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A Catalytic Dual Isomerization/Allylboration Sequence for the Stereoselective Construction of Congested Secondary Homoallylic Alcohols

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ABSTRACT: A catalytic sequence for the diastereo- and enantioselective preparation of homoallylic alcohols with an adjacent quaternary (stereo)center is reported. The one-pot process relies on the use of a single (achiral or chiral) iridium complex to catalyze the concomitant isomerization of primary allylic alcohols and homoallylboronates into (chiral) aldehydes and allylboronates respectively. In the same flask, a chiral Brønsted acid is added next to engage the isomerization products into a stereocontrolled allylboration reaction. Structural variations have been performed on both the allylic alcohols and the homoallylboronates. This mild process affords an array of stereochemically congested and complex chiral secondary homoallylic alcohols in high yield, excellent diastereoselectivity and usually high enantioselectivity.

■ INTRODUCTION

Optically active homoallylic alcohols hold a prominent position in the arsenal of structural subunits used for the synthesis of biologically active polyketide natural products.[1] They also serve as a privileged platform for a number of catalytic transformations.[2] The stereoselective allylation of carbonyl compounds is a particularly straightforward and efficient synthetic method for the preparation of chiral homoallylic alcohols. Nonetheless, the majority of these allylation methods relies on the use of stoichiometric chiral auxiliaries or reagents based on main group metals which generates toxic waste.[3] In this context, the emergence of catalytic stereoselective allylborations of carbonyls has opened new perspectives to identify general and practical systems for the stereocontrolled preparation of chiral homoallyl alcohols. A specific focus has been placed on the development of methods providing access to homoallylic alcohols with two contiguous stereocenters using achiral γ-substituted allylboronate in presence of a chiral catalysts (i.e. Lewis acids or Brønsted acids).[4] The six chiral structural motifs that can be accessed by carbonyl allylation using γ-substituted allyl boronic acids or allyl boronic esters are depicted on Figure 1-A. Some of the most significant advances have been realized using chiral Brønsted acids as exemplified by the key contributions of Miyaura,[5] Shibasaki,[6] Hall,[7] Antilla,[8] Schaus,[9] Kobayashi[10] and Szabó.[11] Remarkably, even chiral tertiary homoallylic alcohols with an adjacent quaternary center are now accessible with high levels of diastereo- and enantioinduction.[12] Although several catalytic enantioselective allylation methods provide access to secondary homoallylic alcohols with a neighboring quaternary stereocenter, to the best of our knowledge, there is no report on their preparation based on a catalytic allylboration of aldehydes.[13]

Over the last few years, Miura and Murakami have developed a series of very elegant isomerization/allylboration tandem processes to access homoallylic alcohols and 3-boryl substituted homoallylic alcohols with high levels of diastereo- and enantiocontrol (Figure 1-B).[14-16] Typically, an isomerization catalyst (Ir, Ru or Pd) is employed for the in situ generation of the reactive allylboronate derivative and is followed by the use of a chiral phosphoric acid for the stereocontrolled allylboration of aldehydes. These systems are particularly effective and selective for alkenylboronates, 1,1- and 1,2-diborylalkenes. Depending on the double bond geometry of the precursor, borylated homoallylic alcohols or 1,2-oxaborinan-3-enes are generated with excellent diastereo- and enantioselectivity.[15e] Quite notably, the most recent [Ru/Brønsted acid] and [Pd/Brønsted acid] combinations provide access to γ-boryl substituted homoallylic alcohols with a proximal *gem*-dimethyl carbon center (i.e. the closest analogs to secondary homoallylic alcohols with an adjacent quaternary stereocenter). Nonetheless, this is achieved either without any stereocontrol or with only very modest enantioinduction (Figure 1-B, right).[15f] These results are a clear testimony of the difficulty associated with the stereocontrolled installation of a secondary alcohol adjacent to a congested quaternary center using allylboration of carbonyl compounds as a C–C bond forming strategy.

Over the past decade, our laboratory has reported several examples of diastereo- and enantioselective isomerizations of primary allylic alcohols into aldehydes. The reaction is triggered by in situ generation of iridium-hydrides and subsequent hydrometallation of the olefin double bond (Figure 1-C).[17] More recently, we also disclosed a very general and selective Ir-catalyzed *anti*-Markovnikov 3,4-hydroboration of branched 1,3-dienes that affords homoallylboronates in high yields (Figure 1-

D).[18] We wondered whether the [(P,N)Ir] catalysts used for the isomerization

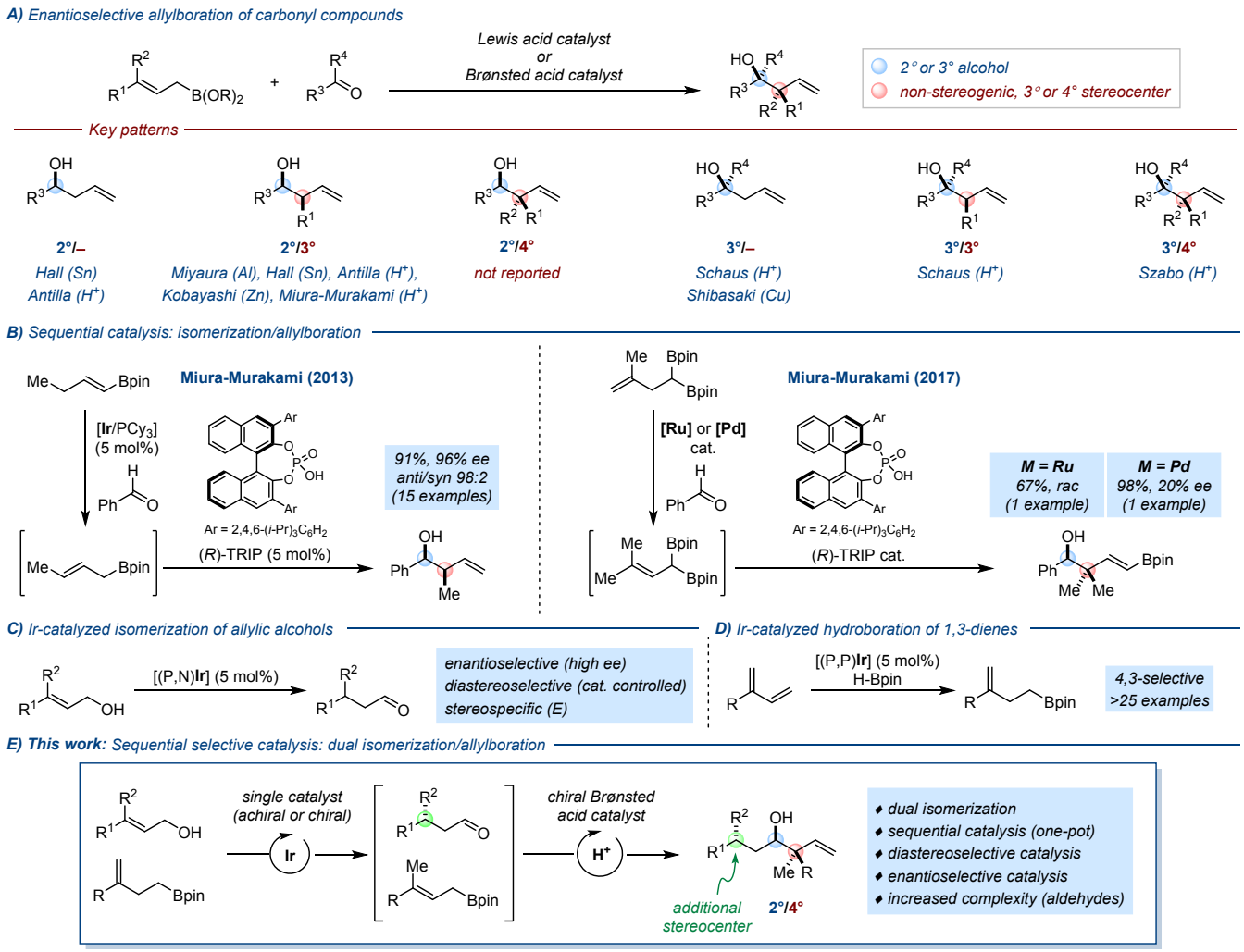


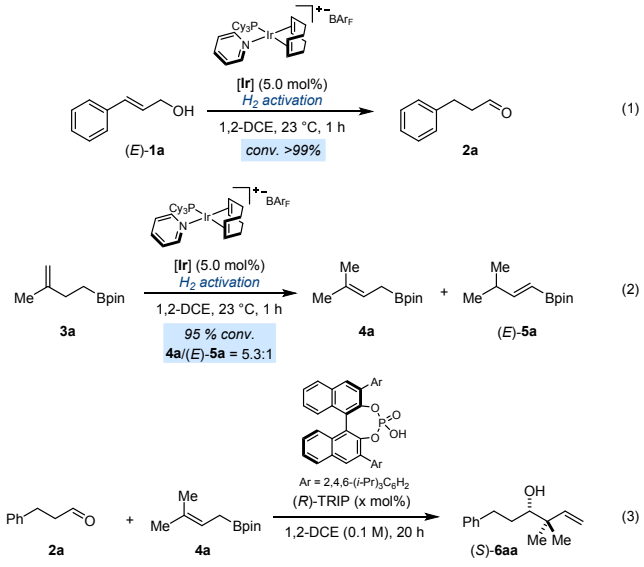
Figure 1. (A) Enantioselective allylborations of carbonyls and representative key patterns of the homoallylic alcohols accessible by this method. (B) Sequential isomerization/allylboration developed by Miura and Murakami. (C) iridium-catalyzed isomerization of allylic alcohols. (D) Iridium-catalyzed hydroboration of 1,3-dienes. (D) Dual isomerization/allylboration sequence.

of allylic alcohols would also prove competent for the isomerization of homoallylboronates into allylboronates. We anticipated that a dual isomerization of allylic alcohols and homoallylboronates could be conducted concomitant--ly using a *single catalyst* to produce –in the same flask– an aliphatic aldehyde and a 3,3-disubstituted allylboronate that would subsequently react stereoselectively in the presence of a chiral Brønsted acid. Successful realization of this strategy would require the following challenges to be overcome: (i) identify a single catalyst for the isomerization of allylic alcohols and homoallylboronates; (ii) produce stereoselectively (*E*)- or (*Z*)-allylboronates because allylborations are stereospecific processes; (iii) minimize non-stereoselective uncatalyzed allylboration; (iv) impart excellent stereocontrol in the C–C bond forming step; (v) meet the requirement for time resolution and compatibility of all the reagents, catalysts and intermediates to a single set of reaction conditions. Moreover, we noticed that in allylborations of carbonyl compounds, the nature of the aldehyde component has not been explored in great details and is often limited to benzaldehyde derivatives. We have shown that chiral aliphatic aldehydes can be obtained by iridium-catalyzed isomerization, therefore we also envisioned that in its ultimate version, our approach could produce chiral secondary homoallylic alcohols possessing both a α quaternary stereocenter and a β' tertiary stereocenter set by a Brønsted acid catalyst and by a chiral iridium catalyst respectively (Figure 1-E).

■ RESULTS AND DISCUSSION

To test the validity of our initial hypothesis and to evaluate the possibility to operate under a single set of reaction conditions, three independent experiments were conducted at the outset of our investigations (Figure 2). Isomerization of 3-phenylprop-2-enol (*E*)-**1a** was performed in 1,2-dichloroethane at room temperature using the Pfaltz-modified version of Crabtree's catalyst to

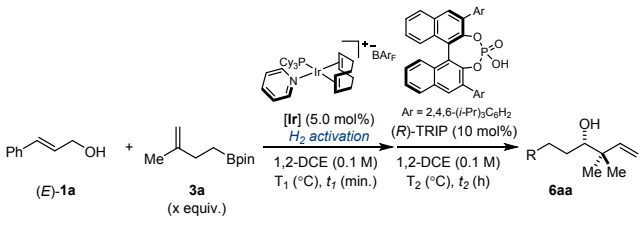
quantitatively deliver aldehyde **2a** within 1 h (eq. (1)).[19] Gratifyingly, under identical conditions, isomerization of homoallylboronate **3a** furnished the desired allylboronate **4a**, together with a small amount of vinylboronate (*E*)-**5a** (eq. (2)). Reacting the independently synthesized aldehyde **2a** and allylboronate **4a** in 1,2-dichloroethane at room temperature in the absence



Entry	T (°C)	(*R*)-TRIP (mol%)	conv. **6a** (%)	*ee* **6a** (%)
1	23	0	85	*rac.*
2	23	10	90	89
3	–30	10	90	97

Figure 2. Exploratory experiments (0.1 mmol scale). Conversion and (*E*)/(*Z*) ratio determined by ^{1}H NMR. Enantiomeric excess determined by HPLC using a chiral stationary phase.

Table 1. Reaction optimization[a]



entry[a]	**3a** (x equiv.)	T_1 (°C)	t_1 (min.)	T_2 (°C)	t_2 (h)	Conv. **6** (%)[b]	*ee* **6** (%)[c]
1	1.0	23	-	23	28	28	65
2	1.0	0	60	0	6	65	66
3	2.0	-20	60	-20	20	42	90
4[d]	1.5	0	40	-20	24	84(80)[e]	89
5[f]	1.5	0	40	-20	24	90(86)[e]	93

[a] Reaction conditions: **1a** (0.1 mmol), **3a** (0.1-0.2 mmol). [b] Determined by ^{1}H NMR using an internal standard. [c] Determined by HPLC using a chiral stationary phase. [d] **3a** is added first. **1a** is added after 30 min. [e] Yield of isolated product after purification by column chromatography in parenthesis. [f] **1a** is added first. **3a** is added after 10 min.

of catalyst, afforded homoallylic alcohol **6aa** in 85% conversion in racemic form. After optimization, we found that the strong uncatalyzed allylboration reaction could be outcompeted using the axially chiral phosphoric acid catalyst(*R*)-TRIP by running the reaction at low temperature. The highest enantioselectivity was obtained at –30 °C (90% conv., 97% *ee*) (eq. (3)). [20] Our efforts were next directed towards the identification of reaction conditions where the two isomerizations processes and the allylboration reaction could be conducted in the same flask. Allylic alcohol (*E*)-**1a** and homoallylboronate **3a** were selected as model substrates. After extensive investigations, we found that the order of addition of the reagents, the reaction time, the temperature and the relative stoichiometries were all important parameters to achieve appreciable reactivity while imparting high levels of stereocontrol (Table 1). When the reaction was conducted in tandem with the iridium catalyst and the Brønsted acid present at the beginning of the reaction, using a stoichiometric amount of allylic alcohol **1a** and homoallylboronate **3a**, homoallylic alcohol **6aa** was generated in 28% and 65% ee (Entry 1). When the isomerizations and allylboration were performed in sequence, the reactivity was increased significantly and an appreciable level of enantiocontrol (90% ee) was achieved at -20 °C using 2.0 equiv. of **3a** (Entries 2-3). While improved performances were obtained by conducting the dual isomerization at 0 °C and the allylboration at -20 °C, we also observed that the order of addition of the allylic alcohol and the homoallylboronate impacted the enantioselectivity of **6aa** (Entries 4-5).[21] We tentatively attribute this phenomenon to a reduced contribution of the uncatalyzed allylboration reaction which may itself depend on the relative rate of isomerization of the two substrates into aldehyde **2a** and allylboronate **4a**.

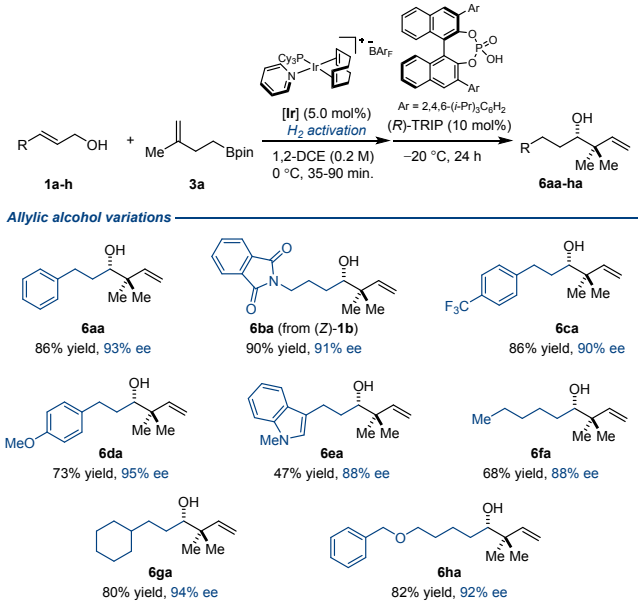


Figure 3. Enantioselective allylborations starting from various allylic alcohols **1a-h** (0.1-0.2 mmol) and homoallylboronate **3a** (1.5 equiv.). Yield of isolated product after purification by column chromatography. Enantiomeric excess determined by HPLC using a chiral stationary phase.

To probe the reaction scope under these optimized conditions, a series of (*E*)- and (*Z*)-configured allylic alcohols was evaluated using **3a** as common homoallylboronate to afford chiral secondary homoallylic alcohols with an adjacent quaternary center (Figure 3).[22] The sequential catalytic system was found to be compatible with a variety of functionalities, including an imide (**6ba**), a trifluoromethyl (**6ca**), a methylether (**6da**), an indole (**6ea**) and a benzyl ether (**6ha**). The allylboration products were isolated in moderate to excellent yield and consistently

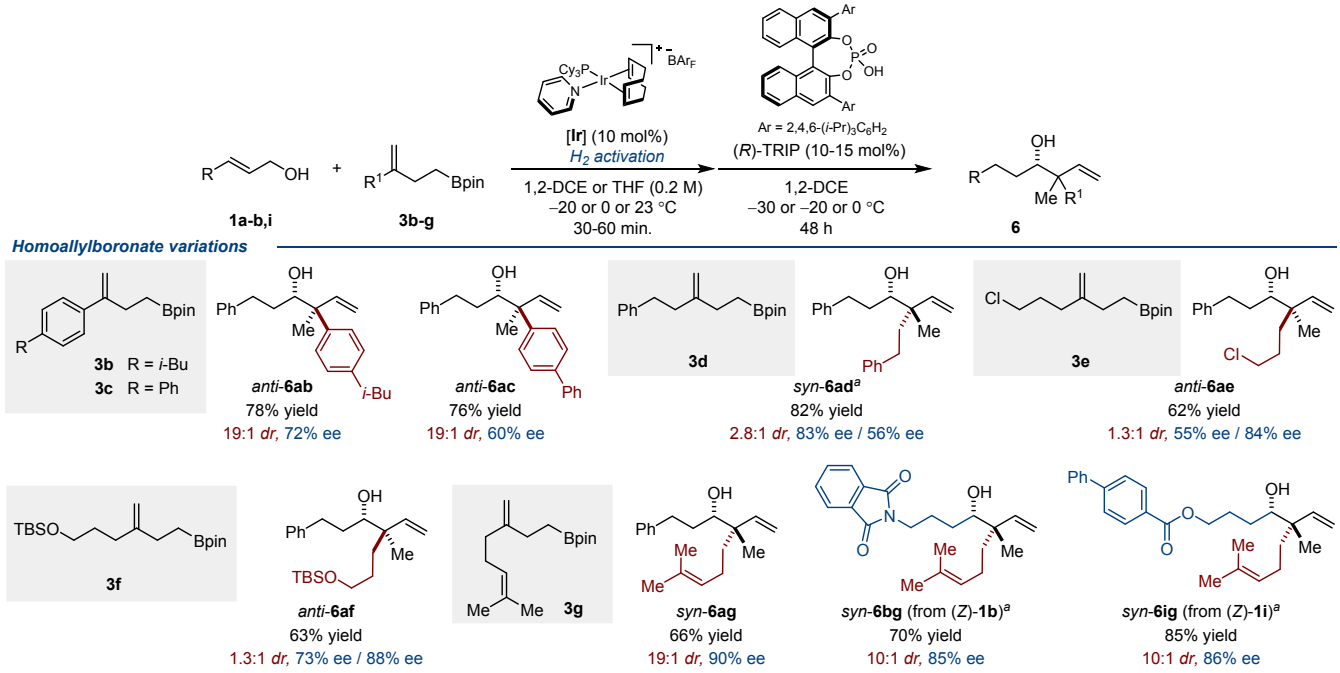


Figure 4. Diastereo- and enantioselective allylborations starting from various allylic alcohols **1a-b,i** (0.1 mmol) and homoallylboronates **3b-g** (2.0 equiv.). Yield of isolated product after purification by column chromatography. Enantiomeric excess determined by HPLC using a chiral stationary phase. Diastereomeric ratio determined by ^{1}H NMR. [a] THF was used for dual isomerization.

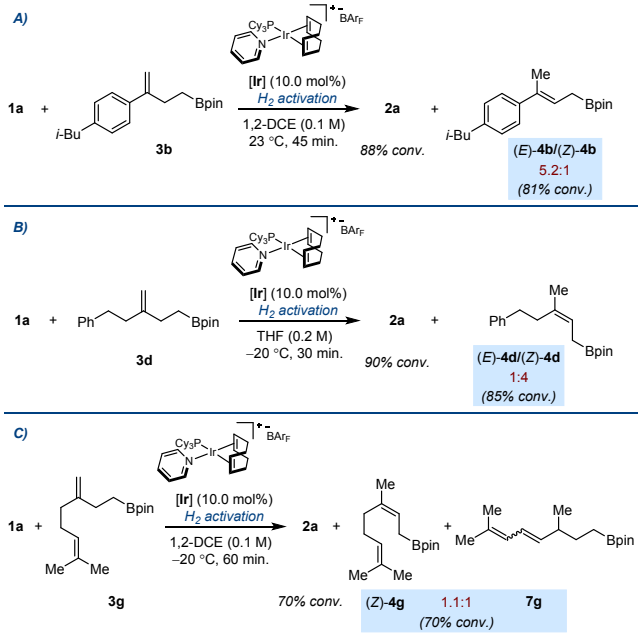


Figure 5. Ir-catalyzed dual isomerization of **3b**, **3d** and **3f** in presence of **1a** (0.1 mmol scale). Conversions determined by ^{1}H NMR using an internal standard.

high levels of enantioselectivity were obtained (88-95% ee).

We next explored the possibility to achieve high diastereo- and enantioselectivity in reactions using diversely substituted homoallylboronates **3b-g** (Figure 4). The catalyst loading in iridium and Brønsted acid was increased to achieve appreciable reactivity. Time and temperature were optimized for each step (See Supporting Information for details). With **3b** and **3c**, two aryl containing derivatives, the catalytic sequence proceeded efficiently and gave *anti*-**6ab** and *anti*-**6ac** in high *dr* (19:1 in both cases) and promising level of enantioselectivity (72% ee and 60% ee respectively). In contrast, with **3d**, an aliphatic derivative, *syn*-**6ad** was isolated as a 2.8:1 mixture of diastereoisomers and with a slightly higher enantioselectivity. Reduced levels of diastereoselection were obtained with other alkyl substituted homoallylboronates such as **3e** and **3f**, leading to nearly 1:1 *anti*/*syn* mixtures. Quite unexpectedly, with **3g**, a homoprenyl substituted homoallylboronate, the sequential process furnished quasi-exclusively *syn*-**6ag** with excellent enantioselectivity (19:1 *dr*, 90% ee). Almost identical catalytic performances were achieved when the allylic alcohol was varied (*syn*-**6bg**: 10:1 *dr*, 85% ee; *syn*-**6ig**: 10:1 *dr*, 86% ee).[23] To gain insight into the origin of this contrasted results, three independent dual isomerizations using **1a** in conjunction with either **3b**, **3d** or **3g** were conducted under conditions identical to those developed for the first step of the corresponding sequential process.

The reactions were interrupted after 30-60 minutes and no Brønsted acid was added so that only marginal amount of allylboration products was generated (Figure 5). Whereas isomerization of **3b** gave **4b** in an appreciable 5.2:1 (*E*)/(*Z*) ratio, **3d** afforded allylboronate **4d** as a 1:4 mixture of stereoisomers. Finally, a nearly equimolar amount of geometrically pure allylboronate (*Z*)-**4g** and of 1,3-diene **7g** was obtained upon isomerization of **3g**. Quite notably, in all cases, the final *dr* measured for homoallylic alcohols **6** reflects the stereochemical preference of the transient allylboronate **4**. For aryl substituted homoallylboronate **3b**, the much higher selectivity measured in the final product (19:1 vs 5.2:1) is due to the lower reactivity of (*Z*)-**4b**, as deduced from quantitative analysis of the crude reaction mixture by ^{1}H NMR analysis. By contrast, the excellent diastereo-differentiation obtained with **3g** originates from the ability of the iridium catalyst to produce (*Z*)-**4g** as a single stereoisomer (along with the unreactive diene **7g**). Overall, these results are consistent with the stereospecific nature of allylborations proceeding via a closed, cyclic Zimmerman-Traxler transition state.[3a,4d-e]

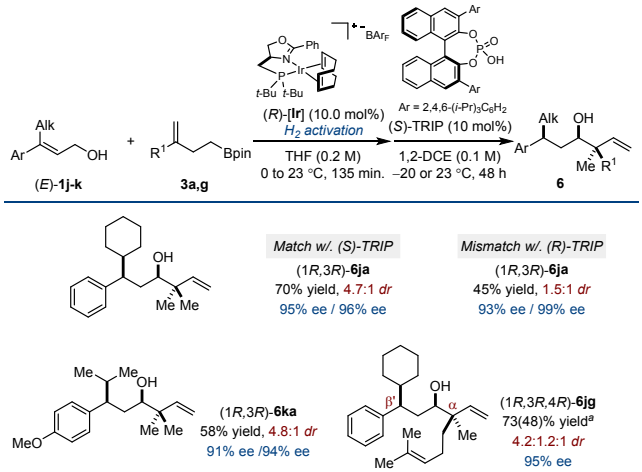


Figure 6. Dual isomerization/allylboration using prochiral allylic alcohols (*E*)-**1j-k** together with **3a**, **3g** (0.1 mmol scale). Yield of isolated product after purification by column chromatography. Diastereomeric ratio determined by ^{1}H NMR using an internal standard. Enantiomeric excess determined by HPLC using a chiral stationary phase. [a] In parenthesis, yield of stereochemically pure (1*R*,3*R*,4*S*)-**6jg** after chromatography.

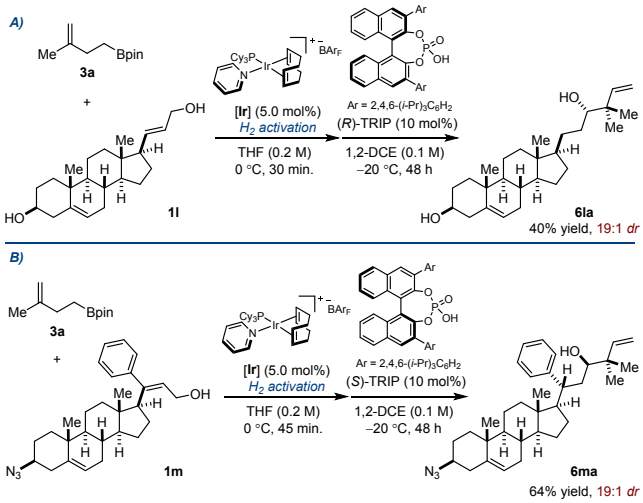


Figure 7. Dual isomerization/allylboration of steroid **1l** and **1m** (0.05-0.1 mmol) using **3a** (2.0 equiv.). Yield of isolated product after purification by column chromatography. Diastereomeric ratio determined by ^{1}H NMR using an internal standard.

To illustrate the structural flexibility offered by our approach, we demonstrated that an additional stereocenter could be implemented using prochiral allylic alcohols and a chiral iridium catalyst for the in situ generation of β-chiral aldehydes (Figure 6). The match combination of (*R*)-[Ir][17d,17f,24] and (*S*)-TRIP catalysts delivered (1*R*,3*R*)-**6ja** in good yield, high *dr* and excellent enantioselectivity. By contrast, the association of (*R*)-[Ir] and (*R*)-TRIP led only to a reduced yield and a lower diastereomeric ratio in favor of the same isomer, thus indicating that the two catalysts do not exert independent stereocontrol. Using the optimal conditions, (1*R*,3*R*)-**6ka** was isolated in 58% yield, 4.8:1 *dr* and 91% ee. Finally, the secondary homoallylic alcohol (1*R*,3*R*,4*R*)-**6jg** –which is characterized by the presence of both an α quaternary stereocenter and a β' tertiary stereocenter– was obtained in 73% yield, 4.2:1.2:1 *dr* and 95% ee for the major stereoisomer.

The effectiveness of the one-pot sequence was further explored using stereochemically complex structures reminiscent of naturally occurring compounds. Two steroid-based allylic alcohols were subjected to catalysis using Crabtree's catalyst for the dual isomerization in THF and (*R*)- or (*S*)-TRIP for the allylboration reaction after switching solvent to 1,2-dichloroethane (Figure 7). Substrate **1j** gave secondary homoallylic alcohol **6la** in 40% yield as a single stereoisomer, indicating that the presence of multiple vicinal stereocenters has essentially no influence on the C–C bond forming event. Similarly and consistent with our previous studies on the isomerization of stereochemically complex allylic alcohols,[17i] **6ma** was isolated with an excellent 19:1 *dr* in 64% yield. As a side note, the compatibility of the catalytic sequence with the alcohol at C3 in **1l** and the azide at C3 in **1m** further highlights the functional group tolerance of the protocol.

■ CONCLUSION

In summary, we have developed a catalytic sequence combining an iridium catalyst and a Brønsted catalyst for the diastereo- and enantioselective synthesis of chiral secondary homoallylic alcohols bearing a vicinal quaternary (stereo)center. The iridium catalyst exerts a dual role as it performs the concomitant isomerization of allylic alcohols into aldehydes and of homoallylboronates into allylboronates. Subsequently, upon addition of a chiral Brønsted acid catalyst to the same flask, the two products of isomerization engage into a highly stereoselective allylboration reaction. When an achiral iridium complex and a chiral Brønsted acid catalyst were used together with primary allylic alcohols and (3-methylbut-3-en-1-yl)boronic ester, secondary homoallylic alcohols with a proximal *gem*-dimethyl carbon center were obtained in excellent yield and enantiomeric excess. Secondary homoallylic alcohols bearing a vicinal quaternary stereocenter were generated in excellent *dr* and high ee for homoallylboronates with an aryl or homoprenyl derivatives. While the former led to *anti*-product, *syn*-homoallylic alcohols were obtained with the latter. Consistent with the stereospecific nature of allylboration reactions, this phenomenon was found to originate from the ability of the iridium catalyst to produce the corresponding transient allylboronates with high (*E*)- or (*Z*)-selectivity. Secondary homoallylic alcohols with an α-quaternary (stereo)center and a β' stereocenter have been prepared with high levels of diastereo- and enantiocontrol using our catalytic sequence. Last, we demonstrated that the protocol is applicable to stereochemically complex and demanding environments using steroid-derived di- and trisubstituted allylic alcohols. Current investigations are directed towards the design of a more general system and of its implementation in the synthesis of biologically and pharmaceutically relevant products.

■ EXPERIMENTAL SECTION

General Experimental Methods for Synthesis and Chemical Characterization. All reactions were carried out under an inert atmosphere of nitrogen using either two-manifold vacuum/inert nitrogen lines or a M. Braun glove-box. Solvents were dried over activated alumina columns and further degassed by three successive "freeze-pump-thaw" cycles if necessary. NMR spectra were recorded on AMX-300, AMX-400 and AMX-500 Bruker Avance spectrometers at 298 K. ^{1}H and $^{13}C\{^{1}H\}$ NMR chemical shifts are given in ppm relative to $SiMe_4$, with the solvent resonance used as internal reference. ^{1}H NMR spectra were referenced to $CDCl_3$ (7.26 ppm) and $^{13}C\{^{1}H\}$ NMR spectra were referenced to $CDCl_3$ (77.16 ppm). Infrared spectra were obtained on a Perkin-Elmer 1650 FT-IR spectrometer using neat samples on a diamond ATR Golden Gate sampler. GC-MS analyses were performed on GC–HP 6890, column Agilent–HP1 (30 m–ID 0.32 mm, Film 0.25 μm) coupled with MS–HP 5973. HRMS were obtained on a Xevo G2 TOF spectrometer (Ionization mode: ESI positive polarity; Mobile phase: MeOH 100 μl/min). Mass spectrum is calibrated by the use of the MS lockspray system (LeuEnk calibration solution). The enantiomeric excesses (ee's) were determined by HPLC, SFC and GC analyses. HPLC analyses performed on a Shimadzu CTO-20AA with column DAICEL OD-H, OJ-H, AD-H and IC. GC analyses were performed on HP–6890, column HYDRODEX DiMOM and HYDRODEX TBDM, 50 m. SFC analyses were performed on a Waters Acquity UPC2 with columns OD-3, OJ-3, OZ-3, OB-H, AZ-3, AD, AS-3, AY-H. Retention times (t_R) are given in minutes. Thin layer chromatography (TLC) was performed on plates of silica precoated with 0.25 mm Kieselgel 60 F254 from Merck. Flash chromatography was performed using silica gel SiliaFlash® P60 (230-400 mesh) from Silicycle. Commercial reagents, precatalysts and ligands were purchased from Aldrich, Fluka, Acros or Strem and used without purification unless otherwise noted.

General procedure for the dual isomerization/allylboration sequence. The iridium catalyst (0.01 mmol, 5 mol%) was introduced into a Schlenk tube in a glove-box and dissolved in anhydrous and degassed 1,2-DCE (0.9 mL). Next hydrogen gas was gently bubbled directly through the solution (2-3 bubbles per second) via a stainless-steel needle at room temperature. The orange solution rapidly became light yellow color. After 1-2 minutes, bubbling was cased and the solution was degassed by two successive freeze-pump-thaw cycles. After the second cycle, the homoallylic boronate **3a** (60 mg, 0.3 mmol, 1.5 equiv.) was added immediately to the cold solution in one portion. The rubber septum was replaced with a polyethylene stopper and the reaction was stirred at 0 °C for 30 min. Then the appropriate allylic alcohol **1** (0.2 mmol, 1.0 equiv., in 0.2 mL of 1,2-DCE) was added to the above solution at 0 °C for the indicated time. After that, the solution was cooled down to –20 °C and the (*R*)-TRIP catalyst (0.02 mmol, 10 mol%, in 0.1 mL of 1,2-DCE) was added. After stirring at –20 °C for 24 h, the reaction mixture was purified by column chromatography (pentane/diethyl ether 9:1 to 5:1) to afford the corresponding homoallylic alcohol **6**. This compound was used for determination of the enantiomeric excess.

Synthesis of (S)-4,4-dimethyl-1-phenylhex-5-en-3-ol ((*S*)-**6aa**). According to the general procedure: isomerization of homoallylic boronate **3a** (30 min, 0 °C); isomerization of allylic alcohol **1a** (10 min, 0 °C). Purification by column chromatography (pentane/diethyl ether 9:1 to 5:1) to afford (*S*)-**6aa** as a colorless oil (35 mg, 86% yield, 93% *ee*). R_f = 0.5 (pentane/diethyl ether 4:1). All spectroscopic and spectrometric analyses were in agreement with the literature.[25] HPLC: 93% *ee*, chiral stationary column: AD-H, mobile phase: hexane/*i*PrOH = 99/1, 1.0 mL/min, 210 nm, 30 °C, t_R (major) = 13.1 min, t_R (minor) = 17.1 min. $[\alpha]^{20}_D$ = –40.7 (*c* 1.93, CH_2Cl_2).

Synthesis of (S)-2-(4-hydroxy-5,5-dimethylhept-6-en-1-yl)isoindoline-1,3-dione ((*S*)-**6ba**). According to the general procedure: isomerization of homoallylic boronate **3a** (30 min, 0 °C); isomerization of allylic alcohol **1b** (60 min, 0 °C). Purification by column chromatography (pentane/diethyl ether 6:1 to 3:1) to afford (*S*)-**6ba** as a colorless oil (51.7 mg, 90% yield, 91% *ee*). TLC: R_f = 0.3 (pentane/diethyl ether 4:1). ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) = 7.84 (dd, $^{3}J_{HH}$ =

5.4, 3.1 Hz, 2H, *H*-11), 7.71 (dd, $^3J_{HH}$ = 5.5, 3.1 Hz, 2H, *H*-12), 5.80 (dd, $^3J_{HH}$ = 17.5, 10.9 Hz, 1H, *H*-2), 5.14 – 4.96 (m, 2H, *H*-1), 3.80 – 3.64 (m, 2H, *H*-8), 3.30 (dd, $^3J_{HH}$ = 10.6, 2.0 Hz, 1H, *H*-4), 2.03 – 1.85 (m, 1H, *H*-6), 1.79 – 1.65 (m, 1H, *H*-6), 1.64 – 1.53 (m, 2H, *H*-5 and O-*H*), 1.37 – 1.26 (m, 1H, *H*-5), 1.00 (s, 6H, *H*-7). $^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$) δ (ppm) = 168.5 (*C*-9), 145.2 (*C*H-2), 133.9 (*C*H-12), 132.2 (*C*-10), 123.2 (*C*H-11), 113.6 (CH_2-1), 77.8 (*C*H-4), 41.7 (*C*-3), 38.0 (CH_2-8), 28.4 (CH_2-5), 26.3 (CH_2-6), 23.1 (CH_3-7), 22.0 (CH_3-7). HRMS (ESI) *m/z* $[M+H]^+$ Calcd for $C_{17}H_{21}NO_3$: 288.1595; Found: 288.1582. IR (neat) ν (cm^{-1}): 3082, 2960, 2871, 1772, 1703, 1639, 1615, 1467, 1439, 1396, 1364, 1188, 1172, 1117, 1070, 1047, 1008, 969, 913, 885, 795, 719, 692. HPLC: 91% *ee*, chiral stationary column: AD-H, mobile phase: hexane/*i*PrOH = 95/5, 1.0 mL/min, 210 nm, 30 °C, t_R (major) = 36.3 min, t_R (minor) = 27.9 min. $[\alpha]^{20}_D$ = –20.2 (*c* 2.93, CH_2Cl_2).

Synthesis of (S)-4,4-dimethyl-1-(4-(trifluoromethyl)phenyl)hex-5-en-3-ol ((*S*)-**6ca**). According to the general procedure: isomerization of homoallylic boronate 3a (0.3 mmol, 30 min, 0 °C), isomerization of allylic alcohol 1c (0.2 mmol, 10 min, 0 °C). Purification by column chromatography (pentane/diethyl ether 9:1 to 4:1) to afford (*S*)-**6ca** as a colorless oil (47 mg, 86% yield, 90% *ee*). TLC: R_f = 0.5 (pentane/diethyl ether 4:1). ^1H NMR (300 MHz, $CDCl_3$) δ (ppm) = 7.53 (d, $^3J_{HH}$ = 8.0 Hz, 2H, *H*-10), 7.32 (d, $^3J_{HH}$ = 8.0 Hz, 2H, *H*-9), 5.78 (dd, $^3J_{HH}$ = 17.5, 10.8 Hz, 1H, *H*-2), 5.17 – 4.98 (m, 2H, *H*-1), 3.26 (dd, $^3J_{HH}$ = 10.7, 1.9 Hz, 1H, *H*-4), 3.03 – 2.91 (m, 1H, *H*-6), 2.75 – 2.61 (m, 1H, *H*-6), 1.91 – 1.77 (m, 1H, *H*-5), 1.66 – 1.56 (m, 1H, *H*-5), 1.55 (s, 1H, O-*H*), 1.00 (s, 6H, *H*-7). $^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$) δ (ppm) = 141.6 (q, $^1J_{FC}$ = 285, *C*-12), 145.1 (*C*H-2), 128.8 (*C*H-9), 128.2 (q, $^2J_{FC}$ = 38, *C*-11), 125.2 (q, $^3J_{FC}$ = 8, *C*H-10), 113.9 (CH_2-1), 77.2 (*C*H-4), 41.7 (*C*-3), 33.0 (CH_2-6), 32.9 (CH_2-5), 23.1 (CH_3-7), 21.8 (CH_3-7). $^{19}F\{^1H\}$ NMR (282 MHz, $CDCl_3$) δ (ppm) = -62.29. HRMS (ESI) *m/z* $[M+K]^+$ Calcd for $C_{15}H_{19}F_3O$: 311.1020; Found: 311.1015. IR (neat) ν (cm^{-1}): 2964, 2931, 2872, 1619, 1467, 1417, 1383, 1365, 1325, 1163, 1123, 1068, 1019, 919, 843, 824, 734, 689, 630. HPLC: 90% *ee*, chiral stationary column: AD-H, mobile phase: hexane/*i*PrOH = 99/1, 1.0 mL/min, 210 nm, 30 °C, t_R (major) = 11.2 min, t_R (minor) = 12.4 min. $[\alpha]^{20}_D$ = –46.5 (*c* 1.40, CH_2Cl_2).

Synthesis of (S)-1-(4-methoxyphenyl)-4,4-dimethylhex-5-en-3-ol ((*S*)-**6da**). According to the general procedure: isomerization of homoallylic boronate 3a (0.3 mmol, 30 min, 0 °C), isomerization of allylic alcohol 1d (0.2 mmol, 5 min, 0 °C). Purification by column chromatography (pentane/diethyl ether 9:1 to 4:1) to afford (*S*)-**6da** as a colorless oil (34 mg, 73% yield, 94.5% *ee*). TLC: R_f = 0.4 (pentane/diethyl ether 4:1). ^1H NMR (300 MHz, $CDCl_3$) δ (ppm) = 7.13 (d, $^3J_{HH}$ = 8.6 Hz, 2H, *H*-10), 6.83 (d, $^3J_{HH}$ = 8.6 Hz, 2H, *H*-9), 5.80 (dd, $^3J_{HH}$ = 17.5, 10.9 Hz, 1H, *H*-2), 5.14 – 4.98 (m, 2H, *H*-1), 3.79 (s, 3H, *H*-12), 3.27 (d, $^3J_{HH}$ = 10.5, 1.8 Hz, 1H, *H*-4), 2.94 – 2.78 (m, 1H, *H*-6), 2.63 – 2.50 (m, 1H, *H*-6), 1.87 – 1.72 (m, 1H, *H*-5), 1.62 – 1.46 (m, 2H, *H*-5 and O-*H*), 1.00 (s, 6H, *H*-7). $^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$) δ (ppm) = 157.8 (*C*-11), 145.3 (*C*H-2), 134.4 (*C*-8), 129.4 (*C*H-10), 113.8 (*C*H-9), 113.5 (CH_2-1), 77.5 (*C*H-4), 55.3 (CH_3-12), 41.7 (*C*-3), 33.5 (CH_2-5), 32.3 (CH_2-6), 23.1 (CH_3-7), 22.0 (CH_3-7). HRMS (ESI) *m/z* $[M+Na]^+$ Calcd for $C_{15}H_{22}O_2$: 257.1512; Found: 257.1509. IR (neat) ν (cm^{-1}): 3081, 2956, 2929, 2865, 1637, 1613, 1584, 1511, 1464, 1416, 1381, 1364, 1300, 1243, 1177, 1108, 1071, 1037, 1007, 914, 830, 770, 689. HPLC: 94.5% *ee*, chiral stationary column: AD-H, mobile phase: hexane/*i*PrOH = 99/1, 1.0 mL/min, 210 nm, 30 °C, t_R (major) = 23.3 min, t_R (minor) = 26.8 min. $[\alpha]^{20}_D$ = –33.3 (*c* 2.20, CH_2Cl_2).

Synthesis of (S)-4,4-dimethyl-1-(1-methyl-1H-indol-3-yl)hex-5-en-3-ol ((*S*)-**6ea**). According to the general procedure: isomerization of homoallylic boronate 3a (0.3 mmol, 30 min, 0 °C); isomerization of allylic alcohol 1e (0.2 mmol, 10 min, 0 °C). Purification by column chromatography (pentane/diethyl ether 9:1 to 3:1) to afford (*S*)-**6ea** as a colorless oil (24 mg, 47% yield, 88% *ee*). **TLC**: R_f = 0.4 (pentane/diethyl ether 4:1). ^1H NMR (400 MHz, $CDCl_3$) δ (ppm) = 7.61 (d, $^3J_{HH}$ = 7.9 Hz, 1H, *H*-13), 7.29 (d, $^3J_{HH}$ = 8.2 Hz, 1H, *H*-11), 7.24 – 7.18 (m, 1H, *H*-12), 7.14 – 7.06 (m, 1H, *H*-10), 6.86 (s, 1H, *H*-16), 5.82 (dd, $^3J_{HH}$ = 17.5, 10.8 Hz, 1H, *H*-2), 5.14 – 5.01 (m, 2H, *H*-1), 3.75 (s, 3H, *H*-15), 3.37 (dd, $^3J_{HH}$ = 10.5, 1.8 Hz, 1H, *H*-4), 3.08 – 2.98 (m, 1H, *H*-6), 2.84 – 2.74 (m, 1H, *H*-6), 2.02 – 1.92 (m, 1H, *H*-5), 1.68 – 1.60 (m, 1H, *H*-5), 1.57 (s, 1H, O-H), 1.00 (s, 6H, *H*-7). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ (ppm) = 145.4 (*C*H-2), 137.1 (*C*-14), 127.9 (*C*-9), 126.2 (*C*H-16), 121.5 (*C*H-12), 119.1 (*C*H-13), 118.6 (*C*H-10), 114.9 (*C*-8), 113.5 (CH_2-1), 109.1 (*C*H-11), 78.0 (*C*H-4), 41.7 (*C*-3), 32.6 (CH_3-15), 32.2 (CH_2-5), 23.2 (CH_3-7), 22.5 (CH_2-6), 22.0 (CH_3-7). HRMS (ESI) *m/z* $[M+H]^+$ Calcd for $C_{17}H_{23}NO$: 258.1853; Found: 258.1852. IR (neat) ν (cm^{-1}): 3456, 3055, 2926, 2855, 1637, 1615, 1555, 1471, 1417, 1377, 1324, 1247, 1203, 1152, 1070, 1044, 1011, 962, 915, 792, 738, 690. HPLC: 88% *ee*, chiral stationary column: IC, mobile phase: hexane/*i*PrOH = 95/5, 1.0 mL/min, 210 nm, 30 °C, t_R (major) = 9.6 min, t_R (minor) = 16.2 min. $[\alpha]^{20}_D$ = –33.6 (*c* 1.40, CH_2Cl_2).

Synthesis of (S)-3,3-dimethylnon-1-en-4-ol ((*S*)-**6fa**). According to the general procedure: isomerization of homoallylic boronate **3a** (30 min, 0 °C); isomerization of allylic alcohol **1f** (60 min, 0 °C). Purification by column chromatography (pentane/diethyl ether 20:1 to 10:1) to afford (*S*)-**6fa** as a colorless oil (23.2 mg, 68% yield, 88% *ee*). TLC: R_f = 0.6 (pentane/diethyl ether 4:1). All spectroscopic and spectrometric analyses were in agreement with the literature.[26] GC: HYDRODEX B-3P, 60°C-1°C/min-170°C, 20. M, H_2, t_R (major) = 33.5 min, t_R (minor) = 35.0 min. $[\alpha]^{20}_D$ = –2.9 (*c* 0.07, CH_2Cl_2).

Synthesis of (S)-1-cyclohexyl-4,4-dimethylhex-5-en-3-ol ((*S*)-**6ga**). According to the general procedure: isomerization of homoallylic boronate 3a (0.3 mmol, 30 min, 0 °C), isomerization of allylic alcohol 1g (0.2 mmol, 5 min, 0 °C). Purification by column chromatography (pentane/diethyl ether 20:1 to 9:1) to afford (*S*)-**6ga** as a colorless oil (34 mg, 80% yield, 94% *ee*). TLC: R_f = 0.7 (pentane/diethyl ether 4:1). ^1H NMR (300 MHz, $CDCl_3$) δ (ppm) = 5.82 (dd, $^3J_{HH}$ = 17.5, 10.9 Hz, 1H, *H*-2), 5.15 – 4.96 (m, 2H, *H*-1), 3.25 – 3.14 (m, 1H, *H*-4), 1.74 – 1.41 (m, 8H), 1.27 – 1.11 (m, 6H), 1.00 (s, 6H, *H*-7), 0.94 – 0.80 (m, 2H). $^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$) δ (ppm) = 145.6 (*C*H-2), 113.2 (CH_2-1), 78.7 (*C*H-4), 41.8 (*C*-3), 37.8 (*C*H-8), 34.8, 33.7, 33.2, 28.7, 26.7, 26.5, 26.4, 23.2 (CH_3-7), 22.1 (CH_3-7). HRMS (ESI)

m/z [M+H-H_2O]$^+$ Calcd for $C_{14}H_{25}O$: 193.1946; Found: 193.1960. IR (neat) ν (cm^{-1}): 3389, 3082, 2921, 2851, 1638, 1450, 1415, 1380, 1304, 1279, 1127, 1072, 1006, 911, 688. Chiral GC: HYDRODEX B-3P, 60°C-1°C/min-170°C, 20. M, H_2, t_R (major) = 68.2 min, t_R (minor) = 69.5 min. $[\alpha]^{20}_D$ = −27.2 (*c* 1.87, CH_2Cl_2).

Synthesis of (S)-8-(benzyloxy)-3,3-dimethyloct-1-en-4-ol ((*S*)-**6ha**). According to the general procedure: isomerization of homoallylic boronate **3a** (0.15 mmol, 30 min, 0 °C), isomerization of allylic alcohol **1h** (0.1 mmol, 15 min, 0 °C), (*R*)-TRIP catalyst (0.015 mmol, 15 mol%). Purification by column chromatography (pentane/diethyl ether 9:1 to 4:1) to afford (*S*)-**6ha** as a colorless oil (21.7 mg, 82% yield, 92% *ee*). TLC: R_f = 0.5 (pentane/diethyl ether 4:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) = 7.31 – 7.23 (m, 4H), 7.22 – 7.18 (m, 1H), 5.73 (dd, $^3J_{HH}$ = 17.5, 10.8 Hz, 1H, *H*-2), 5.05 – 4.93 (m, 2H, *H*-1), 4.43 (s, 2H, *H*-10), 3.46 – 3.36 (m, 2H, *H*-9), 3.17 (dd, $^3J_{HH}$ = 10.4, 1.8 Hz, 1H, *H*-4), 1.64 – 1.51 (m, 3H, *H*-6 and *H*-8), 1.50 – 1.42 (m, 2H, *H*-5 and *O*-H), 1.37 – 1.27 (m, 1H, *H*-6), 1.22 – 1.16 (m, 1H, *H*-5), 0.92 (s, 6H, *H*-7). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ (ppm) = 145.5 (*C*H-2), 138.6 (*C*-Ar), 128.4 (*C*H-Ar), 127.7 (*C*H-Ar), 127.5 (*C*-Ar), 113.4 (CH_2-1), 78.2 (*C*H-4), 72.9 (CH_2-10), 70.4 (CH_2-9), 41.7 (*C*-3), 31.2 (CH_2-5), 29.7 (CH_2-8), 23.8 (CH_2-6), 23.1 (CH_3-7), 22.0 (CH_3-7). HRMS (ESI) *m/z* [M+Na]$^+$ Calcd for $C_{17}H_{26}O_2$: 285.1825; Found: 285.1832. IR (neat) ν (cm^{-1}): 3030, 2931, 2861, 1739, 1638, 1495, 1455, 1415, 1363, 1310, 1205, 1100, 1028, 1006, 911, 735, 697, 614. HPLC: 92% *ee*, chiral stationary column: AD-H, mobile phase: hexane/*i*PrOH = 99/1, 1.0 mL/min, 210 nm, 30 °C, t_R (major) = 22.7 min, t_R (minor) = 20.7 min. $[\alpha]^{20}_D$ = −20.8 (*c* 1.13, CH_2Cl_2).

Synthesis of (3S,4S)-4-(4-isobutylphenyl)-4-methyl-1-phenylhex-5-en-3-ol (anti-**6ab**). The iridium catalyst (0.01 mmol, 10 mol%) was introduced into a Schlenk tube in a glove-box and dissolved in anhydrous and degassed 1,2-DCE (0.9 mL). Next hydrogen gas was gently bubbled directly through the solution (2-3 bubbles per second) via a stainless-steel needle at room temperature. The orange solution rapidly became light yellow color. After 1-2 minutes, bubbling was cased and the solution was degassed by two successive freeze-pump-thaw cycles. After the second cycle, the homoallylic boronate **3b** (0.2 mmol, 2.0 equiv.) was added immediately to the cold solution in one portion. The rubber septum was replaced with a polyethylene stopper and the reaction was stirred at room temperature for 15 min. Then the appropriate allylic alcohol **1a** (0.1 mmol, 1.0 equiv., in 0.2 mL of 1,2-DCE) was added to the above solution at room temperature for 30 min. After that, the solution was cooled down to 0 °C and the (*R*)-TRIP catalyst (0.01 mmol, 10 mol%, in 0.1 mL of 1,2-DCE) was added. After stirring at 0 °C for 48 h, the reaction mixture was purified by column chromatography (pentane/diethyl ether 9:1 to 5:1) to afford the corresponding homoallylic alcohol *anti*-**6ab**. This compound was used for determination of the enantiomeric excess Purification by column chromatography (pentane/diethyl ether 9:1 to 4:1) to afford 6ab as a colorless oil (25 mg, 78% yield, 19:1 *dr*, 72% *ee*). TLC: R_f = 0.5 (pentane/diethyl ether 4:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) = 7.28 – 7.24 (m, 2H), 7.22 – 7.16 (m, 3H), 7.15 – 7.11 (m, 2H), 7.11 – 7.06 (m, 2H), 6.27 (dd, $^3J_{HH}$ = 17.7, 10.9 Hz, 1H, *H*-2), 5.27 (dd, $^3J_{HH}$ = 10.9, 1.3 Hz, 1H, *H*-1), 5.14 (dd, $^3J_{HH}$ = 17.7, 1.3 Hz, 1H, *H*-1), 3.96 – 3.83 (m, 1H, *H*-4), 2.95 – 2.83 (m, 1H, *H*-6), 2.64 – 2.54 (m, 1H, *H*-6), 2.44 (d, $^3J_{HH}$ = 7.2 Hz, 2H, *H*-8), 1.90 – 1.80 (m, 1H, *H*-9), 1.75 – 1.47 (m, 3H, *H*-5 and *O*-H), 1.36 (s, 3H, *H*-7), 0.90 (d, $^3J_{HH}$ = 6.6 Hz, 6H, *H*-10). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ (ppm) = 143.3 (*C*H-2), 142.4 (*C*-Ar), 142.3 (*C*-Ar), 139.8 (*C*-Ar), 129.3 (*C*H-Ar), 128.5 (*C*H-Ar), 128.3 (*C*H-Ar), 126.5 (*C*H-Ar), 125.7 (*C*H-Ar), 114.6 (CH_2-1), 76.6 (*C*H-4), 49.3 (*C*-3), 44.9 (CH_2-8), 33.2 (CH_2-6), 32.9 (CH_2-5), 30.2 (*C*H-9), 22.5 (CH_3-10), 22.4 (CH_3-10), 19.6 (CH_3-7). HRMS (ESI) *m/z* [M+Na]$^+$ Calcd for $C_{23}H_{30}O$: 345.2189; Found: 345.2174. IR (neat) ν (cm^{-1}): 3479, 3085, 3026, 2955, 2926, 2868, 1634, 1604, 1511, 1497, 1455, 1415, 1384, 1282, 1168, 1057, 1018, 919, 845, 794, 747, 699, 667. HPLC: 72% *ee*, chiral stationary column: OJ-H, mobile phase: hexane/*i*PrOH = 99/1, 1.0 mL/min, 210 nm, 30 °C, t_R (major) = 11.4 min, t_R (minor) = 13.4 min. $[\alpha]^{20}_D$ = −4.9 (*c* 1.40, CH_2Cl_2).

Synthesis of (3S,4S)-4-([1,1'-biphenyl]-4-yl)-4-methyl-1-phenylhex-5-en-3-ol (*anti*-**6ac**). The iridium catalyst (0.01 mmol, 10 mol%) was introduced into a Schlenk tube in a glove-box and dissolved in anhydrous and degassed 1,2-DCE (0.9 mL). Next hydrogen gas was gently bubbled directly through the solution (2-3 bubbles per second) via a stainless-steel needle at room temperature. The orange solution rapidly became light yellow color. After 1-2 minutes, bubbling was cased and the solution was degassed by two successive freeze-pump-thaw cycles. After the second cycle, the homoallylic boronate **3c** (0.2 mmol, 2.0 equiv.) was added immediately to the cold solution in one portion. The rubber septum was replaced with a polyethylene stopper and the reaction was stirred at 0 °C for 15 min. Then the appropriate allylic alcohol **1a** (0.1 mmol, 1.0 equiv., in 0.2 mL of 1,2-DCE) was added to the above solution at 0 °C for 30 min. After that, the solution was cooled down to 0 °C and the (*R*)-TRIP catalyst (0.01 mmol, 10 mol%, in 0.1 mL of 1,2-DCE) was added. After stirring at 0 °C for 48 h, the reaction mixture was purified by column chromatography (pentane/diethyl ether 9:1 to 5:1) to afford the corresponding homoallylic alcohol *anti*-**6ac**. This compound was used for determination of the enantiomeric excess. Purification by column chromatography (pentane/diethyl ether 9:1 to 4:1) to afford 6ac as a colorless oil (26 mg, 76% yield, 19:1 *dr*, 60% *ee*). TLC: R_f = 0.5 (pentane/diethyl ether 4:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) = 7.62 – 7.53 (m, 4H), 7.48 – 7.42 (m, 2H), 7.41 – 7.33 (m, 3H), 7.32 – 7.26 (m, 2H), 7.22 – 7.14 (m, 3H), 6.31 (dd, $^3J_{HH}$ = 17.7, 10.9 Hz, 1H, *H*-2), 5.31 (dd, $^3J_{HH}$ = 10.9, 1.2 Hz, 1H, *H*-1), 5.19 (dd, $^3J_{HH}$ = 17.6, 1.3 Hz, 1H, *H*-1), 3.98 (d, $^3J_{HH}$ = 9.2 Hz, 1H, *H*-4), 2.97 – 2.87 (m, 1H, *H*-6), 2.67 – 2.59 (m, 1H, *H*-6), 1.75 – 1.60 (m, 3H, *H*-5 and *O*-H), 1.42 (s, 3H, *H*-7). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ (ppm) = 144.4 (*C*-Ar), 143.1 (*C*H-2), 142.2 (*C*-Ar), 140.7 (*C*-Ar), 139.2 (*C*-Ar), 128.8 (*C*H-Ar), 128.6 (*C*H-Ar), 128.4 (*C*H-Ar), 127.3 (*C*H-Ar), 127.3 (*C*H-Ar), 127.2 (*C*H-Ar), 127.0 (*C*H-Ar), 125.8 (*C*H-Ar), 115.0 (CH_2-1), 76.5 (*C*H-4), 49.5 (*C*-3), 33.2 (CH_2-6), 33.0 (CH_2-5), 19.7 (CH_3-7). HRMS (ESI) *m/z* [M+Na]$^+$

Calcd for $C_{25}H_{26}O$: 365.1876; Found: 365.1888. IR (neat) ν (cm^{-1}): 3580, 3028, 2927, 1602, 1487, 1454, 1397, 1264, 1059, 1007, 919, 840, 766, 736, 698. SFC: 60% *ee*, chiral stationary column: OB, mobile phase: 20% MeOH, 2.0 mL/min, 254 nm, 30 °C, t_R (major) = 7.1 min, t_R (minor) = 6.1 min. $[\alpha]^{20}_D$ = 13.3 (*c* 1.11, CH_2Cl_2).

Synthesis of (3S,4S)-4-methyl-4-phenethyl-1-phenylhex-5-en-3-ol (*syn*-**6ad**). The iridium catalyst (0.01 mmol, 10 mol%) was introduced into a Schlenk tube in a glove-box and dissolved in anhydrous and degassed THF (0.5 mL). Next hydrogen gas was gently bubbled directly through the solution (2-3 bubbles per second) via a stainless-steel needle at room temperature. The orange solution rapidly became light yellow color. After 1-2 minutes, bubbling was cased and the solution was degassed by two successive freeze-pump-thaw cycles. After the second cycle, the homoallylic boronate **3d** (0.2 mmol, 2.0 equiv.) was added immediately to the cold solution in one portion. The rubber septum was replaced with a polyethylene stopper and the reaction was stirred at –20 °C for 15 min. Then the appropriate allylic alcohol **1a** (0.1 mmol, 1.0 equiv., in 0.2 mL of THF) was added to the above solution at –20 °C for 15 min. After that, the solvent THF was removed slowly under vacuum. Then the mixture was cooled down to –30 °C and the (*R*)-TRIP catalyst (0.015 mmol, 15 mol%, in 1.0 mL of 1,2-DCE) was added. After stirring at –30 °C for 48 h, the reaction mixture was purified by column chromatography (pentane/diethyl ether 9:1 to 4:1) to afford the corresponding homoallylic alcohol *syn*-**6ad**. This compound was used for determination of the enantiomeric excess. Purification by column chromatography (pentane/diethyl ether 9:1 to 4:1) to afford 6ad as a colorless oil (24 mg, 82% yield, 2.8:1 *dr*, 83% ee/ 56% *ee*). TLC: R_f = 0.4 (pentane/diethyl ether 4:1). ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) = 7.36 – 7.29 (m, 4H), 7.28 – 7.15 (m, 6H), 5.94 – 5.74 (m, 1H, *H*-2), 5.37 – 5.25 (m, 1H, *H*-1), 5.22 – 5.10 (m, 1H, *H*-1), 3.46 – 3.36 (m, 1H, *H*-4), 3.04 – 2.90 (m, 1H, *H*-6), 2.72 – 2.61 (m, 1H, *H*-6), 2.60 – 2.47 (m, 2H, *H*-9), 2.00 – 1.86 (m, 1H, *H*-5), 1.77 – 1.62 (m, 3H, *H*-5 and *H*-8), 1.52 – 1.38 (m, 1H, *O*-H), 1.14 (s, 2.3H, *syn*-isomer *H*-7), 1.10 (s, 0.8H, *anti*-isomer *H*-7). ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$) δ (ppm) = 143.90 (*syn*, *C*H-2), 143.13 (*anti*, *C*H-2), 143.03 (*syn*, *C*-Ar), 142.94 (*anti*, *C*-Ar), 142.38 (*anti*, *C*-Ar), 142.26 (*syn*, *C*-Ar), 128.53 (*syn*, *C*H-Ar), 128.41 (*syn*, *C*H-Ar), 128.38 (*syn*, *C*H-Ar), 128.33 (*syn*, *C*H-Ar), 125.84 (*syn*, *C*H-Ar), 125.82 (*anti*, *C*H-Ar), 125.75 (*anti*, *C*H-Ar), 125.71 (*syn*, *C*H-Ar), 115.81 (*anti*, CH_2-1), 115.21 (*syn*, CH_2-1), 77.39 (*syn*, *C*H-4), 76.41 (*anti*, *C*H-4), 45.27 (*anti*, *C*-3), 45.03 (*syn*, *C*-3), 39.62 (*anti*, CH_2-8), 39.56 (*syn*, CH_2-8), 33.80 (*syn*, CH_2-5), 33.29 (*anti*, CH_2-5), 33.26 (*syn*, CH_2-6), 32.93 (*anti*, CH_2-6), 30.68 (*anti*, CH_2-9), 30.56 (*syn*, CH_2-9), 17.81 (*syn*, CH_3-7), 16.7 (*anti*, CH_3-7). HRMS (ESI) *m*/*z* [M+Na]$^+$ Calcd for $C_{21}H_{26}O$: 317.1876; Found: 317.1886. IR (neat) ν (cm^{-1}): 3452, 3063, 3027, 2928, 2862, 1634, 1604, 1496, 1455, 1414, 1377, 1301, 1154, 1032, 1007, 916, 740, 699. HPLC: chiral stationary column: IC, mobile phase: hexane/*i*PrOH = 99/1, 1.0 mL/min, 210 nm, 30 °C, for major diastereoisomer: t_R (major) = 13.1 min, t_R (minor) = 20.0 min, for minor diastereoisomer: t_R (major) = 10.5 min, t_R (minor) = 14.7 min. $[\alpha]^{20}_D$ = –16.9 (*c* 0.83, CH_2Cl_2).

Synthesis of ((3S,4R)-7-chloro-4-methyl-1-phenyl-4-vinylheptan-3-ol (*anti*-**6ae**). The iridium catalyst (0.01 mmol, 10 mol%) was introduced into a Schlenk tube in a glove-box and dissolved in anhydrous and degassed 1,2-DCE (0.9 mL). Next hydrogen gas was gently bubbled directly through the solution (2-3 bubbles per second) via a stainless-steel needle at room temperature. The orange solution rapidly became light yellow color. After 1-2 minutes, bubbling was cased and the solution was degassed by two successive freeze-pump-thaw cycles. After the second cycle, the homoallylic boronate **3e** (0.2 mmol, 2.0 equiv.) was added immediately to the cold solution in one portion. The rubber septum was replaced with a polyethylene stopper and the reaction was stirred at 0 °C for 30 min. Then the appropriate allylic alcohol **1a** (0.1 mmol, 1.0 equiv., in 0.2 mL of 1,2-DCE) was added to the above solution at 0 °C for 10 min. Then the mixture was cooled down to –30 °C and the (*R*)-TRIP catalyst (0.015 mmol, 15 mol%, in 0.1 mL of 1,2-DCE) was added. After stirring at –30 °C for 48 h, the reaction mixture was purified by column chromatography (pentane/diethyl ether 9:1 to 4:1) to afford the corresponding homoallylic alcohol *anti*-**6ae**. This compound was used for determination of the enantiomeric excess. Purification by column chromatography (pentane/diethyl ether 9:1 to 4:1) to afford 6ae as a colorless oil (16.5 mg, 62% yield, 1.3:1 *dr*, 55% ee/ 84% *ee*). TLC: R_f = 0.5 (pentane/diethyl ether 4:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) = 7.35 – 7.27 (m, 2H), 7.25 – 7.15 (m, 3H), 5.77 – 5.61 (m, 1H, *H*-2), 5.26 – 5.16 (m, 1H, *H*-1), 5.10 – 5.00 (m, 1H, *H*-1), 3.54 – 3.46 (m, 2H, *H*-10), 3.35 – 3.28 (m, 1H, *H*-4), 2.98 – 2.87 (m, 1H, *H*-6), 2.66 – 2.56 (m, 1H, *H*-6), 1.91 – 1.79 (m, 1H, *H*-5), 1.72 – 1.44 (m, 6H), 0.99 (s, 1.3H, *syn*-isomer *H*-7), 0.96 (s, 1.7H, *anti*-isomer *H*-7). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ (ppm) = 143.48 (*anti*, *C*H-2), 142.94 (*syn*, *C*H-2), 142.30 (*anti*, *C*-Ar), 142.17 (*syn*, *C*-Ar), 128.53 (*anti*, *C*H-Ar), 128.52 (*syn*, *C*H-Ar), 128.44 (*syn*, *C*H-Ar), 128.42 (*anti*, *C*H-Ar), 125.88 (*syn*, *C*H-Ar), 125.86 (*anti*, *C*H-Ar), 115.88 (*anti*, CH_2-1), 115.24 (*syn*, CH_2-1), 77.37 (*syn*, *C*H-4), 76.50 (*anti*, *C*H-4), 45.84 (*syn*, CH_2-10), 45.78 (*anti*, CH_2-10), 44.76 (*anti*, *C*-3), 44.57 (*syn*, *C*-3), 34.39 (*anti*, CH_2-9), 34.37 (*syn*, CH_2-9), 33.71 (CH_2-5), 33.24 (*anti*, CH_2-6), 32.93 (*syn*, CH_2-6), 27.58 (*anti*, CH_2-8), 27.49 (*syn*, CH_2-8), 17.57 (*syn*, CH_3-7), 16.85 (*anti*, CH_3-7). HRMS (ESI) *m*/*z* [M+Na]$^+$ Calcd for $C_{16}H_{23}ClO$: 289.1330; Found: 289.1313. IR (neat) ν (cm^{-1}): 3427, 3027, 2955, 2862, 1636, 1604, 1496, 1454, 1415, 1376, 1308, 1156, 1034, 1007, 967, 917, 748, 699, 649. HPLC: chiral stationary column: AD-H, mobile phase: hexane/*i*PrOH = 99/1, 1.0 mL/min, 210 nm, 30 °C, for major diastereoisomer: t_R (major) = 20.8 min, t_R (minor) = 24.1 min, for minor diastereoisomer: t_R (major) = 26.3 min, t_R (minor) = 33.6 min.

Synthesis of (3S,4R)-7-((tert-butyldimethylsilyl)oxy)-4-methyl-1-phenyl-4-vinylheptan-3-ol (*anti*-**6af**). The iridium catalyst (0.01 mmol, 10 mol%) was introduced into a Schlenk tube in a glove-box and dissolved in anhydrous and degassed 1,2-DCE (0.9 mL). Next hydrogen gas was gently bubbled directly through the solution (2-3 bubbles

per second) via a stainless-steel needle at room temperature. The orange solution rapidly became light yellow color. After 1-2 minutes, bubbling was cased and the solution was degassed by two successive freeze-pump-thaw cycles. After the second cycle, the homoallylic boronate **3f** (0.2 mmol, 2.0 equiv.) was added immediately to the cold solution in one portion. The rubber septum was replaced with a polyethylene stopper and the reaction was stirred at –20 °C for 30 min. Then the appropriate allylic alcohol **1a** (0.1 mmol, 1.0 equiv., in 0.2 mL of 1,2-DCE) was added to the above solution at –20 °C for 30 min. Then the mixture was cooled down to –20 °C and the (*R*)-TRIP catalyst (0.015 mmol, 15 mol%, in 0.1 mL of 1,2-DCE) was added. After stirring at –20 °C for 48 h, the reaction mixture was purified by column chromatography (pentane/diethyl ether 9:1 to 4:1) to afford the corresponding homoallylic alcohol *anti*-**6af**. This compound was deprotected using TBAF (1.0 M in THF) for determination of the enantiomeric excess (*vide infra*). Purification by column chromatography (pentane/diethyl ether 9:1 to 4:1) to afford **6af** as a colorless oil (23 mg, 63% yield, 1.3:1 *dr*, 73% ee/ 88% *ee*). TLC: R_f = 0.5 (pentane/diethyl ether 4:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) = 7.31 – 7.26 (m, 2H), 7.24 – 7.15 (m, 3H), 5.78 – 5.62 (m, 1H, *H*-2), 5.23 – 5.11 (m, 1H, *H*-1), 5.08 – 4.98 (m, 1H, *H*-1), 3.60 – 3.52 (m, 2H, *H*-10), 3.38 – 3.28 (m, 1H, *H*-4), 2.98 – 2.88 (m, 1H, *H*-6), 2.66 – 2.56 (m, 1H, *H*-6), 1.88 – 1.77 (m, 1H, *H*-5), 1.74 – 1.72 (br, 0.45H, *O*-H), 1.63 – 1.56 (m, 1.5H, *H*-5 and *O*-H), 1.46 – 1.31 (m, 4H, *H*-8 and *H*-9), 0.98 (s, 1.3H, *syn*-isomer *H*-7), 0.94 (s, 1.7H, *anti*-isomer *H*-7), 0.89 (s, 9H, *H*-12), 0.06 (s, 6H, *H*-11). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ (ppm) = 144.08 (*anti*, *C*H-2), 143.37 (*syn*, *C*H-2), 142.49 (*anti*, *C*-Ar), 142.41 (*syn*, *C*-Ar), 128.53 (*C*H-Ar), 128.36 (*C*H-Ar), 125.76 (*C*H-Ar), 115.26 (*anti*, CH_2-1), 114.73 (*syn*, CH_2-1), 76.93 (*syn*, *C*H-4), 76.21 (*anti*, *C*H-4), 63.82 (*syn*, CH_2-10), 63.76 (*anti*, CH_2-10), 44.73 (*anti*, *C*-3), 44.51 (*syn*, *C*-3), 33.63, 33.34, 33.31, 33.28, 32.84, 27.37 (*anti*, CH_2-8), 27.19 (*syn*, CH_2-8), 26.00 (CH_3-12), 18.41 (*C*-13), 18.00, 16.83, -5.25 (CH_3-11). HRMS (ESI) *m*/*z* [M+Na]$^+$ Calcd for $C_{22}H_{38}O_2Si$: 385.2534; Found: 385.2520. IR (neat) ν (cm^{-1}): 3476, 2953, 2930, 2858, 1638, 1604, 1496, 1460, 1388, 1254, 1068, 1006, 937, 915, 836, 776, 748, 699. HPLC: The compound *anti*-6af was deprotected using TBAF (1.0 M in THF) for determination of the enantiomeric excess. Chiral stationary column: OD-H, mobile phase: hexane/*i*PrOH = 96/4, 1.0 mL/min, 210 nm, 30 °C, for the major diastereoisomer: t_R (major) = 28.2 min, t_R (minor) = 25.4 min, for the minor diastereoisomer: t_R (major) = 75.1 min, t_R (minor) = 68.6 min.

Synthesis of (3S,4S)-4,8-dimethyl-1-phenyl-4-vinylnon-7-en-3-ol (*syn*-**6ag**). The iridium catalyst (0.01 mmol, 10 mol%) was introduced into a Schlenk tube in a glove-box and dissolved in anhydrous and degassed 1,2-DCE (0.9 mL). Next hydrogen gas was gently bubbled directly through the solution (2-3 bubbles per second) via a stainless-steel needle at room temperature. The orange solution rapidly became light yellow color. After 1-2 minutes, bubbling was cased and the solution was degassed by two successive freeze-pump-thaw cycles. After the second cycle, the homoallylic boronate **3g** (0.2 mmol, 2.0 equiv.) was added immediately to the cold solution in one portion. The rubber septum was replaced with a polyethylene stopper and the reaction was stirred at –20 °C for 30 min. Then the appropriate allylic alcohol **1a** (0.1 mmol, 1.0 equiv., in 0.2 mL of 1,2-DCE) was added to the above solution at –20 °C for 30 min. Then the mixture was cooled down to –30 °C and the (*R*)-TRIP catalyst (0.015 mmol, 15 mol%, in 0.1 mL of 1,2-DCE) was added. After stirring at –30 °C for 48 h, the reaction mixture was purified by column chromatography (pentane/diethyl ether 20:1 to 9:1) to afford the corresponding homoallylic alcohol *syn*-**6ag**. Purification by column chromatography (pentane/diethyl ether 20:1 to 9:1) to afford *syn*-6ag as a colorless oil (18 mg, 66% yield, 19:1 *dr*, 90% *ee*). TLC: R_f = 0.7 (pentane/diethyl ether 4:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) = 7.32 – 7.26 (m, 2H), 7.23 – 7.16 (m, 3H), 5.69 (dd, $^3J_{HH}$ = 17.6, 10.9 Hz, 1H, *H*-2), 5.16 (dd, $^3J_{HH}$ = 10.9, 1.4 Hz, 1H, *H*-1), 5.11 – 5.05 (m, 1H, *H*-10), 5.02 (dd, $^3J_{HH}$ = 17.6, 1.5 Hz, 1H, *H*-1), 3.35 – 3.29 (m, 1H, *H*-4), 2.95 – 2.87 (m, 1H, *H*-6), 2.66 – 2.56 (m, 1H, *H*-6), 1.90 – 1.81 (m, 3H, *H*-5 and *H*-9), 1.67 (s, 3H, *H*-12), 1.57 (s, 3H, *H*-13), 1.56 – 1.50 (m, 1H, *H*-5), 1.42 – 1.35 (m, 3H, *H*-8 and *O*-H), 1.01 (s, 3H, *H*-7). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ (ppm) = 143.3 (*C*H-2), 142.4 (*C*-Ar), 131.4 (*C*-11), 128.5 (*C*H-Ar), 128.4 (*C*H-Ar), 125.8 (*C*H-Ar), 124.8 (*C*H-10), 114.9 (CH_2-1), 77.4 (*C*H-4), 44.9 (*C*-3), 37.3 (CH_2-8), 33.8 (CH_2-5), 33.3 (CH_2-6), 25.7 (CH_3-12), 22.6 (CH_2-9), 17.8 (CH_3-13), 17.6 (CH_3-7). HRMS (ESI) *m*/*z* [M+Na]$^+$ Calcd for $C_{19}H_{28}O$: 295.2033; Found: 295.2044. IR (neat) ν (cm^{-1}): 3414, 3083, 3027, 2967, 2925, 2858, 1637, 1604, 1496, 1454, 1415, 1377, 1072, 1040, 1006, 915, 838, 748, 699. HPLC: Chiral stationary column: AD-H, mobile phase: hexane/*i*PrOH = 99/1, 1.0 mL/min, 210 nm, 30 °C, t_R (major) = 12.8 min, t_R (minor) = 17.7 min. $[\alpha]^{20}_D$ = –33.8 (*c* 1.00, CH_2Cl_2).

Synthesis of 2-((4S,5S)-4-hydroxy-5,9-dimethyl-5-vinyldec-8-en-1-yl)isoindoline-1,3-dione (*syn*-**6bg**). The iridium catalyst (0.01 mmol, 10 mol%) was introduced into a Schlenk tube in a glove-box and dissolved in anhydrous and degassed THF (0.5 mL). Next hydrogen gas was gently bubbled directly through the solution (2-3 bubbles per second) via a stainless-steel needle at room temperature. The orange solution rapidly became light yellow color. After 1-2 minutes, bubbling was cased and the solution was degassed by two successive freeze-pump-thaw cycles. After the second cycle, the homoallylic boronate **3g** (0.4 mmol, 4.0 equiv.) was added immediately to the cold solution in one portion. The rubber septum was replaced with a polyethylene stopper and the reaction was stirred at –20 °C for 15 min. Then the appropriate allylic alcohol (*Z*)-**1b** (0.1 mmol, 1.0 equiv., in 0.2 mL of THF) was added to the above solution at –20 °C for 15 min. After that, the solvent THF was removed slowly under vacuum. Then the mixture was cooled down to –20 °C and the (*R*)-TRIP catalyst (0.015 mmol, 15 mol%, in 1.0 mL of 1,2-DCE) was added. After stirring at –20 °C for 48 h, the reaction mixture was purified by column chromatography (pentane/diethyl ether 6:1 to 2:1) to afford the corresponding homoallylic alcohol *syn*-**6bg**. Purification by column chromatography (pentane/diethyl ether 6:1 to 2:1) to afford *syn*-**6bg** as a

colorless oil (25 mg, 70% yield, 10:1 *dr*, 85% *ee*). TLC: R_f = 0.3 (pentane/diethyl ether 4:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) = 7.84 (dd, $^3J_{HH}$ = 5.4, 3.1 Hz, 2H), 7.71 (dd, $^3J_{HH}$ = 5.5, 3.0 Hz, 2H), 5.78 – 5.64 (m, 1H, *H*-2), 5.14 (dd, $^3J_{HH}$ = 10.9, 1.5 Hz, 1H, *H*-1), 5.11 – 5.05 (m, 1H, *H*-10), 5.04 – 4.97 (m, 1H, *H*-1), 3.71 (t, $^3J_{HH}$ = 7.3 Hz, 2H, *H*-14), 3.36 – 3.29 (m, 1H, *H*-4), 1.98 – 1.91 (m, 1H, *H*-6), 1.90 – 1.83 (m, 2H, *H*-9), 1.75 – 1.68 (m, 1H, *H*-6), 1.66 (s, 3H, *H*-12), 1.64 – 1.57 (m, 2H, *H*-5 and *O*-H), 1.56 (s, 3H, *H*-13), 1.41 – 1.34 (m, 2H, *H*-8), 1.31 – 1.25 (m, 1H, *H*-5), 0.99 (s, 3H, *H*-7, *syn*-isomer), 0.95 (s, 0.3H, *H*-7, *anti*-isomer). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ (ppm) = 168.6 (*C*-15), 143.2 (*C*H-2), 134.0 (*C*H-Ar), 132.1 (*C*-Ar), 131.5 (*C*-11), 124.7 (*C*H-10), 123.3 (*C*H-Ar), 115.0 (CH_2-1), 77.8 (*C*H-4), 45.0 (*C*-3), 38.0 (CH_2-14), 37.3 (CH_2-8), 28.7 (CH_2-6), 26.5 (CH_2-5), 25.8 (CH_3-12), 22.7 (CH_2-9), 17.7 (CH_3-13), 17.5 (CH_3-7). HRMS (ESI) *m/z* $[M+H-H_2O]^+$ Calcd for $C_{22}H_{29}NO_3$: 338.2110; Found: 338.2108. IR (neat) ν (cm^{-1}): 3527, 2928, 2179, 2119, 2040, 2013, 1976, 1959, 1772, 1708, 1439, 1398, 1369, 1188, 1045, 913, 720. HPLC: Chiral stationary column: OD-H, mobile phase: hexane/*i*PrOH = 96/4, 1.0 mL/min, 210 nm, 30 °C, t_R (major) = 17.9 min, t_R (minor) = 40.4 min. $[\alpha]^{20}_D$ = –7.7 (*c* 0.98, CH_2Cl_2).

Synthesis of (4S,5S)-4-hydroxy-5,9-dimethyl-5-vinyldec-8-en-1-yl [1,1'-biphenyl]-4-carboxylate (*syn*-**6ig**). The iridium catalyst (0.01 mmol, 10 mol%) was introduced into a Schlenk tube in a glovebox and dissolved in anhydrous and degassed THF (0.5 mL). Next hydrogen gas was gently bubbled directly through the solution (2-3 bubbles per second) via a stainless-steel needle at room temperature. The orange solution rapidly became light yellow color. After 1-2 minutes, bubbling was cased and the solution was degassed by two successive freeze-pump-thaw cycles. After the second cycle, the homoallylic boronate **3g** (0.4 mmol, 4.0 equiv.) was added immediately to the cold solution in one portion. The rubber septum was replaced with a polyethylene stopper and the reaction was stirred at –20 °C for 15 min. Then the appropriate allylic alcohol (*Z*)-**1i** (0.1 mmol, 1.0 equiv., in 0.2 mL of THF) was added to the above solution at –20 °C for 15 min. After that, the solvent THF was removed slowly under vacuum. Then the mixture was cooled down to –30 °C and the (*R*)-TRIP catalyst (0.015 mmol, 15 mol%, in 1.0 mL of 1,2-DCE) was added. After stirring at –30 °C for 48 h, the reaction mixture was purified by column chromatography (pentane/diethyl ether 9:1 to 5:1) to afford the corresponding homoallylic alcohol *syn*-**6ig**. Purification by column chromatography (pentane/diethyl ether 9:1 to 5:1) to afford *syn*-**6ig** as a colorless oil (34.4 mg, 85% yield, 10:1 *dr*, 86% *ee*). TLC: R_f = 0.3 (pentane/diethyl ether 4:1). ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) = 8.18 – 7.99 (m, 2H), 7.71 – 7.58 (m, 4H), 7.55 – 7.31 (m, 3H), 5.74 (dd, $^3J_{HH}$ = 17.6, 10.9 Hz, 1H, *H*-2), 5.21 – 5.14 (m, 1H, *H*-1), 5.14 – 4.98 (m, 2H, *H*-1 and *H*-10), 4.37 (t, $^3J_{HH}$ = 6.5 Hz, 2H, *H*-14), 3.42 – 3.31 (m, 1H, *H*-4), 2.14 – 2.02 (m, 1H, *H*-6), 1.98 – 1.86 (m, 2H, *H*-6 and *H*-9), 1.86 – 1.70 (m, 2H, *H*-9 and *O*-H), 1.67 (s, 3H, *H*-12), 1.58 (s, 3H, *H*-13), 1.51 – 1.33 (m, 4H, *H*-5 and *H*-8), 1.04 (s, 3H, *H*-7, *syn*-isomer), 0.99 (s, 0.3H, *H*-7, *anti*-isomer). ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$) δ (ppm) = 166.6 (*C*-15), 145.6 (*C*-Ar), 143.3 (*C*H-2), 140.1 (*C*-Ar), 131.5 (*C*-11), 130.1 (*C*H-Ar), 129.2 (*C*-Ar), 128.9 (*C*H-Ar), 128.1 (*C*H-Ar), 127.3 (*C*H-Ar), 127.1 (*C*H-Ar), 124.7 (*C*H-10), 114.9 (CH_2-1), 77.7 (*C*H-4), 65.0 (CH_2-14), 44.9 (*C*-3), 37.4 (CH_2-8), 28.2 (CH_2-6), 26.4 (CH_2-5), 25.7 (CH_3-12), 22.7 (CH_2-9), 17.8 (CH_3-13), 17.6 (CH_3-7). HRMS (ESI) *m/z* $[M+Na]^+$ Calcd for $C_{27}H_{34}O_3$: 429.2401; Found: 429.2393. IR (neat) ν (cm^{-1}): 3520, 2964, 2924,2338, 2233, 2178, 2160, 2045, 2019, 1988, 1715, 1610, 1565, 1487, 1450, 1406, 1380, 1276, 1181, 1116, 1007, 971, 914, 856, 784, 748, 698. HPLC: Chiral stationary column: OD-H, mobile phase: hexane/*i*PrOH = 98/2, 1.0 mL/min, 210 nm, 30 °C, t_R (major) = 23.2 min, t_R (minor) = 38.3 min. $[\alpha]^{20}_D$ = –12.7 (*c* 1.49, CH_2Cl_2).

Synthesis of ((1R,3R)-1-cyclohexyl-4,4-dimethyl-1-phenylhex-5-en-3-ol (**6ja**). The iridium catalyst (*R*)-[Ir] (0.01 mmol, 10 mol%) was introduced into a Schlenk tube in a glove-box and dissolved in anhydrous and degassed THF (0.5 mL). Next hydrogen gas was gently bubbled directly through the solution (2-3 bubbles per second) via a stainless-steel needle at room temperature. The orange solution rapidly became light yellow color. After 5 minutes, bubbling was cased and the solution was degassed by two successive freeze-pump-thaw cycles. After the second cycle, the homoallylic boronate **3a** (0.2 mmol, 2.0 equiv.) was added immediately to the cold solution in one portion. The rubber septum was replaced with a polyethylene stopper and the reaction was stirred at 0 °C for 15 min. Then the appropriate allylic alcohol **1j** (0.1 mmol, 1.0 equiv., in 0.2 mL of THF) was added to the above solution at room temperature for 2 h. After that, the solvent THF was removed slowly under vacuum. Then the mixture was cooled down to –20 °C and the (*S*)-TRIP catalyst (0.01 mmol, 10 mol%, in 1.0 mL of 1,2-DCE) was added. After stirring at –20 °C for 48 h, the reaction mixture was purified by column chromatography (pentane/diethyl ether 15:1 to 8:1) to afford the corresponding homoallylic alcohol **6ja**. Purification by column chromatography (pentane/diethyl ether 15:1 to 8:1) to afford **6ja** as a colorless oil (20 mg, 70% yield, 4.7:1 *dr*, 95% ee/ 96% *ee*). TLC: R_f = 0.8 (pentane/diethyl ether 4:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) = 7.33 – 7.26 (m, 2H), 7.21 – 7.09 (m, 3H), 5.82 (dd, $^3J_{HH}$ = 17.5, 10.9 Hz, 0.2H, *H*-2, *anti*-isomer), 5.68 (dd, $^3J_{HH}$ = 17.5, 10.8 Hz, 1H, *H*-2, *syn*-isomer), 5.07 – 4.95 (m, 2H, *H*-1), 2.84 (dd, $^3J_{HH}$ = 10.5, 4.8 Hz, 1H, *H*-4), 2.67 – 2.59 (m, 1H, *H*-6), 1.93 – 1.86 (m, 1H), 1.81 – 1.65 (m, 3H), 1.63 – 1.57 (m, 2H), 1.46 – 1.30 (m, 3H), 1.27 – 1.02 (m, 4H), 0.91 (s, 6H, *H*-7), 0.83 – 0.74 (m, 1H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ (ppm) = major *syn*-**6ja** isomer; 145.5 (*C*-Ar), 143.9 (*C*H-2), 128.8 (*C*H-Ar), 128.0 (*C*H-Ar), 125.9 (*C*H-Ar), 113.2 (CH_2-1), 75.3 (*C*H-4), 48.4 (*C*H-6), 43.80, 41.5 (*C*-3), 34.1, 31.4, 31.2, 26.6, 22.90 (CH_3-7), 22.05 (CH_3-7). HRMS (ESI) *m/z* $[M+Na]^+$ Calcd for $C_{20}H_{30}O$: 309.2189; Found: 309.2175. IR (neat) ν (cm^{-1}): 3481, 3027, 2925, 2853, 2029, 1637, 1493, 1450, 1380, 1061, 1032, 912, 758, 702. HPLC: Chiral stationary column: OD-H, mobile phase: hexane/*i*PrOH = 99/1, 0.5 mL/min, 210 nm, 30 °C, for major diastereoisomer: t_R (major) = 9.2 min, t_R (minor) = 10.5 min, for minor diastereoisomer: t_R (major) = 11.3 min, t_R (minor) = 12.4 min. $[\alpha]^{20}_D$ = 32.1 (*c* 1.00, CH_2Cl_2).

Synthesis of (4R,6R)-6-(4-methoxyphenyl)-3,3,7-trimethyloct-1-en-4-ol (**6ka**). The iridium catalyst (R)-[Ir]

(0.01 mmol, 10 mol%) was introduced into a Schlenk tube in a glove-box and dissolved in anhydrous and degassed THF (0.5 mL). Next hydrogen gas was gently bubbled directly through the solution (2-3 bubbles per second) via a stainless-steel needle at room tempera-ture. The orange solution rapidly became light yellow color. After 5 minutes, bubbling was cased and the solution was degassed by two successive freeze-pump-thaw cycles. After the second cycle, the homoallylic boronate 3a (0.2 mmol, 2.0 equiv.) was added immediately to the cold solution in one portion. The rubber septum was replaced with a polyethylene stopper and the reaction was stirred at 0 °C for 15 min. Allylic alcohol **1b** (0.1 mmol, 1.0 equiv., in 0.2 mL of THF) was added to the above solution at room temperature for 2 h. After that, the solvent THF was removed slowly under vacuum. Then the mixture was cooled down to –20 °C and the (S)-TRIP catalyst (0.01 mmol, 10 mol%, in 1.0 mL of 1,2-DCE) was added. After stirring at –20 °C for 48 h, the reaction mixture was purified by column chromatography (pentane/diethyl ether 9:1 to 4:1) to afford the corresponding homoallylic alcohol **6ka**. Purification by column chromatography (pentane/diethyl ether 9:1 to 4:1) to afford 6ka as a colorless oil (16 mg, 58% yield, 4.8:1 *dr,* 91% ee/ 94% *ee*). TLC: R_f = 0.6 (pentane/diethyl ether 4:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) = 7.04 – 7.01 (m, 2H), 6.85 – 6.81 (m, 2H), 5.82 (dd, $^3J_{HH}$ = 17.5, 10.9 Hz, 0.2H, *H*-2, *anti*-isomer), 5.69 (dd, $^3J_{HH}$ = 17.5, 10.9 Hz, 1H, *H*-2, *syn*-isomer), 5.07 – 4.96 (m, 2H, *H*-1), 3.80 (s, 3H, *H*-10), 2.86 (dd, $^3J_{HH}$ = 10.5, 1.7 Hz, 1H, *H*-4), 2.55 (td, $^3J_{HH}$ = 7.8, 3.8 Hz, 1H, *H*-6), 1.77 – 1.68 (m, 2H, *H*-5 and *H*-8), 1.66 – 1.58 (m, 1H, *H*-5), 1.34 (br, 1H, *O*-H), 0.97 – 0.85 (m, 9H, *H*-7 and *H*-9), 0.71 (d, $^3J_{HH}$ = 6.8, 3H, *H*-9). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ (ppm) = major *syn*-6ka isomer; 157.7 (*C*-Ar), 145.5 (*C*H-2), 135.7 (*C*-Ar), 129.5 (*C*H-Ar), 113.4 (*C*H-Ar), 113.2 (CH_2-1), 75.3 (*C*H-4), 55.2 (CH_3-10), 48.4 (*C*H-6), 41.5 (*C*-3), 34.5 (CH_2-5), 34.1 (*C*H-8), 22.9 (CH_3-7), 22.1 (CH_3-9), 21.0 (CH_3-9), 20.7 (CH_3-7). IR (neat) n (cm^{-1}): 3481, 3027, 2925, 2853, 2029, 1637, 1493, 1450, 1380, 1061, 1032, 912, 758, 702. HRMS (ESI) *m/z* $[M+Na]^+$ Calcd for $C_{18}H_{28}O_2$: 299.1982; Found: 299.1997. IR (neat) ν (cm^{-1}): 3474, 2958, 2872, 2168, 2029, 1964, 1612, 1511, 1467, 1383, 1246, 1179, 1038, 914, 826, 804, 748. HPLC: Chiral stationary column: AD-H, mobile phase: hexane/*i*PrOH = 99/1, 1.0 mL/min, 210 nm, 30 °C, for major diastereoisomer: t_R (major) = 10.3 min, t_R (minor) = 11.1 min, for minor diastereoisomer: t_R (major) = 9.5 min, t_R (minor) = 13.8 min. $[\alpha]^{20}_D$ = 41.2 (*c* 0.73, CH_2Cl_2).

Synthesis of (1R,3R,4R)-1-cyclohexyl-4,8-dimethyl-1-phenyl-4-vinylnon-7-en-3-ol (*syn*-**6jg**). The iridium catalyst (*R*)-[Ir] (0.01 mmol, 10 mol%) was introduced into a Schlenk tube in a glove-box and dissolved in anhydrous and degassed THF (0.5 mL). Next hydrogen gas was gently bubbled directly through the solution (2-3 bubbles per second) via a stainless-steel needle at room temperature. The orange solution rapidly became light yellow color. After 5 minutes, bubbling was cased and the solution was degassed by two successive freeze-pump-thaw cycles. After the second cycle, the homoallylic boronate **3g** (0.2 mmol, 2.0 equiv.) was added immediately to the cold solution in one portion. The rubber septum was replaced with a polyethylene stopper and the reaction was stirred at 0 °C for 15 min. Then the appropriate allylic alcohol **1j** (0.1 mmol, 1.0 equiv., in 0.2 mL of THF) was added to the above solution at room temperature for 2 h. After that, the solvent THF was removed slowly under vacuum. Then (*S*)-TRIP catalyst (0.01 mmol, 10 mol%, in 1.0 mL of 1,2-DCE) was added. After stirring at room temperature for 48 h, the reaction mixture was purified by column chromatography (pentane/diethyl ether 20:1 to 15:1) to afford the corresponding homoallylic alcohol **6jg**. Purification by column chromatography (pentane/diethyl ether 20:1 to 15:1) to afford pure *syn*-**6jg** as a colorless oil (13 mg, 48% yield, 95% ee). TLC: R_f = 0.6 (pentane/diethyl ether 8:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) = 7.30 – 7.27 (m, 1H), 7.21 – 7.15 (m, 1H), 7.21 – 7.15 (m, 1H), 7.12 – 7.07 (m, 2H), 5.57 (dd, $^3J_{HH}$ = 17.6, 10.9 Hz, 1H, *H*-2), 5.15 – 5.09 (m, 1H, *H*-1), 5.06 – 5.00 (m, 1H, *H*-10), 4.99 – 4.92 (m, 1H, *H*-1), 2.87 (dd, $^3J_{HH}$ = 10.7, 6.4 Hz, 1H, *H*-4), 2.61 (ddd, $^3J_{HH}$ = 11.6, 7.6, 3.6 Hz, 1H, *H*-6), 1.92 – 1.88 (m, 1H), 1.81 – 1.67 (m, 5H), 1.65 (s, 3H, *H*-12), 1.62 – 1.57 (m, 2H), 1.52 (s, 3H, *H*-13), 1.43 – 1.36 (m, 2H), 1.31 – 1.20 (m, 4H), 1.11 – 1.03 (m, 2H), 0.96 – 0.88 (m, 4H), 0.82 – 0.74 (m, 1H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ (ppm) = 143.9 (*C*-Ar), 143.6 (*C*H-2), 131.3 (*C*-11), 128.8 (*C*H-Ar), 128.0 (*C*H-Ar), 125.9 (*C*H-Ar), 124.9 (*C*H-10), 114.4 (CH_2-1), 75.1 (*C*H-4), 48.5 (*C*H-6), 44.7 (*C*-3), 43.7 (*C*H-14), 37.1, 34.4, 31.4, 31.2, 26.60, 26.58, 26.56, 25.7 (CH_3-12), 22.6, 17.6 (CH_3-7 and CH_3-13). HRMS (ESI) *m/z* $[M+Na]^+$ Calcd for $C_{25}H_{38}O$: 377.2815; Found: 377.2799. IR (neat) ν (cm^{-1}): 3471, 2924, 2853, 2370, 2304, 2032, 2009, 1493, 1450, 1376, 1271, 1006, 913, 757, 702, 647. HPLC: Chiral stationary column: IA, mobile phase: hexane/*i*PrOH = 99/1, 1.0 mL/min, 210 nm, 23 °C, t_R (major) = 9.1 min, t_R (minor) = 7.0 min. $[\alpha]^{20}_D$ = 20.0 (*c* 0.64, CH_2Cl_2).

Synthesis of (**6la**). The iridium catalyst (0.005 mmol, 5 mol%) was introduced into a Schlenk tube in a glove-box and dissolved in anhydrous and degassed THF (0.5 mL). Next hydrogen gas was gently bubbled directly through the solution (2-3 bubbles per second) via a stainless-steel needle at room temperature. The orange solution rapidly became light yellow color. After 1-2 minutes, bubbling was cased and the solution was degassed by two successive freeze-pump-thaw cycles. After the second cycle, the homoallylic boronate **3a** (0.2 mmol, 2.0 equiv.) was added immediately to the cold solution in one portion. The rubber septum was replaced with a polyethylene stopper and the reaction was stirred at 0 °C for 15 min. Then the appropriate allylic alcohol **1l** (0.1 mmol, 1.0 equiv., in 0.4 mL of THF) was added to the above solution at 0 °C for 15 min. After that, the solvent THF was removed slowly under vacuum. Then the mixture was cooled down to –20 °C and the (*R*)-TRIP catalyst (0.01 mmol, 10 mol%, in 1.0 mL of 1,2-DCE) was added. After stirring at –20 °C for 48 h, the reaction mixture was purified by preparative TLC (pentane/acetone 4:1) to afford the corresponding homoallylic alcohol **6la**. Purification by preparative TLC (pentane/acetone 4:1) to afford **6la** as a white solid (16 mg, 40% yield, 19:1 *dr*). TLC: R_f = 0.3 (pentane/acetone 4:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) = 5.81 (dd, $^3J_{HH}$ = 17.5, 10.8 Hz, 1H, *H*-2), 5.35 (dd, $^3J_{HH}$ = 5.0, 2.6 Hz, 1H, *H*-8), 5.12 –

4.99 (m, 2H, *H*-1), 3.52 (tt, $^3J_{HH}$ = 10.8, 4.8 Hz, 1H, *H*-10), 3.22 (dd, $^3J_{HH}$ = 10.2, 1.8 Hz, 1H, *H*-4), 2.34 – 2.20 (m, 2H), 2.02 – 1.92 (m, 1H), 1.88 – 1.70 (m, 5H), 1.63 – 1.38 (m, 10H), 1.26 – 1.08 (m, 5H), 1.03 – 0.92 (m, 12H), 0.59 (s, 3H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ (ppm) = 145.5 (*C*H-2), 140.8 (*C*-9), 121.7 (*C*H-8), 113.4 (CH_2-1), 79.1 (*C*H-4), 71.8 (*C*H-10), 56.1, 51.2, 50.5, 42.3, 42.1, 41.8, 37.9, 37.3, 36.6, 32.0, 31.9, 31.7, 30.6, 28.6, 28.0, 24.7, 23.3, 21.9, 20.9, 19.5, 12.4. HRMS (ESI) *m/z* $[M+Na]^+$ Calcd for $C_{27}H_{44}O_2$: 423.3234; Found: 423.3225. IR (neat) ν (cm^{-1}): 3580, 3283, 2931, 2862, 2359, 2052, 1639, 1450, 1415, 1376, 1251, 1195, 1060, 1034, 1006, 977, 954, 914, 878, 838, 799, 739, 690. $[\alpha]^{20}_D$ = −47.0 (*c* 0.80, CH_2Cl_2).

Synthesis of (**6ma**). The iridium catalyst (0.0025 mmol, 5 mol%) was introduced into a Schlenk tube in a glove-box and dissolved in anhydrous and degassed THF (0.5 mL). Next hydrogen gas was gently bubbled directly through the solution (2-3 bubbles per second) via a stainless-steel needle at room temperature. The orange solution rapidly became light yellow color. After 1-2 minutes, bubbling was cased and the solution was degassed by two successive freeze-pump-thaw cycles. After the second cycle, the homoallylic boronate **3a** (0.1 mmol, 2.0 equiv.) was added immediately to the cold solution in one portion. The rubber septum was replaced with a polyethylene stopper and the reaction was stirred at 0 °C for 15 min. Then the appropriate allylic alcohol **1m** (0.05 mmol, 1.0 equiv., in 0.2 mL of THF) was added to the above solution at rt for 30 min. After that, the solvent THF was removed slowly under vacuum. Then the mixture was cooled down to −20 °C and the (*S*)-TRIP catalyst (0.005 mmol, 10 mol%, in 0.5 mL of 1,2-DCE) was added. After stirring at −20 °C for 48 h, the reaction mixture was purified by column chromatography (pentane/diethyl ether 9:1 to 5:1) to afford the corresponding homoallylic alcohol **6ma**. Purification by column chromatography (pentane/diethyl ether 9:1 to 5:1) to afford 6ma as a colorless oil (16 mg, 64% yield, 19:1 *dr*). TLC: R_f = 0.5 (pentane/diethyl ether 4:1). ^1H NMR (400 MHz, $CDCl_3$) δ (ppm) = 7.26 – 7.21 (m, 2H), 7.19 – 7.13 (m, 3H), 5.61 (dd, $^3J_{HH}$ = 17.5, 10.8 Hz, 1H, *H*-2), 5.36 –5.32 (m, 1H, *H*-8), 5.05 – 4.92 (m, 2H, *H*-1), 3.19 – 3.11 (m, 1H, *H*-10), 2.80 – 2.69 (m, 2H, *H*-6 and *H*-4), 2.27 – 2.21 (m, 2H), 2.00 – 1.90 (m, 2H), 1.82 – 1.46 (m, 9H), 1.40 – 1.29 (m, 2H), 1.16 – 1.04 (m, 3H), 1.01 – 0.93 (m, 2H), 0.90 – 0.82 (m, 9H), 0.82 – 0.74 (m, 1H), 0.68 (s, 3H), 0.53 (td, $^3J_{HH}$ = 12.7, 4.9 Hz, 1H), 0.32 (dt, $^3J_{HH}$ = 12.9, 3.5 Hz, 1H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ (ppm) = 145.4 (*C*H-2), 144.8 (*C*-Ar), 139.9 (*C*-9), 128.7 (*C*H-Ar), 128.0 (*C*H-Ar), 125.9 (*C*H-Ar), 122.4 (*C*H-8), 113.1 (CH_2-1), 74.5 (*C*H-4), 61.1 (*C*H-10), 56.5, 56.2, 50.0, 44.5 (*C*H-6), 42.5, 41.3, 38.4, 38.1, 37.5, 37.2, 36.5, 31.8, 31.8, 28.3, 27.9, 24.1, 22.9, 22.0, 20.8, 19.2, 12.3. HRMS (ESI) *m/z* $[M+Na]^+$ Calcd for $C_{33}H_{47}N_3O$: 524.3612; Found: 524.3600. IR (neat) ν (cm^{-1}): 3482, 3026, 2939, 2868, 2094, 1721, 1636, 1455, 1378, 1253, 1069, 1017, 914, 802, 773, 703, 619. $[\alpha]^{20}_D$ = 25.9 (*c* 0.78, CH_2Cl_2).

■ ASSOCIATED CONTENT

Supporting Information. Experimental procedures, characterization of all new compounds. This material is available free of charge via the Internet at http://pubs.acs.org.

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SYNOPSIS TOC