-H40C	109.5	C47-C46-C42	119.2(7)
H40B-C40-H40C	109.5	C51-C46-C42	122.8(6)
C45-C41-C44	114.0(6)	C48-C47-C46	121.3(7)
C45-C41-C43	117.0(7)	C48-C47-H47	119.3
C44-C41-C43	120.8(6)	C46-C47-H47	119.3

Table 2.6, continue.

C47-C48-C49	120.8(6)	C58-C57-C56	117.8(7)
C47-C48-H48	119.6	C58-C57-C60	120.0(8)
C49-C48-H48	119.6	C56-C57-C60	122.2(9)
C50-C49-C48	117.4(6)	C57-C58-C59	120.9(7)
C50-C49-C52	121.9(7)	C57-C58-H58	119.5
C48-C49-C52	120.7(7)	C59-C58-H58	119.5
C49-C50-C51	121.7(7)	C58-C59-C54	120.8(8)
C49-C50-H50	119.1	C58-C59-H59	119.6
C51-C50-H50	119.1	C54-C59-H59	119.6
C50-C51-C46	120.7(6)	C57-C60-H60A	109.5
C50-C51-H51	119.6	C57-C60-H60B	109.5
C46-C51-H51	119.6	H60A-C60-H60B	109.5
C49-C52-H52A	109.5	C57-C60-H60C	109.5
C49-C52-H52B	109.5	H60A-C60-H60C	109.5
H52A-C52-H52B	109.5	H60B-C60-H60C	109.5
C49-C52-H52C	109.5	C63-C61-C62	60.6(4)
H52A-C52-H52C	109.5	C63-C61-C65	116.5(5)
H52B-C52-H52C	109.5	C62-C61-C65	116.9(6)
C54-C53-C43	111.5(6)	C63-C61-C64	120.9(6)
C54-C53-H53A	109.3	C62-C61-C64	118.8(6)
C43-C53-H53A	109.3	C65-C61-C64	113.4(5)
C54-C53-H53B	109.3	C66-C62-C61	123.7(5)
C43-C53-H53B	109.3	C66-C62-C63	121.4(6)
H53A-C53-H53B	108.0	C61-C62-C63	59.6(4)
C55-C54-C59	117.8(7)	C66-C62-H62	113.9
C55-C54-C53	122.2(7)	C61-C62-H62	113.9
C59-C54-C53	120.0(7)	C63-C62-H62	113.9
C54-C55-C56	120.9(8)	C61-C63-C73	125.1(6)
C54-C55-H55	119.6	C61-C63-C62	59.8(4)
C56-C55-H55	119.6	C73-C63-C62	121.3(6)
C55-C56-C57	121.8(8)	C61-C63-H63	113.4
C55-C56-H56	119.1	C73-C63-H63	113.4
C57-C56-H56	119.1	C62-C63-H63	113.4

Table 2.6, continue.

C61-C64-H64A	109.5	C69-C72-H72C	109.5
C61-C64-H64B	109.5	H72A-C72-H72C	109.5
H64A-C64-H64B	109.5	H72B-C72-H72C	109.5
C61-C64-H64C	109.5	C74-C73-C63	111.0(6)
H64A-C64-H64C	109.5	C74-C73-H73A	109.4
H64B-C64-H64C	109.5	C63-C73-H73A	109.4
O4-C65-C61	110.3(5)	C74-C73-H73B	109.4
O4-C65-H65A	109.6	C63-C73-H73B	109.4
C61-C65-H65A	109.6	H73A-C73-H73B	108.0
O4-C65-H65B	109.6	C79-C74-C75	117.5(7)
C61-C65-H65B	109.6	C79-C74-C73	122.0(6)
H65A-C65-H65B	108.1	C75-C74-C73	120.4(7)
C67-C66-C71	117.7(7)	C76-C75-C74	121.4(8)
C67-C66-C62	122.0(7)	C76-C75-H75	119.3
C71-C66-C62	120.3(6)	C74-C75-H75	119.3
C66-C67-C68	121.2(7)	C77-C76-C75	120.9(7)
C66-C67-H67	119.4	C77-C76-H76	119.5
C68-C67-H67	119.4	C75-C76-H76	119.5
C69-C68-C67	121.2(7)	C78-C77-C76	117.7(7)
C69-C68-H68	119.4	C78-C77-C80	122.4(8)
C67-C68-H68	119.4	C76-C77-C80	119.9(7)
C68-C69-C70	117.6(7)	C77-C78-C79	121.4(7)
C68-C69-C72	121.3(7)	C77-C78-H78	119.3
C70-C69-C72	121.0(7)	C79-C78-H78	119.3
C69-C70-C71	121.6(7)	C74-C79-C78	121.1(6)
C69-C70-H70	119.2	C74-C79-H79	119.5
C71-C70-H70	119.2	C78-C79-H79	119.5
C70-C71-C66	120.6(6)	C77-C80-H80A	109.5
C70-C71-H71	119.7	C77-C80-H80B	109.5
C66-C71-H71	119.7	H80A-C80-H80B	109.5
C69-C72-H72A	109.5	C77-C80-H80C	109.5
C69-C72-H72B	109.5	H80A-C80-H80C	109.5
H72A-C72-H72B	109.5	H80B-C80-H80C	109.5

Table 2.6, continue.

C5-O1-H1O	109.5	C45-O3-H3O	109.5
C25-O2-H2O	109.5	C65-O4-H4O	109.5

Table 2.7 Anisotropic displacement parameters ($Å^2 x 10^3$) for 1. The anisotropic displacement factor exponent takes the form: $-2 \pi^2[h^2 a^{*2} U^{11} + ... + 2 h k a^* b^* U^{12}]$

	U^{11}	U^{22}	U^{33}	U^{23}	U^{13}	U^{12}
C1	22(3)	9(3)	24(3)	-1(2)	-1(2)	2(2)
C2	21(3)	19(3)	17(3)	2(2)	-4(2)	1(2)
C3	23(3)	13(3)	21(3)	5(2)	-1(2)	0(2)
C4	29(3)	14(3)	31(3)	5(3)	-5(3)	1(3)
C5	20(3)	21(4)	25(3)	0(3)	0(2)	1(3)
C6	18(3)	21(3)	21(3)	-2(2)	-4(2)	-1(2)
C7	24(3)	18(3)	24(3)	2(2)	1(2)	-1(3)
C8	28(3)	24(4)	22(3)	2(3)	-1(2)	1(3)
C9	23(3)	29(4)	23(3)	2(3)	1(2)	5(3)
C10	26(3)	23(4)	28(3)	1(3)	-1(2)	-8(3)
C11	32(3)	17(3)	22(3)	-1(2)	1(2)	-2(3)
C12	24(3)	41(5)	29(3)	1(3)	-7(3)	2(3)
C13	20(3)	28(4)	28(3)	4(3)	0(2)	3(3)
C14	15(3)	26(4)	31(3)	4(3)	-1(2)	-2(3)
C15	22(3)	30(4)	27(3)	-4(3)	-1(2)	-5(3)
C16	24(3)	40(4)	30(3)	-1(3)	1(3)	2(3)
C17	18(3)	29(4)	38(3)	2(3)	3(2)	6(3)
C18	27(3)	21(4)	34(3)	2(3)	-1(3)	-3(3)
C19	24(3)	27(4)	25(3)	-1(3)	0(2)	2(3)
C20	36(4)	41(5)	41(4)	18(4)	3(3)	1(4)
C21	23(3)	18(3)	24(3)	-1(3)	-2(2)	3(3)
C22	23(3)	19(3)	28(3)	-2(3)	-5(2)	2(3)
C23	21(3)	15(3)	26(3)	1(3)	-1(2)	3(2)
C24	23(3)	32(4)	36(4)	-2(3)	3(3)	3(3)
C25	20(3)	25(4)	24(3)	1(3)	-6(2)	-1(3)
C26	21(3)	12(3)	27(3)	-4(2)	-3(2)	-5(2)

Table 2.7, continue.

C27	21(3)	17(3)	35(3)	-1(3)	4(2)	-1(3)
C28	21(3)	27(4)	42(4)	-5(3)	3(3)	1(3)
C29	22(3)	36(4)	34(3)	1(3)	6(3)	-6(3)
C30	21(3)	27(4)	38(3)	1(3)	-8(3)	-6(3)
C31	22(3)	15(3)	35(3)	-1(3)	-4(2)	-5(3)
C32	31(4)	61(6)	38(4)	-9(4)	9(3)	-10(4)
C33	26(3)	20(4)	29(3)	-3(3)	-2(2)	3(3)
C34	22(3)	31(4)	23(3)	-5(3)	-1(2)	0(3)
C35	23(3)	28(4)	27(3)	0(3)	-3(2)	-5(3)
C36	35(3)	19(4)	30(3)	1(3)	-6(3)	-4(3)
C37	33(3)	26(4)	31(3)	-5(3)	-7(3)	0(3)
C38	24(3)	41(5)	29(3)	3(3)	-1(2)	1(3)
C39	30(3)	17(3)	29(3)	0(3)	-1(3)	0(3)
C40	41(4)	28(4)	42(4)	3(3)	-8(3)	4(3)
C41	23(3)	28(4)	22(3)	-3(3)	-2(2)	-3(3)
C42	27(3)	21(4)	21(3)	2(3)	-3(2)	-3(3)
C43	26(3)	22(4)	22(3)	-2(3)	-5(2)	-1(3)
C44	36(4)	29(4)	27(3)	-9(3)	-2(3)	-3(3)
C45	20(3)	36(4)	22(3)	2(3)	2(2)	0(3)
C46	21(3)	20(4)	23(3)	2(2)	3(2)	-3(3)
C47	31(3)	21(4)	24(3)	-2(3)	4(2)	1(3)
C48	25(3)	26(4)	28(3)	2(3)	3(2)	7(3)
C49	21(3)	26(4)	27(3)	-1(3)	0(2)	-1(3)
C50	27(3)	23(4)	26(3)	1(3)	-1(2)	-1(3)
C51	27(3)	16(3)	24(3)	-1(3)	-1(2)	6(3)
C52	29(3)	48(5)	27(3)	-2(3)	-6(3)	-2(3)
C53	26(3)	54(5)	22(3)	-1(3)	-6(2)	-7(3)
C54	20(3)	30(4)	27(3)	7(3)	-3(2)	-5(3)
C55	27(3)	43(5)	36(3)	9(3)	-3(3)	-4(3)
C56	26(3)	27(4)	62(5)	7(4)	-8(3)	4(3)
C57	19(3)	33(4)	42(4)	-6(3)	2(3)	-4(3)
C58	32(3)	35(4)	28(3)	0(3)	1(3)	0(3)
C59	25(3)	27(4)	24(3)	5(3)	0(2)	-3(3)

Table 2.7, continue.

C60	38(4)	58(7)	63(6)	-23(5)	9(4)	4(4)
C61	26(3)	7(3)	21(3)	-4(2)	-3(2)	3(2)
C62	23(3)	15(3)	22(3)	-3(2)	-3(2)	6(3)
C63	25(3)	6(3)	25(3)	-2(2)	1(2)	-2(2)
C64	33(3)	5(3)	40(4)	3(3)	-7(3)	-4(3)
C65	23(3)	5(3)	24(3)	-1(2)	-6(2)	0(2)
C66	19(3)	18(3)	30(3)	0(3)	-2(2)	2(2)
C67	27(3)	18(3)	26(3)	-5(3)	-2(2)	-3(3)
C68	27(3)	22(4)	28(3)	-3(3)	1(2)	-2(3)
C69	22(3)	28(4)	30(3)	2(3)	1(2)	-2(3)
C70	23(3)	16(3)	31(3)	-1(3)	-2(2)	-3(3)
C71	21(3)	22(4)	25(3)	-4(3)	1(2)	0(3)
C72	34(4)	39(5)	37(4)	1(4)	8(3)	-4(4)
C73	19(3)	24(4)	27(3)	1(3)	-1(2)	-3(3)
C74	27(3)	28(4)	20(3)	2(3)	0(2)	-1(3)
C75	24(3)	40(5)	26(3)	-4(3)	-4(2)	4(3)
C76	22(3)	47(5)	27(3)	0(3)	-3(2)	0(3)
C77	33(3)	28(4)	24(3)	2(3)	-6(2)	-3(3)
C78	38(3)	24(4)	26(3)	0(3)	-4(3)	4(3)
C79	23(3)	36(4)	26(3)	3(3)	0(2)	1(3)
C80	43(4)	32(5)	30(3)	-1(3)	-13(3)	-8(4)
O1	23(2)	29(3)	20(2)	-4(2)	3(2)	-3(2)
O2	21(2)	43(3)	28(2)	11(2)	-8(2)	-7(2)
O3	23(2)	29(3)	19(2)	4(2)	-1(2)	2(2)
O4	21(2)	32(3)	22(2)	-3(2)	-3(2)	2(2)

Table 2.8 Hydrogen coordinates (x 10^4) and isotropic displacement parameters ($Å^2$x 10^3) for 1.

	x	y	z	U(eq)
H2	1906	5458	3980	23
H3	1938	799	3657	23
H4A	2225	7248	3209	37
H4B	1774	6604	3265	37
H4C	2011	5517	2902	37
H5A	2751	4026	3381	26
H5B	2584	1601	3524	26
H7	2160	306	4354	26
H8	2659	-624	4812	29
H10	3191	5426	4601	31
H11	2696	6367	4149	28
H12A	3376	2946	5206	47
H12B	3532	1054	4901	47
H12C	3211	382	5223	47
H13A	1336	4298	3565	30
H13B	1343	2109	3276	30
H15	1232	3593	4305	32
H16	884	1504	4777	38
H18	690	-3479	3953	33
H19	1039	-1395	3481	31
H20A	260	-2049	4728	59
H20B	656	-2402	4988	59
H20C	532	-4229	4649	59
H22	4031	7913	3259	28
H23	3748	3321	3071	25

Table 2.8, continue.

H24A	3364	8733	3461	45
H24B	2987	7746	3225	45
H24C	3236	9777	3033	45
H25A	3367	7402	2397	28
H25B	3538	4863	2456	28
H27	4422	3384	2813	29
H28	4823	3168	2249	36
H30	4470	9443	1908	34
H31	4077	9699	2470	29
H32A	5137	7307	1669	64
H32B	4775	6313	1410	64
H32C	5064	4601	1647	64
H33A	3697	6004	3804	30
H33B	3425	3809	3729	30
H35	3646	594	4101	31
H36	4137	-1831	4346	34
H38	4954	2582	3951	37
H39	4462	4933	3682	31
H40A	4952	-1128	4635	56
H40B	5167	-1042	4214	56
H40C	4852	-3005	4297	56
H42	3028	10250	6045	28
H43	3054	5384	6264	29
H44A	2962	9497	7103	46
H44B	2697	11283	6853	46
H44C	3150	10981	6753	46
H45A	2216	8146	6618	31
H45B	2393	5871	6425	31
H47	2278	11189	5834	30
H48	1781	10345	5372	31
H50	2292	4246	5146	30
H51	2788	5091	5612	27
H52A	1681	5030	4819	52

Table 2.8, continue.

H52B	1675	7648	4676	52
H52C	1403	6838	5034	52
H53A	3611	9079	6423	41
H53B	3644	6697	6660	41
H55	3948	3430	6337	42
H56	4293	1931	5808	46
H58	4062	7563	5145	38
H59	3722	9127	5680	31
H60A	4282	3906	4823	79
H60B	4466	1967	5110	79
H60C	4688	4356	5057	79
H62	866	10738	6914	24
H63	1407	6871	6865	23
H64A	1861	12613	6980	39
H64B	1518	13618	7248	39
H64C	1440	13120	6780	39
H65A	1599	10173	7730	21
H65B	1553	7641	7548	21
H67	797	10315	7806	28
H68	447	8025	8243	31
H70	358	3116	7394	28
H71	711	5384	6955	27
H72A	32	2506	8003	55
H72B	-75	4711	8264	55
H72C	316	3297	8366	55
H73A	1277	10593	6296	28
H73B	1628	8799	6256	28
H75	584	9082	6231	36
H76	157	6470	5922	39
H78	1076	2573	5612	35
H79	1503	5167	5927	34
H80A	267	3013	5242	53
H80B	36	2720	5651	53

Table 2.8, continue.

H80C	391	1040	5554	53
H1O	2662	3017	2793	36
H2O	2836	5805	2396	46
H3O	2683	5964	7109	36
H4O	2181	9167	7664	38

Table 2.9 Torsion angles [°] for 1.

C4-C1-C2-C6	-134.0(7)	C3-C13-C14-C15	77.4(9)
C5-C1-C2-C6	9.2(9)	C3-C13-C14-C19	-101.2(7)
C3-C1-C2-C6	114.3(7)	C19-C14-C15-C16	0.4(10)
C4-C1-C2-C3	111.7(6)	C13-C14-C15-C16	-178.2(6)
C5-C1-C2-C3	-105.1(6)	C14-C15-C16-C17	0.3(11)
C6-C2-C3-C13	138.5(6)	C15-C16-C17-C18	-1.1(10)
C1-C2-C3-C13	-112.8(7)	C15-C16-C17-C20	179.6(7)
C6-C2-C3-C1	-108.7(7)	C16-C17-C18-C19	1.1(10)
C4-C1-C3-C13	1.2(10)	C20-C17-C18-C19	-179.6(7)
C5-C1-C3-C13	-145.7(6)	C17-C18-C19-C14	-0.4(11)
C2-C1-C3-C13	109.4(7)	C15-C14-C19-C18	-0.3(10)
C4-C1-C3-C2	-108.2(7)	C13-C14-C19-C18	178.3(6)
C5-C1-C3-C2	104.9(6)	C24-C21-C22-C23	111.9(7)
C4-C1-C5-O1	-57.1(8)	C25-C21-C22-C23	-106.6(7)
C2-C1-C5-O1	158.0(6)	C24-C21-C22-C26	-133.6(7)
C3-C1-C5-O1	92.2(7)	C23-C21-C22-C26	114.5(7)
C3-C2-C6-C11	147.7(6)	C25-C21-C22-C26	7.8(10)
C1-C2-C6-C11	74.8(9)	C26-C22-C23-C21	-108.1(7)
C3-C2-C6-C7	-32.0(9)	C26-C22-C23-C33	139.3(7)
C1-C2-C6-C7	-105.0(7)	C21-C22-C23-C33	-112.6(7)
C11-C6-C7-C8	-0.9(9)	C24-C21-C23-C22	-107.4(7)
C2-C6-C7-C8	178.9(6)	C25-C21-C23-C22	105.8(7)
C6-C7-C8-C9	-0.9(10)	C24-C21-C23-C33	2.3(10)
C7-C8-C9-C10	2.4(10)	C22-C21-C23-C33	109.7(7)
C7-C8-C9-C12	179.7(6)	C25-C21-C23-C33	-144.5(6)
C8-C9-C10-C11	-2.2(10)	C24-C21-C25-O2	-58.1(8)
C12-C9-C10-C11	-179.5(7)	C23-C21-C25-O2	91.3(7)
C9-C10-C11-C6	0.5(11)	C22-C21-C25-O2	158.4(6)
C7-C6-C11-C10	1.0(10)	C23-C22-C26-C31	143.4(6)
C2-C6-C11-C10	-178.7(6)	C21-C22-C26-C31	70.9(9)
C2-C3-C13-C14	-91.4(8)	C23-C22-C26-C27	-35.0(9)
C1-C3-C13-C14	-163.8(6)	C21-C22-C26-C27	-107.5(8)

Table 2.9, continue.

C31-C26-C27-C28	0.2(9)	C42-C41-C43-C53	107.2(8)
C22-C26-C27-C28	178.6(6)	C46-C42-C43-C41	-108.1(7)
C26-C27-C28-C29	-1.1(10)	C46-C42-C43-C53	137.7(7)
C27-C28-C29-C30	1.5(11)	C41-C42-C43-C53	-114.2(7)
C27-C28-C29-C32	-179.9(7)	C44-C41-C45-O3	-57.8(9)
C28-C29-C30-C31	-1.1(11)	C43-C41-C45-O3	90.9(7)
C32-C29-C30-C31	-179.7(6)	C42-C41-C45-O3	159.1(6)
C27-C26-C31-C30	0.2(9)	C43-C42-C46-C47	155.4(6)
C22-C26-C31-C30	-178.2(6)	C41-C42-C46-C47	83.7(9)
C29-C30-C31-C26	0.2(10)	C43-C42-C46-C51	-24.4(10)
C22-C23-C33-C34	-92.3(8)	C41-C42-C46-C51	-96.1(8)
C21-C23-C33-C34	-164.8(6)	C51-C46-C47-C48	2.1(10)
C23-C33-C34-C35	-121.3(7)	C42-C46-C47-C48	-177.7(6)
C23-C33-C34-C39	58.8(9)	C46-C47-C48-C49	-0.9(10)
C39-C34-C35-C36	-2.8(10)	C47-C48-C49-C50	-0.4(10)
C33-C34-C35-C36	177.3(7)	C47-C48-C49-C52	179.4(7)
C34-C35-C36-C37	2.5(11)	C48-C49-C50-C51	0.6(10)
C35-C36-C37-C38	-0.6(11)	C52-C49-C50-C51	-179.2(7)
C35-C36-C37-C40	179.1(7)	C49-C50-C51-C46	0.6(10)
C36-C37-C38-C39	-0.8(11)	C47-C46-C51-C50	-2.0(10)
C40-C37-C38-C39	179.5(7)	C42-C46-C51-C50	177.8(6)
C37-C38-C39-C34	0.4(11)	C41-C43-C53-C54	-162.0(7)
C35-C34-C39-C38	1.4(10)	C42-C43-C53-C54	-90.1(9)
C33-C34-C39-C38	-178.7(6)	C43-C53-C54-C55	-96.5(8)
C45-C41-C42-C46	6.5(10)	C43-C53-C54-C59	80.6(9)
C44-C41-C42-C46	-134.9(7)	C59-C54-C55-C56	0.4(11)
C43-C41-C42-C46	113.8(8)	C53-C54-C55-C56	177.6(7)
C45-C41-C42-C43	-107.3(8)	C54-C55-C56-C57	-0.4(12)
C44-C41-C42-C43	111.2(7)	C55-C56-C57-C58	0.0(11)
C45-C41-C43-C42	106.7(6)	C55-C56-C57-C60	-179.0(8)
C44-C41-C43-C42	-106.8(8)	C56-C57-C58-C59	0.6(11)
C45-C41-C43-C53	-146.1(7)	C60-C57-C58-C59	179.6(7)
C44-C41-C43-C53	0.4(11)	C57-C58-C59-C54	-0.6(11)

Table 2.9, continue.

C55-C54-C59-C58	0.1(10)	C62-C66-C67-C68	-180.0(6)
C53-C54-C59-C58	-177.1(6)	C66-C67-C68-C69	-1.1(11)
C63-C61-C62-C66	109.6(7)	C67-C68-C69-C70	0.5(10)
C65-C61-C62-C66	2.9(9)	C67-C68-C69-C72	178.9(7)
C64-C61-C62-C66	-139.0(7)	C68-C69-C70-C71	-0.3(10)
C65-C61-C62-C63	-106.7(6)	C72-C69-C70-C71	-178.7(7)
C64-C61-C62-C63	111.3(7)	C69-C70-C71-C66	0.7(10)
C62-C61-C63-C73	109.0(7)	C67-C66-C71-C70	-1.3(9)
C65-C61-C63-C73	-143.6(6)	C62-C66-C71-C70	-179.9(6)
C64-C61-C63-C73	1.1(10)	C61-C63-C73-C74	-157.3(6)
C65-C61-C63-C62	107.4(6)	C62-C63-C73-C74	-84.3(8)
C64-C61-C63-C62	-107.9(7)	C63-C73-C74-C79	-98.3(8)
C66-C62-C63-C61	-113.2(6)	C63-C73-C74-C75	76.4(9)
C66-C62-C63-C73	131.6(7)	C79-C74-C75-C76	0.5(11)
C61-C62-C63-C73	-115.2(7)	C73-C74-C75-C76	-174.4(7)
C63-C61-C65-O4	86.4(7)	C74-C75-C76-C77	-0.4(12)
C62-C61-C65-O4	155.1(5)	C75-C76-C77-C78	0.0(11)
C64-C61-C65-O4	-60.9(7)	C75-C76-C77-C80	-178.4(7)
C61-C62-C66-C67	66.1(9)	C76-C77-C78-C79	0.4(11)
C63-C62-C66-C67	138.3(7)	C80-C77-C78-C79	178.8(7)
C61-C62-C66-C71	-115.4(7)	C75-C74-C79-C78	-0.1(10)
C63-C62-C66-C71	-43.1(8)	C73-C74-C79-C78	174.7(7)
C71-C66-C67-C68	1.5(10)	C77-C78-C79-C74	-0.3(11)

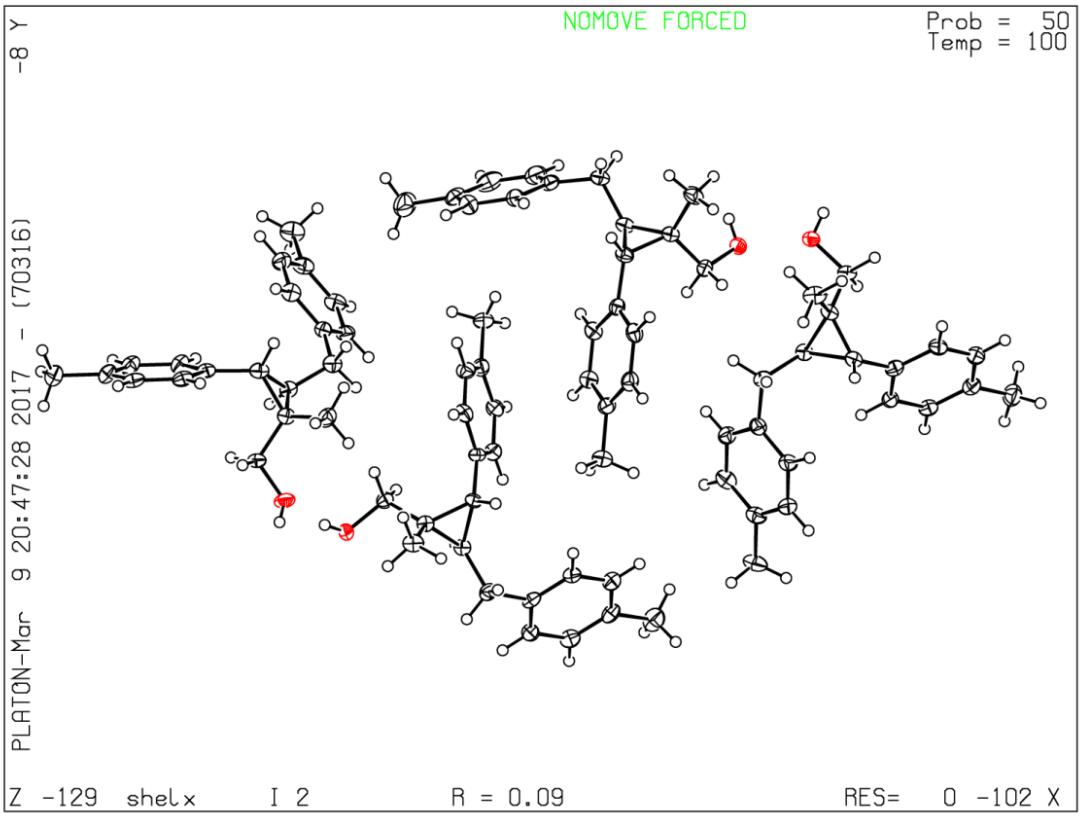
Table 2.10 Hydrogen bonds for 1 [Å and °].

D-H...A	d(D-H)	d(H...A)	d(D...A)	<(DHA)
O1-H1O...O2	0.84	1.80	2.632(7)	170.2
O2-H2O...O1#1	0.84	1.81	2.645(7)	170.3
O3-H3O...O4#2	0.84	2.03	2.662(6)	131.0
O4-H4O...O3#3	0.84	1.94	2.662(7)	143.0

Symmetry transformations used to generate equivalent atoms:

#1 -x+1/2,y+1/2,-z+1/2 #2 -x+1/2,y-1/2,-z+3/2

#3 -x+1/2,y+1/2,-z+3/2


NOMOVE FORCED
Prob = 50
Temp = 100
-8 Y
PLATON-Mar 9 20:47:28 2017 - (70316)
Z -129 shelx I 2 R = 0.09 RES= 0 -102 X

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