

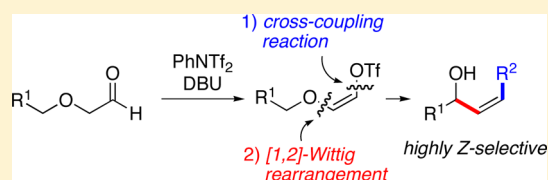
(Z)-Selective Enol Triflation of α -Alkoxyacetaldehydes: Application to Synthesis of (Z)-Allylic Alcohols via Cross-Coupling Reaction and [1,2]-Wittig Rearrangement

Fumiya Kurosawa, Takeo Nakano, Takahiro Soeta, Kohei Endo, and Yutaka Ukaji*

Division of Material Chemistry, Graduate School of Natural Science and Technology, Kanazawa University, Kakuma, Kanazawa, Ishikawa 920-1192, Japan

S Supporting Information

ABSTRACT: The stereoselective transformation of α -alkoxyacetaldehydes to the corresponding (Z)-vinyl triflates was achieved by treatment with phenyl triflimide and DBU. The stereochemistry was explained by the “syn-effect,” which was attributed primarily to an $\sigma \rightarrow \pi^*$ interaction. The β -alkoxy vinyl triflates obtained were applied to the stereoselective synthesis of structurally diverse (Z)-allylic alcohols via transition metal-catalyzed cross-coupling reaction and [1,2]-Wittig rearrangement.



INTRODUCTION

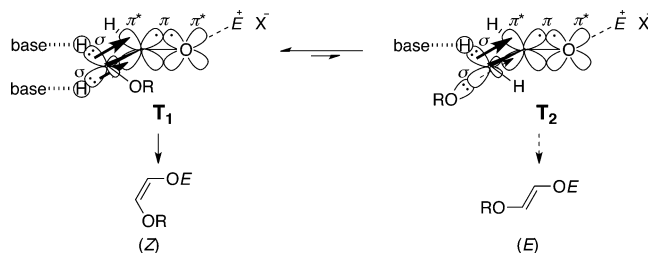
Stereoselective synthesis of alkenes has been studied extensively. The (Z)-alkenes, especially, are versatile two-carbon units present in many biologically active compounds and are useful starting materials for chemical transformations, although their preparation is usually more difficult than that for the E-isomers. One reason is that (Z)-alkenes are generally thermodynamically less stable.¹

Cross-coupling reaction is quite useful method to prepare alkenes stereospecifically from the corresponding vinyl halides. Vinyl triflates have been also used as synthetic intermediates toward transition metal-mediated cross-coupling reactions in addition to vinyl cation and alkylidene carbene precursors.^{2–4} For cross-coupling reactions, stereoselective preparation of (Z)-vinyl triflates is essential for the subsequent transformation to (Z)-alkenes. For 1,3-dicarbonyl compounds, Z-selective preparation of vinyl triflates was achieved.^{2d,5} Chelation-controlled preparation of (Z)-vinyl triflates from α -alkoxy ketones also has been reported.⁶ Recently, Cu-catalyzed electrophilic vinyl triflation of alkynes was reported to afford (Z)-triflates.⁷ For preparation of vinyl triflates from aldehydes, a mixture of (Z)- and (E)-vinyl triflates was formed through the use of triflic anhydride ($\text{ Tf}_2\text{O}$) and 4-methyl-2,6-(di-*t*-butyl)pyridine (DTBMP).⁸ Alternatively, trimethylsilyl enol ethers could be converted to vinyl triflates by treatment with methyllithium and $\text{ Tf}_2\text{O}$;⁹ however, (Z)-selective preparation of trimethylsilyl enol ethers from an aldehyde is then an issue.¹⁰

Previously, a series of isomerization reactions and elimination reactions using a base were performed to investigate the stereochemistry of the isomerized and eliminated products. The results showed that sterically unfavorable (Z)-alkenes were formed predominantly. These results were explained by the action of a “syn-effect,”¹¹ caused primarily by $\sigma \rightarrow \pi^*$ interactions.^{12,13} Oxygen-substituted substrates always produced excellent Z-selectivities. For example, conformation T_1 was preferred to conformation T_2 during deprotonation of α -

alkoxyacetaldehyde due to the low donor ability of the C–O bond compared with the C–H bond, affording the corresponding (Z)-vinyl ethers predominantly as shown in Scheme 1.^{12b}

Scheme 1. Transition State Model for Deprotonation of α -Alkoxyacetaldehydes in the Presence of Triisopropylsilyl Triflate ($\text{ E} = i\text{-Pr}_3\text{Si}$, $\text{ X} = \text{OTf}$)^{12b}



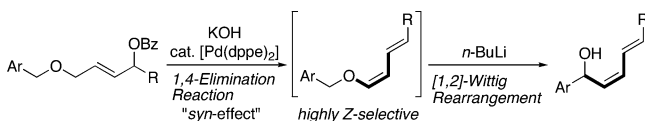
Furthermore, [1,2]-Wittig rearrangement¹⁴ of the resulting (Z)-vinyl ethers proceeded after the initial 1,4-eliminative ring opening reaction of vinyl oxiranes and 1,4-elimination of allylic sulfones and allylic benzoates to give (2Z)-2,4-pentadien-1-ol derivatives in a highly stereoselective manner (Scheme 2).^{12c,e,f} These results demonstrate that the greatest Z-selectivity based on the “syn-effect” for oxygen-substituted substrates could be applied to stereoselective C–C bond formation.

Investigation of isomerization reactions revealed that α -alkoxyacetaldehydes were converted to the corresponding (Z)- β -alkoxy silyl enol ethers with excellent Z-selectivities.^{12b,15} Thus, a (Z)- β -alkoxy vinyl triflate could be prepared if the enolate is trapped by a triflic-cationic species instead of a silyl cation. In addition, the resulting (Z)-vinyl triflate should be accompanied by sequential stereoselective C–C bond for-

Received: March 23, 2015

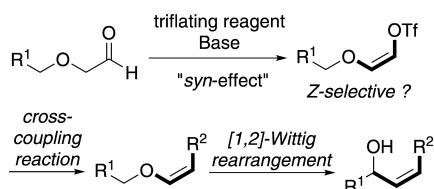
Published: May 13, 2015

Scheme 2. Previous Example of Stereoselective Transformation by the Combination of "Syn-Effect" and [1,2]-Wittig Rearrangement^{12f}



mation via cross-coupling reaction in combination with [1,2]-Wittig rearrangement (Scheme 3). The present report describes the stereoselective enol triflation of α -alkoxyacetaldehydes, followed by cross-coupling reaction and [1,2]-Wittig rearrangement to afford various (*Z*)-allylic alcohols stereoselectively.

Scheme 3. Strategy toward Synthesis of (*Z*)-Allylic Alcohols



RESULTS AND DISCUSSION

First, the enol triflation reaction of (α -benzyloxy)acetaldehyde (**1A**) using triflic anhydride ($\text{ Tf}_2\text{O}$) (1.2 equiv) and 2,6-di-*tert*-butyl-4-methylpyridine (DTBMP) was conducted in CH_2Cl_2 under reflux conditions for 2 d.^{8c} However, very little of the desired vinyl triflate was obtained, while 48% of **1A** was recovered (Table 1, entry 1). The desired vinyl triflate also was not obtained when DBU (2.0 equiv) was used as the base in CH_2Cl_2 at rt (entry 2). When phenyl triflimide (PhNTf_2) was used instead of $\text{ Tf}_2\text{O}$,¹⁶ the reaction proceeded rapidly. The stereoselectivity of the resulting vinyl triflate was high (*Z/E* = 95/5) (entry 3). DBU was chosen as the base because no reaction occurred using other bases such as DTBMP and Et_3N . Other β -benzyloxy-type vinyl triflates **2B–2D** were also obtained stereoselectively from the corresponding α -alkoxyacetaldehydes **1B–1D** (entries 4–6). Furthermore, α -(propargyloxy)acetaldehyde **1E** could be stereoselectively transformed into the corresponding vinyl triflate **2E** stereoselectively (entry 7); using 2.5 equiv of DBU improved the chemical yield (entry 8).

Table 1. Enol Triflation of α -Alkoxyacetaldehydes **1**

entry	R ¹	A	triflating reagent	base	time	yield/%	<i>Z/E</i> ^a
1 ^b	Ph	A	$\text{ Tf}_2\text{O}$	DTBMP	2 d	trace	-
2			$\text{ Tf}_2\text{O}$	DBU	12 h	-	-
3			PhNTf_2	DBU	10 min	84	95/5
4	2-MeC ₆ H ₄	B	PhNTf_2	DBU	10 min	84	95/5
5	4-(MeO)C ₆ H ₄	C	PhNTf_2	DBU	10 min	82	95/5
6	4-ClC ₆ H ₄	D	PhNTf_2	DBU	10 min	88	94/6
7	<i>i</i> -Pr ₃ SiC \equiv C	E	PhNTf_2	DBU	10 min	37	92/8
8 ^c			PhNTf_2	DBU	10 min	71	95/5

^aThe ratios were determined by 400 MHz ¹H NMR spectra. ^bDTBMP (1.2 equiv) under CH_2Cl_2 reflux. ^cDBU (2.5 equiv).

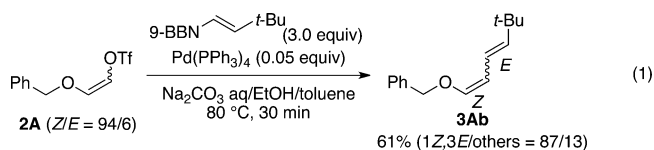
Next, the cross-coupling reaction was investigated using (*Z*)- β -alkoxy vinyl triflate **2**. Introduction of a phenyl group was accomplished via Suzuki–Miyaura coupling with PhB(OH)_2 and using $\text{Pd(PPh}_3)_4$ as a catalyst¹⁷ to give the β -alkoxy styrenes with retention of *Z*-stereochemistry as shown in Table 2.

Table 2. Coupling Reactions of Vinyl Triflates **2**

entry	R ¹	2 (<i>Z/E</i>) ^a	time	3	yield/%	<i>Z/E</i> ^a
1 ^b	Ph	A (94/6)	40 min	Aa	69	95/5
2	2-MeC ₆ H ₄	B (94/6)	30 min	Ba	49	93/7
3	4-MeOC ₆ H ₄	C (94/6)	1 h	Ca	74	95/5
4	4-ClC ₆ H ₄	D (97/3)	20 min	Da	65	95/5
5 ^c	<i>i</i> -Pr ₃ SiC \equiv C	E (95/5)	45 min	Ea	79	97/3

^aThe ratios were determined by 400 MHz ¹H NMR spectra. ^b $\text{Pd(PPh}_3)_4$ (0.03 equiv). ^c $\text{Pd(PPh}_3)_4$ (0.10 equiv) at a reaction temperature of 60 °C.

Suzuki–Miyaura coupling reaction of vinylic borane compounds generated *in situ* was performed as shown in eq 1.¹⁸ The diene **3Ab** was obtained with nearly full retention of stereochemistry.¹⁹



Sonogashira coupling was also examined (Table 3).²⁰ 3,3-Dimethyl-1-butyne was used as a substrate for the transformation to give *Z*-enynes **3Ac** and **3Ec** in high chemical yield with high stereoselectivity.

Next, an alkyl group was introduced via alkyl boron reagent generated *in situ* from styrene and 9-BBN.²¹ However, the reaction was sluggish, and a mixture of the desired product, benzyl vinyl ether, and inseparable byproducts was obtained in poor yield. After intensive investigation, Kumada–Tamao–Corriu coupling reaction of **2A** using *n*-BuMgCl in the presence of $\text{NiCl}_2(\text{dppp})$ ²² resulted in the addition of a primary alkyl

Table 3. Sonogashira Coupling Reaction of Vinyl Triflates 2

entry	R ¹	2 (Z/E) ^a	time	3	yield/%	Z/E ^a
1	Ph	A (95/5)	20 min	Ac	88	95/5
2 ^b	<i>i</i> -Pr ₃ SiC≡C	E (95/5)	1 h	Ec	98	96/4

^aThe ratios were determined by 400 MHz ¹H NMR spectra. ^b3,3-Dimethyl-1-butyne (2 equiv); CuI (0.1 equiv).

group. Although slight isomerization was observed, the corresponding vinyl ether **3Ad** was obtained with high *Z*-selectivity (Table 4, entry 1). In contrast, the coupling reaction of propargyloxy triflate **1E** underwent extensive isomerization to give a ca. 2/1 mixture of **3Ed** (entry 2).

Table 4. Introduction of an Alkyl Group via Kumada–Tamao–Corriu Coupling

entry	R ¹	2 (Z/E) ^a	time	3	yield/%	Z/E ^a
1	Ph	A (94/6)	15 min	Ad	81	91/9
2	<i>i</i> -Pr ₃ SiC≡C	E (95/5)	2 h	Ed	38	68/32

^aThe ratios were determined by 400 MHz ¹H NMR spectra.

After establishing a procedure for addition of substituents via cross-coupling reaction of vinyl triflates **2**, the [1,2]-Wittig rearrangement of vinyl ethers **3** was investigated. For benzyl-type ethereal substrates **3Aa**, **3Ba**, **3Da**, **3Ab**, and **3Ac**, the rearrangement proceeded to give the corresponding (*Z*)-allylic alcohols stereoselectively (Table 5, entries 1, 2, 4, 6, and 7). In the case of (4-methoxyphenyl)methyl ether **3Ca**, a specific reaction conditions were required. When the **3Ca** was treated with *n*-BuLi (3.0 equiv) in THF, the rearrangement did not proceed cleanly and yielded the allylic alcohol **4Ca** in low yield of 19% with 92/8 selectivity. By the addition of *N,N,N',N'*-tetramethylethylenediamine (TMEDA) using an excess amount of *n*-BuLi, **4Ca** was obtained in enhanced chemical yield (entry

3). Although the reaction of propargylic ethers **3Ea** and **3Ec** provided rearranged alcohols at slightly lower chemical yields, excellent *Z*-stereoselectivity was realized (entries 5 and 8). With the use of a vinyl ether with a primary alkyl group at the β-position, treatment with *n*-BuLi gave a complex mixture. In this case, the addition of TMEDA using an excess amount of *n*-BuLi was also effective to realize the rearrangement affording (*Z*)-allylic alcohol **4Ad** in good chemical yield (entry 9).

In summary, a useful synthetic scheme for (*Z*)-allylic alcohols was established based on the novel (*Z*)-selective vinyl-triflation of α-alkoxyacetaldehydes followed by cross-coupling and [1,2]-Wittig rearrangement. This synthetic scheme allowed the preparation of a wide array of structurally diverse (*Z*)-allylic alcohols in a stereoselective manner. These (*Z*)-allylic alcohols are versatile synthetic intermediates for stereospecific transformations such as Katsuki–Sharpless and related epoxidations and Simmons–Smith cyclopropanation.^{23,24} The synthetic method presented here can be used in place of the technique using (*Z*)-allylic alcohols with triple bonds, which could not be prepared by conventional Lindlar reduction of diynols.²⁵

EXPERIMENTAL SECTION

General Method. ¹H NMR spectra were recorded on a 400 MHz NMR spectrometer. Chemical shifts δ are reported in ppm using TMS as an internal standard. Data are reported as follows: chemical shift, multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet), coupling constant (*J*) and integration. ¹³C NMR spectra were recorded on a 100 MHz NMR spectrometer. The chemical shifts are reported relative to CDCl₃ (δ = 77.0 ppm). The wavenumbers of maximum absorption peaks in IR spectra are presented in cm⁻¹. HRMS (EI positive, ESI-TOF) spectra were measured with quadrupole and TOF mass spectrometers. All of the melting points were measured with a micro melting point apparatus. THF was freshly distilled from sodium diphenylketyl. CH₂Cl₂ was distilled and stored over drying agents. Anhydrous CH₃CN was purchased and stored over drying agents.

2-(2-Methylbenzyl)oxyethanol. To a suspension of NaH (2.4 g, 60% in mineral oil, 60 mmol) in THF (160 mL) was added ethylene glycol (10.0 mL, 180 mmol) in THF (40 mL) at 0 °C under N₂ atmosphere. After 30 min of stirring, 1-(chloromethyl)-2-methylbenzene (9.66 g, 60 mmol) in THF (40 mL) and *n*-Bu₄Ni (1.11 g, 1.2 mmol) were added, and the mixture was refluxed for 1 d. Water was added and aqueous layer was separated and extracted with Et₂O. The combined organic extracts were washed with brine, dried over Na₂SO₄, and solvent was removed under reduced pressure. The crude product was purified by silica gel column chromatography (hexane/AcOEt =

Table 5. [1,2]-Wittig Rearrangement of Vinyl Ethers 3 to Allylic Alcohols 4

entry	R ¹	R ²	3 (Z/E) ^a	time	yield/%	Z/E ^a
1	Ph	Ph	Aa (95/5)	15 min	86	98/2
2	2-MeC ₆ H ₄	Ph	Ba (>98/2)	4 min	54	>98/2
3 ^{b,c}	4-MeOC ₆ H ₄	Ph	Ca (95/5)	10 min	47	97/3
4	4-ClC ₆ H ₄	Ph	Da (96/4)	4 min	63	97/3
5	<i>i</i> -Pr ₃ SiC≡C	Ph	Ea (>98/2)	4 min	56	>98/2
6	Ph	<i>t</i> -BuCH=CH	Ab (87/13) ^d	4 min	85	95/5
7	Ph	<i>t</i> -BuC≡C	Ac (93/7)	3 min	49	93/7
8	<i>i</i> -Pr ₃ SiC≡C	<i>t</i> -BuC≡C	Ec (96/4)	4 min	31	>98/2
9 ^{b,c}	Ph	<i>n</i> -Bu	Ad (91/9)	10 min	81	89/11

^aThe ratios were determined by 400 MHz ¹H NMR spectra. ^b*n*-BuLi (8 equiv) and TMEDA (1 equiv) were added. ^cTemperature was adjusted from –78 °C to rt over 10 min. ^dRatio of (1*Z*,3*E*)-isomer/other isomers was 87/13.

3/1) to give 2-((2-methylbenzyl)oxy)ethanol (7.08 g, 64%) as an oil. ^1H NMR (400 MHz, CDCl_3): 2.24 (s, 3H), 2.42 (brs, 2H), 3.46–3.49 (m, 2H), 3.62 (dd, $J = 9.2, 5.5$ Hz, 1H), 4.44 (s, 2H), 7.05–7.14 (m, 3H), 7.19–7.22 (m, 1H). ^{13}C NMR (100 MHz, CDCl_3): 18.7, 61.7, 71.4, 71.5, 125.7, 127.9, 128.6, 130.2, 135.7, 136.6. IR (neat): 3421, 2865, 1459, 1355, 1102, 893, 745 cm^{-1} . HRMS (ESI-TOF): calcd for $\text{C}_{10}\text{H}_{14}\text{O}_2\text{Na}$ [$\text{M} + \text{Na}$] $^+$ 189.0891, found 189.0887.

2-((2-Methylbenzyl)oxy)acetaldehyde (1B). To a solution of oxalyl chloride (1.27 mL, 15 mmol) in CH_2Cl_2 (50 mL) was added DMSO (1.42 mL, 20 mmol) in CH_2Cl_2 (3 mL) at -78°C . After 5 min of stirring, 2-((2-methylbenzyl)oxy)ethanol (1.66 g, 10 mmol) in CH_2Cl_2 (3 mL) was added dropwise. After 15 min, Et_3N (7.0 mL, 50 mmol) was added to the reaction mixture and this was allowed to warm to rt. After 1 h of stirring, the insoluble substrate in the reaction mixture was filtered off through a bed of Celite and solvent was evaporated. The residue was purified by silica gel column chromatography (hexane/AcOEt = 3/1) to give **1B** (1.16 g, 71%) as an oil. ^1H NMR (400 MHz, CDCl_3): 2.28 (s, 3H), 4.00 (d, $J = 0.9$ Hz, 2H), 4.54 (s, 2H), 7.06–7.17 (m, 3H), 7.20–7.23 (m, 1H), 9.61 (t, $J = 0.9$ Hz, 1H). ^{13}C NMR (100 MHz, CDCl_3): 18.7, 71.9, 75.2, 125.8, 128.3, 128.9, 130.4, 134.7, 136.9, 200.5. IR (neat): 3029, 2867, 1736, 1492, 1460, 1376, 1104, 746 cm^{-1} . HRMS (ESI-TOF): calcd for $\text{C}_{10}\text{H}_{14}\text{O}_2\text{Na}$ [$\text{M} + \text{Na}$] $^+$ 187.0735, found 187.0740.

In a similar manner, 2-alkoxyacetaldehyde **1A**,²⁶ **1C**,²⁷ and **1D**²⁸ were prepared from ethylene glycol.

Ethyl 2-((3-(Triisopropylsilyl)prop-2-yn-1-yl)oxy)acetate. To a solution of 3-(triisopropylsilyl)prop-2-yn-1-ol²⁹ (3.19 g, 15 mmol) and HMPA (10.4 mL, 60 mmol) in THF (15 mL) was added MeMgBr (15 mL of 1.0 M solution in THF, 15 mmol) dropwise at 0°C under N_2 atmosphere. After 10 min of stirring, ethyl bromoacetate (2.51 g, 15 mmol) in THF (5 mL) was added, and the resulting solution was warmed 50°C , and stirred for 1 h. The reaction mixture was quenched with a satd aq solution of NaHCO_3 (5 mL). After insoluble substance was filtered off through a bed of Celite, the organic layer was dried over Na_2SO_4 and the solvent was evaporated. The crude product was purified by silica gel column chromatography (hexane/AcOEt = 20/1) to give ethyl 2-((3-(triisopropylsilyl)prop-2-yn-1-yl)oxy)acetate (1.92 g, 49%) as an oil. ^1H NMR (400 MHz, CDCl_3): 1.00 (s, 21H), 1.23 (t, $J = 6.8$ Hz, 3H), 4.16 (s, 2H), 4.17 (q, $J = 6.8$ Hz, 2H), 4.29 (s, 2H). ^{13}C NMR (100 MHz, CDCl_3): 11.0, 14.1, 18.5, 58.9, 60.9, 65.7, 89.1, 101.7, 170.0. IR (neat): 2944, 2865, 2171, 1754, 1463, 1204, 1121, 1000, 883, 677 cm^{-1} . HRMS (EI): calcd for $\text{C}_{16}\text{H}_{30}\text{O}_3\text{Si}$ [M^+] 298.1964, found 298.1981.

2-((3-(Triisopropylsilyl)prop-2-yn-1-yl)oxy)acetaldehyde (1E). To a solution of ethyl 2-((3-(triisopropylsilyl)prop-2-yn-1-yl)oxy)acetate (1.92 g, 7.4 mmol) in toluene (50 mL) was added DIBAL-H (7.4 mL of 1.0 M solution in toluene, 7.4 mmol) dropwise over 5 min at -78°C under N_2 atmosphere. After 5 min, MeOH (7 mL) was added and the reaction mixture was warmed to rt. A satd aq solution of potassium sodium tartrate was added and the resulting mixture was stirred for 3 h. After insoluble substance was filtered off through a bed of Celite, the aqueous layer was separated and extracted with Et_2O . The combined organic extracts were washed with brine and dried over Na_2SO_4 , and the solvent was evaporated. The crude product was purified by silica gel column chromatography (hexane/AcOEt = 6/1) to give **1E** (1.00 g, 53%) as an oil. ^1H NMR (400 MHz, CDCl_3): 1.07 (s, 21H), 4.21 (s, 2H), 4.35 (s, 2H), 9.77 (s, 1H). ^{13}C NMR (100 MHz, CDCl_3): 11.0, 18.5, 59.5, 74.3, 89.5, 101.6, 200.1. IR (neat): 2943, 2891, 2865, 2716, 1739, 1463, 1382, 1366, 1242, 1114, 1009, 883, 678 cm^{-1} . HRMS (EI): calcd for $\text{C}_{14}\text{H}_{26}\text{O}_2\text{Si}$ [M^+] 254.1702, found 254.1706.

(Z)-2-(Benzlyoxy)vinyl Trifluoromethanesulfonate (2A). To a solution of **1A** (597 mg, 4.0 mmol) in CH_2Cl_2 (35 mL) were added DBU (1.21 g, 8.0 mmol) in CH_2Cl_2 (5 mL) and PhNTf_2 (1.71 g, 4.8 mmol) in CH_2Cl_2 (10 mL) at rt under Ar atmosphere. After reaction completion (monitored by TLC), the reaction was quenched with a phosphate buffer solution (pH 7). The aqueous layer was separated and extracted with Et_2O . The combined organic extracts were washed with brine, dried over Na_2SO_4 , and solvent was evaporated. The crude product was purified by silica gel column chromatography (hexane/

AcOEt = 6/1) to give **2A** (948 mg, 84%, $Z/E = 95/5$ mixture from ^1H NMR) as an oil. ^1H NMR (400 MHz, CDCl_3): 4.94 (s, 2H), 6.00 (d, $J = 3.2$ Hz, 1H), 6.04 (d, $J = 3.2$ Hz, 1H), 7.27–7.42 (m, 5H). Selected data of (*E*)-isomer; 4.77 (s, 2H), 6.57 (d, $J = 10.1$ Hz, 1H), 7.01 (d, $J = 10.1$ Hz, 1H). ^{13}C NMR (100 MHz, CDCl_3): 75.3, 118.6 ($J = 320.7$ Hz), 118.9, 123.7, 127.7, 128.7, 129.7, 138.5. IR (neat): 3134, 3067, 3035, 2938, 2883, 1684, 1497, 1421, 1211, 1141 987, 847, 698 cm^{-1} . HRMS (EI): calcd for $\text{C}_{10}\text{H}_9\text{F}_3\text{O}_4\text{S}$ [M^+] 282.0174, found: 282.0170.

In a similar manner, (*Z*)-vinyl triflates **2B–2E** were obtained from **1B–1E**.

(Z)-2-((2-Methylbenzyl)oxy)vinyl Trifluoromethanesulfonate (2B). Compound **2B** (749 mg, 84%, $Z/E = 95/5$) was obtained as an oil from **1B** (493 mg, 3.0 mmol), DBU (913 mg, 6.0 mmol), and PhNTf_2 (1.29 g, 3.6 mmol). ^1H NMR (400 MHz, CDCl_3): 2.36 (s, 3H), 4.95 (s, 2H), 5.99 (d, $J = 3.2$ Hz, 1H), 6.05 (d, $J = 3.2$ Hz, 1H), 7.20–7.30 (m, 4H). Selected data of (*E*)-isomer; 2.33 (s, 3H), 4.77 (s, 2H), 6.60 (d, $J = 10.5$ Hz, 1H), 7.01 (d, $J = 10.5$ Hz, 1H). ^{13}C NMR (100 MHz, CDCl_3): 18.7, 74.0, 118.6 ($J = 320.7$ Hz), 118.9, 126.0, 128.9, 129.0, 130.7, 133.4, 137.1, 138.3. IR (neat): 3136, 3025, 2956, 2890, 1683, 1421, 1352, 1221, 1141, 986, 744, 693 cm^{-1} . HRMS (EI): calcd for $\text{C}_{11}\text{H}_{11}\text{F}_3\text{O}_4\text{S}$ [M^+] 296.0330, found: 296.0336.

(Z)-2-((4-Methoxybenzyl)oxy)vinyl Trifluoromethanesulfonate (2C). Compound **2C** (244 mg, 82%, $Z/E = 95/5$) was obtained as an oil from **1C** (180 mg, 1.0 mmol), DBU (304 mg, 2.0 mmol), and PhNTf_2 (429 mg, 1.2 mmol). ^1H NMR (400 MHz, CDCl_3): 3.82 (s, 3H), 4.86 (s, 2H), 5.97 (d, $J = 3.2$ Hz, 1H), 6.03 (d, $J = 3.2$ Hz, 1H), 6.91 (d, $J = 8.7$ Hz, 2H), 7.27 (d, $J = 8.7$ Hz, 2H). Selected data of (*E*)-isomer; 4.69 (s, 2H), 6.55 (d, $J = 10.1$ Hz, 1H), 6.99 (d, $J = 10.1$ Hz, 1H). ^{13}C NMR (100 MHz, CDCl_3): 55.2, 75.1, 114.1, 118.6 ($J = 320.7$ Hz), 118.8, 127.6, 129.6, 138.3, 159.9. IR (neat): 3135, 3005, 2941, 2840, 1684, 1614, 1517, 1420, 1246, 1211, 1142, 825, 692 cm^{-1} . HRMS (EI): calcd for $\text{C}_{11}\text{H}_{11}\text{F}_3\text{O}_5\text{S}$ [M^+] 312.0279, found: 312.0282.

(Z)-2-((4-Chlorobenzyl)oxy)vinyl Trifluoromethanesulfonate (2D). Compound **2D** (139 mg, 88%, $Z/E = 94/6$) was obtained as an oil from **1D** (92 mg, 0.5 mmol), DBU (152 mg, 1.0 mmol), and PhNTf_2 (214 mg, 0.6 mmol). ^1H NMR (400 MHz, CDCl_3): 4.91 (s, 2H), 6.01 (d, $J = 3.7$ Hz, 1H), 6.02 (d, $J = 3.7$ Hz, 1H), 7.26–7.42 (m, 4H). Selected data of (*E*)-isomer; 4.74 (s, 3H), 6.56 (d, $J = 10.1$ Hz, 1H), 6.99 (d, $J = 10.1$ Hz, 1H). ^{13}C NMR (100 MHz, CDCl_3): 74.5, 118.6 ($J = 320.7$ Hz), 119.2, 128.9, 129.0, 129.7, 134.0, 138.4. IR (neat): 3321, 3134, 2942, 2884, 1684, 1600, 1495, 1211, 1142, 966, 812, 693 cm^{-1} . HRMS (EI): calcd for $\text{C}_{10}\text{H}_8\text{ClF}_3\text{O}_4\text{S}$ [M^+] 315.9784, found: 315.9786.

(Z)-2-((3-(Triisopropylsilyl)prop-2-yn-1-yl)oxy)vinyl Trifluoromethanesulfonate (2E). Compound **2E** (82 mg, 71%, $Z/E = 95/5$) was obtained as an oil from **1E** (76 mg, 0.3 mmol), DBU (114 mg, 0.75 mmol), and PhNTf_2 (129 mg, 0.36 mmol). ^1H NMR (400 MHz, CDCl_3): 1.07 (s, 21H), 4.55 (s, 2H), 6.10 (d, $J = 3.2$ Hz, 1H), 6.23 (d, $J = 3.2$ Hz, 1H). Selected data of (*E*)-isomer; 4.47 (s, 2H), 6.66 (d, $J = 10.1$ Hz, 1H), 6.96 (d, $J = 10.1$ Hz, 1H). ^{13}C NMR (100 MHz, CDCl_3): 11.0, 18.4, 61.1, 91.4, 99.9, 118.7 ($J = 320.7$ Hz), 119.6, 136.9. IR (neat): 3137, 2946, 2868, 2170, 1685, 1425, 1245, 1117, 1045, 1009, 951, 883, 845, 706, 681 cm^{-1} . HRMS (EI): calcd for $\text{C}_{15}\text{H}_{25}\text{F}_3\text{O}_4\text{SSi}$ [M^+] 386.1195, found: 386.1169.

(Z)-2-(Benzlyoxy)vinylbenzene (3Aa).³⁰ To a solution of **2A** (282 mg, 1.0 mmol, $Z/E = 94/6$) in toluene (15 mL) and EtOH (2.5 mL) was added 2 M aq solution of Na_2CO_3 (15 mL). After $\text{Pd}(\text{PPh}_3)_4$ (37 mg, 0.03 mmol) and $\text{PhB}(\text{OH})_2$ (156 mg, 1.3 mmol) were added, the reaction mixture was stirred at 80°C for 30 min under Ar atmosphere.^{17b} The reaction mixture was cooled to rt and insoluble substance was filtered off through a bed of Celite. The aqueous layer of the filtrate was separated and extracted with Et_2O . The combined organic extracts were washed with water and brine, dried over Na_2SO_4 , and solvent was evaporated. The crude product was purified by silica gel column chromatography (hexane/AcOEt = 20/1) to give **3Aa** (144 mg, 69%, $Z/E = 95/5$) as an oil. ^1H NMR (400 MHz, CDCl_3): 5.00 (s, 2H), 5.27 (d, $J = 6.9$ Hz, 1H), 6.29 (d, $J = 6.9$ Hz, 1H), 7.06–7.39 (m, 8H), 7.63 (d, $J = 7.3$ Hz, 2H). Selected data of (*E*)-isomer; 4.91 (s, 2H), 5.96 (d, $J = 12.8$ Hz, 1H), 7.08 (d, $J = 12.8$ Hz, 1H). ^{13}C NMR

(100 MHz, CDCl₃): 74.9, 106.3, 125.8, 127.2, 128.0, 128.2, 128.3, 128.6, 135.8, 137.2, 146.2.

In a similar manner, (*Z*)-vinyl ethers **3Ba**–**3Ea** were obtained from **2B**–**2E**.

(Z)-1-Methyl-2-((styryloxy)methyl)benzene (3Ba). Compound **3Ba** (55 mg, 49%, *Z/E* = 93/7) was obtained as an oil from **2B** (148 mg, 0.50 mmol, *Z/E* = 94/6), Pd(PPh₃)₄ (29 mg, 0.025 mmol), and PhB(OH)₂ (79 mg, 0.65 mmol). ¹H NMR (400 MHz, CDCl₃): 2.38 (s, 3H), 4.99 (s, 2H), 5.26 (d, *J* = 7.4 Hz, 1H), 6.30 (d, *J* = 7.4 Hz, 1H), 7.12–7.38 (m, 7H), 7.61 (d, *J* = 7.4 Hz, 2H). Selected data of (*E*)-isomer; 2.33 (s, 3H), 4.89 (s, 2H), 5.98 (d, *J* = 12.8 Hz, 1H). ¹³C NMR (100 MHz, CDCl₃): 18.9, 73.6, 106.1, 125.7, 126.0, 128.18, 128.22, 128.27, 128.29, 130.4, 135.1, 135.9, 136.5, 146.2. IR (neat): 3024, 2927, 1650, 1493, 1447, 1365, 1265, 1120, 1086, 779, 746, 694 cm⁻¹. HRMS (EI): calcd for C₁₆H₁₆O [M⁺] 224.1201, found 224.1200.

(Z)-1-Methoxy-4-((styryloxy)methyl)benzene (3Ca). Compound **3Ca** (156 mg, 74%, *Z/E* = 95/5) was obtained as an oil from **2C** (260 mg, 0.88 mmol, *Z/E* = 94/6), Pd(PPh₃)₄ (51 mg, 0.04 mmol), and PhB(OH)₂ (139 mg, 1.14 mmol). ¹H NMR (400 MHz, CDCl₃): 3.81 (s, 3H), 4.92 (s, 2H), 5.25 (d, *J* = 7.3 Hz, 1H), 6.28 (d, *J* = 7.3 Hz, 1H), 6.91 (d, *J* = 8.7 Hz, 2H), 7.12–7.46 (m, 5H), 7.60 (d, *J* = 8.7 Hz, 2H). Selected data of (*E*)-isomer; 3.78 (s, 3H), 4.83 (s, 2H), 5.95 (d, *J* = 12.8 Hz, 1H). ¹³C NMR (100 MHz, CDCl₃): 55.3, 74.6, 106.1, 113.9, 125.7, 128.16, 128.24, 129.0, 129.2, 135.9, 146.1, 159.5. IR (neat): 3031, 2933, 2836, 1650, 1613, 1513, 1447, 1366, 1250, 1174, 1031, 823, 780, 696 cm⁻¹. HRMS (EI): calcd for C₁₆H₁₆O₂ [M⁺] 240.1150, found 240.1143.

(Z)-1-Chloro-4-((styryloxy)methyl)benzene (3Da). Compound **3Da** (79 mg, 65%, *Z/E* = 95/5) was obtained as an oil from **2D** (190 mg, 0.60 mmol, *Z/E* = 97/3), Pd(PPh₃)₄ (35 mg, 0.03 mmol), and PhB(OH)₂ (95 mg, 0.78 mmol). ¹H NMR (400 MHz, CDCl₃): 4.93 (s, 2H), 5.28 (d, *J* = 7.3 Hz, 1H), 6.23 (d, *J* = 7.3 Hz, 1H), 7.13–7.36 (m, 7H), 7.60 (d, *J* = 7.3 Hz, 2H). Selected data of (*E*)-isomer; 4.87 (s, 2H), 5.95 (d, *J* = 12.8 Hz, 1H), 7.05 (d, *J* = 12.8 Hz, 1H). ¹³C NMR (100 MHz, CDCl₃): 74.1, 106.7, 125.9, 127.1, 128.2, 128.3, 128.5, 128.8, 133.8, 135.6, 145.9. IR (neat): 3085, 3031, 2928, 2972, 1651, 1600, 1492, 1447, 1403, 1365, 1266, 1200, 1088, 1014, 806, 779, 695 cm⁻¹. HRMS (EI): calcd for C₁₅H₁₃ClO [M⁺] 244.0655, found 244.0656.

(Z)-Triisopropyl(3-((styryloxy)prop-1-yn-1-yl)silane (3Ea). Compound **3Ea** (74 mg, 79%, 97/3) was obtained as an oil from **2E** (116 mg, 0.3 mmol, *Z/E* = 95/5), Pd(PPh₃)₄ (35 mg, 0.03 mmol, 10 mol %), and PhB(OH)₂ (48 mg, 0.39 mmol). ¹H NMR (400 MHz, CDCl₃): 1.07 (s, 21H), 4.56 (s, 2H), 5.34 (d, *J* = 6.8 Hz, 1H), 6.37 (d, *J* = 6.8 Hz, 1H), 7.13–7.16 (m, 1H), 7.24–7.36 (m, 2H), 7.58–7.61 (m, 2H). Selected data of (*E*)-isomer; 4.54 (s, 2H), 5.99 (d, *J* = 12.8 Hz, 1H). ¹³C NMR (100 MHz, CDCl₃): 11.1, 18.5, 60.4, 89.4, 101.8, 107.3, 125.9, 128.1, 128.4, 135.6, 144.6. IR (neat): 2942, 2864, 2725, 2174, 1652, 1493, 1462, 1450, 1356, 1274, 1086, 1034, 999, 883, 777, 693, 678, 666 cm⁻¹. HRMS (EI): calcd for C₂₀H₃₀OSi [M⁺] 314.2066, found 314.2070.

(((1Z,3E)-5,5-Dimethylhexa-1,3-dien-1-yl)oxy)methyl)benzene (3Ab). To a solution of 3,3-dimethyl-1-butyne (123 mg, 1.5 mmol) in THF (1 mL) was added 9-BBN (3.0 mL of 0.5 M solution in THF, 1.5 mmol) and stirred 1 d.¹⁸ To the solution, 2 M aq solution of Na₂CO₃ (5 mL) and **2A** (141 mg, 0.5 mmol, *Z/E* = 94/6) in THF (1 mL), and Pd(PPh₃)₄ (29 mg, 0.025 mmol), in EtOH (1 mL) were added and the reaction mixture was stirred at 80 °C for 30 min. The reaction mixture was cooled to rt and insoluble substance was filtered off through a bed of Celite. The aqueous layer of the filtrate was separated and extracted with Et₂O. The combined organic extracts were washed with water and brine, dried over Na₂SO₄, and solvent was evaporated. The crude product was purified by silica gel column chromatography (hexane/benzene = 1/1) to give **3Ab** (59 mg, 61%, 1Z,3E/others = 87/13) as an oil. ¹H NMR (400 MHz, CDCl₃): 1.04 (s, 9H), 4.85 (s, 2H), 5.07 (dd, *J* = 6.0, 11.0 Hz, 1H), 5.60 (d, *J* = 15.6 Hz, 1H), 5.96 (d, *J* = 6.0 Hz, 1H), 6.36 (dd, *J* = 11.0, 15.6 Hz, 1H), 7.24–7.35 (m, 5H). ¹³C NMR (100 MHz, CDCl₃): 29.7, 33.2, 74.0, 108.0, 117.6, 127.4, 127.9, 128.5, 137.4, 142.7, 144.0. IR (neat): 3034,

2959, 2863, 1654, 1615, 1455, 1365, 1285, 1267, 1194, 1131, 1090, 1071, 975, 734 cm⁻¹. HRMS (EI): calcd for C₁₅H₂₀O [M⁺] 216.1514, found 216.1509.

(Z)-(((5,5-Dimethylhex-1-en-3-yn-1-yl)oxy)methyl)benzene (3Ac). To a solution of Et₃N (252 mg, 2.5 mmol), 3,3-dimethyl-1-butyne (62 mg, 0.75 mmol), and **2A** (141 mg, 0.5 mmol, *Z/E* = 95/5) in MeCN (1 mL) was added Pd(PPh₃)₄ (29 mg, 0.025 mmol) in MeCN (1 mL) and CuI (5 mg, 0.026 mmol) at rt under Ar atmosphere and the reaction mixture was stirred at 60 °C for 20 min.^{20b} The reaction mixture was cooled to rt, insoluble substance was filtered off through a bed of Celite, and solvent of the filtrate was evaporated. The crude product was purified by silica gel column chromatography (hexane/AcOEt = 10/1) to give **3Ac** (94 mg, 88%, *Z/E* = 95/5) as an oil. ¹H NMR (400 MHz, CDCl₃): 1.27 (s, 9H), 4.55 (d, *J* = 6.4 Hz, 1H), 4.97 (s, 2H), 6.29 (d, *J* = 6.4 Hz, 1H), 7.28–7.36 (m, 5H). Selected data of (*E*)-isomer; 1.23 (s, 9H), 4.78 (s, 2H), 5.01 (d, *J* = 12.8 Hz, 1H), 6.83 (d, *J* = 12.8 Hz, 1H). ¹³C NMR (100 MHz, CDCl₃): 28.2, 31.1, 72.9, 74.0, 86.8, 102.1, 127.2, 127.9, 128.5, 137.0, 153.2. IR (neat): 3065, 3034, 2967, 2927, 2866, 2222, 1632, 1455, 1364, 1264, 1123, 1051, 730, 696 cm⁻¹. HRMS (EI): calcd for C₁₅H₁₈O [M⁺] 214.1358, found 214.1359.

In a similar manner, (*Z*)-vinyl ethers **3Ec** were obtained from **2E**.

(Z)-3-(((5,5-Dimethylhex-1-en-3-yn-1-yl)oxy)prop-1-yn-1-yl)triisopropylsilane (3Ec). Compound **3Ec** (88 mg, 98%, *Z/E* = 96/4) was obtained as an oil from **2E** (116 mg, 0.3 mmol, *Z/E* = 95/5), Et₃N (152 mg, 1.5 mmol), 3,3-dimethyl-1-butyne (49 mg, 0.6 mmol), Pd(PPh₃)₄ (20 mg, 0.017 mmol), and CuI (6 mg, 0.03 mmol). ¹H NMR (400 MHz, CDCl₃): 1.07 (s, 21H), 1.26 (s, 9H), 4.54 (s, 2H), 4.61 (d, *J* = 6.4 Hz, 1H), 6.45 (d, *J* = 6.4 Hz, 1H). Selected data of (*E*)-isomer; 4.42 (s, 2H), 5.03 (d, *J* = 12.8 Hz, 1H), 6.76 (d, *J* = 12.8 Hz, 1H). ¹³C NMR (100 MHz, CDCl₃): 11.0, 18.5, 28.2, 31.1, 60.1, 72.6, 87.4, 89.7, 101.3, 102.2, 151.5. IR (neat): 3043, 2965, 2944, 2866, 2726, 2230, 2176, 1634, 1564, 1462, 1359, 1264, 1229, 1115, 1028, 998, 883, 727, 678 cm⁻¹. HRMS (EI): calcd for C₂₀H₃₄OSi [M⁺] 318.2379, found 318.2370.

(Z)-((Hex-1-en-1-yloxy)methyl)benzene (3Ad). To a solution of **2A** (141 mg, 0.5 mmol, *Z/E* = 94/6) in toluene (3 mL) were added NiCl₂(dppp) (28 mg, 0.05 mmol) and *n*-BuMgCl (1.1 mL of 0.91 M solution in THF, 1.0 mmol) and the reaction mixture was stirred at rt for 30 min under Ar atmosphere.^{22d} The reaction was quenched with a satd aq solution of NH₄Cl and insoluble substance was filtered off through a bed of Celite. The aqueous layer of the filtrate was separated and extracted with Et₂O. The combined organic extracts were washed with water and brine, dried over Na₂SO₄, and solvent was evaporated. The crude product was purified by silica gel column chromatography (hexane/AcOEt = 10/1) to give **3Ad** (77 mg, 81%, *Z/E* = 91/9) as an oil. ¹H NMR (400 MHz, CDCl₃): 0.87–0.91 (m, 3H), 1.25–1.37 (m, 4H), 2.09–2.15 (m, 2H), 4.39 (dt, *J* = 6.0, 7.3 Hz, 1H), 4.79 (s, 2H), 6.00 (dt, *J* = 6.0, 1.4 Hz, 1H), 7.26–7.36 (m, 5H). Selected data of (*E*)-isomer; 1.90–1.95 (m, 2H), 4.71 (s, 2H), 4.88 (dt, *J* = 12.8, 7.3 Hz, 1H), 6.32 (d, *J* = 12.8 Hz, 1H). ¹³C NMR (100 MHz, CDCl₃): 13.9, 22.3, 23.7, 31.9, 73.5, 108.0, 127.2, 127.7, 128.4, 137.8, 144.3. IR (neat): 3065, 3031, 2956, 2926, 2871, 1668, 1463, 1362, 1271, 1209, 1129, 1095, 1027, 732, 695 cm⁻¹. HRMS (EI): calcd for C₁₃H₁₈O [M⁺] 190.1358, found 190.1362.

In a similar manner, vinyl ethers **3Ed** were obtained from **2E**.

3-((Hex-1-en-1-yloxy)prop-1-yn-1-yl)triisopropylsilane (3Ed). Compound **3Ed** (44 mg, 38%, *Z/E* = 68/32) was obtained as an oil from **2E** (77 mg, 0.2 mmol, *Z/E* = 95/5), NiCl₂(dppp) (11 mg, 0.02 mmol), and *n*-BuMgCl (0.43 mL of 0.94 M solution in THF, 0.4 mmol). ¹H NMR (400 MHz, CDCl₃): 0.86–0.91 (m, 3H), 1.07 (s, 21H), 1.30–1.35 (m, 4H), 2.05–2.11 (m, 2H), 4.38 (s, 2H), 4.48 (dt, *J* = 6.4, 7.4 Hz, 1H), 6.06 (d, *J* = 6.4 Hz, 1H). Selected data of (*E*)-isomer; 1.89–1.95 (m, 2H), 4.37 (s, 2H), 4.92 (dt, *J* = 12.4, 7.4 Hz, 1H), 6.24 (d, *J* = 12.4 Hz, 1H). ¹³C NMR (100 MHz, CDCl₃): (*Z*)-isomer; 11.1, 13.9, 18.5, 22.3, 23.6, 31.9, 59.5, 88.3, 102.6, 109.1, 143.0; (*E*)-isomer; 11.1, 13.9, 18.5, 22.0, 27.3, 32.6, 57.4, 88.2, 102.3, 106.3, 144.3. IR (neat): 3035, 2943, 2865, 2175, 1666, 1617, 1463, 1382, 1353, 1274, 1134, 1092, 997, 919, 883, 731, 677 cm⁻¹. HRMS

(ESI-TOF): calcd for $C_{18}H_{34}OSiNa [(M + Na)^+]$ 317.2277, found 317.2268.

(Z)-1,3-Diphenylprop-2-en-1-ol (4Aa).³¹ To a solution of **3Aa** (63 mg, 0.3 mmol, $Z/E = 95/5$) in THF (3 mL) was added *n*-BuLi (0.56 mL of 1.62 M solution in hexane, 0.9 mmol) at 0 °C under Ar atmosphere and the reaction mixture was stirred at 0 °C for 10 min. The reaction was quenched with water. The aqueous layer was separated and extracted with Et_2O . The combined organic extracts were washed with brine, dried over Na_2SO_4 , and solvent was evaporated. The crude product was purified by silica gel column chromatography (hexane/AcOEt = 6/1) to give **4Aa** (48 mg, 86%, $Z/E = 98/2$) as an oil. 1H NMR (400 MHz, $CDCl_3$): 1.97 (brs, 1H), 5.64 (d, $J = 9.2$ Hz, 1H), 5.94 (dd, $J = 11.4, 9.2$ Hz, 1H), 6.70 (d, $J = 11.4$ Hz, 1H), 7.26–7.47 (m, 10H). Selected data of (*E*)-isomer: 5.40 (d, $J = 6.9$ Hz, 1H), 6.39 (dd, $J = 16.0, 6.9$ Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): 70.0, 126.3, 127.5, 127.8, 128.3, 128.7, 128.8, 131.4, 133.2, 136.3, 143.1.

In a similar manner, (*Z*)-allylic alcohols **4Ba**, **4Da**, **4Ea**, **4Ab**, **4Ac**, and **4Ec** were obtained from the corresponding (*Z*)-vinyl ethers **3Ba**, **3Da**, **3Ea**, **3Ab**, **3Ac**, and **3Ec**, respectively.

(Z)-3-Phenyl-1-(*o*-tolyl)prop-2-en-1-ol (4Ba). Compound **4Ba** (28 mg, 54%, $Z/E = >98/2$) was obtained as a solid from **3Ba** (52 mg, 0.23 mmol, $Z/E = >98/2$) and *n*-BuLi (0.42 mL of 1.65 M solution in hexane, 0.69 mmol). Mp 84–86 °C (from AcOEt). 1H NMR (400 MHz, $CDCl_3$): 1.89 (d, $J = 4.1$ Hz, 1H), 2.11 (s, 3H), 5.72 (dd, $J = 4.1, 9.2$ Hz, 1H), 5.89 (dd, $J = 9.2, 11.4$ Hz, 1H), 6.66 (d, $J = 11.4$ Hz, 1H), 7.13–7.37 (m, 8H), 7.58 (d, $J = 7.3$ Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): 18.9, 67.6, 125.4, 126.3, 127.4, 127.6, 128.3, 128.7, 130.6, 131.5, 132.6, 135.6, 136.4, 141.5. IR (KBr): 3274, 3022, 2925, 1492, 1458, 1209, 1039, 997, 870, 770, 751 cm^{-1} . Anal. Calcd for $C_{16}H_{16}O$: C, 85.68; H, 7.19. Found: C, 85.59; H, 7.33.

(Z)-1-(4-Chlorophenyl)-3-phenylprop-2-en-1-ol (4Da). Compound **4Da** (50 mg, 63%, $Z/E = 97/3$) was obtained as an oil from **3Da** (80 mg, 0.33 mmol, $Z/E = 96/4$) and *n*-BuLi (0.61 mL of 1.65 M solution in hexane, 1.0 mmol). 1H NMR (400 MHz, $CDCl_3$): 1.98 (d, $J = 3.2$ Hz, 1H), 5.62 (dd, $J = 9.2, 3.2$ Hz, 1H), 5.87 (dd, $J = 11.5, 9.2$ Hz, 1H), 6.71 (d, $J = 11.5$ Hz, 1H), 7.26–7.39 (m, 9H). Selected data of (*E*)-isomer: 6.33 (dd, $J = 16.0, 6.8$ Hz, 1H), 6.68 (d, $J = 16.0$ Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): 69.4, 127.6, 127.7, 128.4, 128.70, 128.73, 131.8, 132.7, 133.4, 136.1, 141.5. IR (neat): 3337, 3057, 3023, 2927, 1597, 1491, 1446, 1408, 1213, 1091, 1046, 1013, 867, 827, 801, 771, 701 cm^{-1} . HRMS (EI): Calcd for $C_{15}H_{13}ClO [M^+]$ 244.0655, found 244.0652.

(Z)-1-Phenyl-5-(triisopropylsilyl)pent-1-en-4-yn-3-ol (4Ea). Compound **4Ea** (40 mg, 56%, $Z/E = >98/2$) was obtained as an oil from **3Ea** (72 mg, 0.23 mmol, $>98/2$) and *n*-BuLi (0.42 mL of 1.65 M solution in hexane, 0.69 mmol). 1H NMR (400 MHz, $CDCl_3$): 1.01 (s, 21H), 1.97 (d, $J = 5.0$ Hz, 1H), 5.17 (dd, $J = 5.0, 8.7$ Hz, 1H), 5.76 (dd, $J = 8.7, 11.0$ Hz, 1H), 6.55 (d, $J = 11.0$ Hz, 1H), 7.22–7.30 (m, 5H). ^{13}C NMR (100 MHz, $CDCl_3$): 11.1, 18.6, 59.5, 86.9, 107.3, 127.6, 128.3, 129.0, 130.9, 131.2, 136.0. IR (neat): 3343, 3059, 3025, 2942, 2864, 2170, 1494, 1462, 1383, 1026, 883, 701, 677 cm^{-1} . HRMS (EI): Calcd for $C_{20}H_{30}OSi [M^+]$ 314.2066, found 314.2068.

(2Z,4E)-6,6-Dimethyl-1-phenylhepta-2,4-dien-1-ol (4Ab). Compound **4Ab** (47 mg, 85%, $2Z,4E/2E,4E = 95/5$) was obtained as an oil from **3Ab** (55 mg, 0.25 mmol, $1Z,3E/others = 87/13$) and *n*-BuLi (0.45 mL of 1.65 M solution in hexane, 0.75 mmol). 1H NMR (400 MHz, $CDCl_3$): 1.06 (s, 9H), 1.88 (brs, 1H), 5.51 (dd, $J = 10.6, 9.2$ Hz, 1H), 5.72 (d, $J = 9.2, 9.2$ Hz, 1H), 5.83 (d, $J = 15.6$ Hz, 1H), 6.11 (dd, $J = 11.0, 10.6$ Hz, 1H), 6.40 (dd, $J = 15.6, 11.0$ Hz, 1H), 7.26–7.42 (m, 5H). Selected data of (*E,E*)-isomer: 1.02 (s, 9H), 5.96 (dd, $J = 15.6, 10.6$ Hz, 1H), 6.26 (dd, $J = 15.6, 11.0$ Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): 29.4, 33.5, 69.9, 119.5, 125.8, 127.4, 128.5, 130.6, 130.9, 143.4, 149.0. IR (neat): 3340, 3030, 2959, 2901, 2864, 1650, 1602, 1452, 1389, 1362, 1037, 1020, 985, 950, 743, 698 cm^{-1} . HRMS (EI): calcd for $C_{15}H_{20}O [M^+]$ 216.1514, found 216.1515.

(Z)-6,6-Dimethyl-1-phenylhept-2-en-4-yn-1-ol (4Ac). Compound **4Ac** (21 mg, 49%, $Z/E = 93/7$) was obtained as an oil from **3Ac** (43 mg, 0.20 mmol, $Z/E = 93/7$) and *n*-BuLi (0.36 mL of 1.65 M solution in hexane, 0.6 mmol). 1H NMR (400 MHz, $CDCl_3$): 1.29 (s,

9H), 2.18 (d, $J = 3.2$ Hz, 1H), 5.59 (dd, $J = 10.5, 0.9$ Hz, 1H), 5.79 (dd, $J = 8.2, 3.2$ Hz, 1H), 5.99 ($J = 10.5, 8.2$ Hz, 1H), 7.26–7.46 (m, 5H). Selected data of (*E*)-isomer: 1.22 (s, 9H), 5.22–5.24 (m, 1H), 6.19 (dd, $J = 15.6, 6.0$ Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): 28.2, 30.9, 72.0, 75.1, 104.8, 110.4, 125.7, 127.6, 128.5, 142.67, 142.71. IR (neat): 3342, 2968, 2928, 2866, 2213, 1602, 1493, 1475, 1453, 1362, 1266, 1203, 1036, 1003, 854, 744, 698 cm^{-1} . HRMS (EI): calcd for $C_{15}H_{18}O [M^+]$ 214.1358, found 214.1355.

(Z)-8,8-Dimethyl-1-(triisopropylsilyl)nona-4-en-1,6-diy-3-ol (4Ec). Compound **4Ec** (14 mg, 31%, $Z/E = >98/2$) was obtained as an oil from **3Ec** (45 mg, 0.15 mmol, $Z/E = 96/4$) and *n*-BuLi (0.27 mL of 1.65 M solution in hexane, 0.45 mmol). 1H NMR (400 MHz, $CDCl_3$): 1.07 (s, 21H), 1.26 (s, 9H), 2.08 (d, $J = 5.0$ Hz, 1H), 5.37 (dd, $J = 8.3, 5.0$ Hz, 1H), 5.61 (dd, $J = 10.6, 0.9$ Hz, 1H), 5.93 (dd, $J = 10.6, 8.3$ Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): 11.1, 18.6, 28.2, 30.8, 60.7, 74.2, 86.3, 105.8, 106.4, 112.0, 139.4. IR (neat): 3383, 2945, 2865, 2212, 2170, 1616, 1463, 1385, 1363, 1266, 1038, 883, 678 cm^{-1} . HRMS (EI): calcd for $C_{20}H_{34}OSi [M^+]$ 318.2379, found 318.2384.

(Z)-1-(4-Methoxyphenyl)-3-phenylprop-2-en-1-ol (4Ca). To a solution of **3Ca** (21 mg, 0.09 mmol, $Z/E = 95/5$) and N,N,N',N' -tetramethylethylenediamine (TMEDA) (15 μ L, 0.09 mmol) in THF (1 mL) was added *n*-BuLi (0.45 mL of 1.60 M solution in hexane, 0.72 mmol) at –78 °C under Ar atmosphere and the reaction mixture was warmed to rt over 10 min. The reaction was quenched with water. The aqueous layer was separated and extracted with Et_2O . The combined organic extracts were washed with brine, dried over Na_2SO_4 , and solvent was evaporated. The crude product was purified by silica gel column chromatography (hexane/AcOEt = 8/1) to give **4Ca** (10 mg, 47%, $Z/E = 97/3$) as an oil. 1H NMR (400 MHz, $CDCl_3$): 3.82 (s, 3H), 5.60 (d, $J = 9.2$ Hz, 1H), 5.95 (dd, $J = 11.4, 9.2$ Hz, 1H), 6.67 (d, $J = 11.4$ Hz, 1H), 6.91 (d, $J = 8.7$ Hz, 2H), 7.26–7.38 (m, 7H), the signal of OH proton was not clearly observed. Selected data of (*E*)-isomer: 5.25 (d, $J = 6.9$ Hz, 1H), 6.27 (dd, $J = 13.8, 6.9$ Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): 55.3, 69.7, 114.0, 127.4, 127.6, 128.3, 128.8, 130.9, 133.4, 135.4, 136.4, 159.2. IR (neat): 3371, 3057, 3021, 2956, 2934, 2835, 1610, 1509, 1463, 1302, 1247, 1173, 1032, 831, 699 cm^{-1} . HRMS (EI): Calcd for $C_{16}H_{16}O_2 [M^+]$ 240.1150, found 240.1148.

In a similar manner, (*Z*)-allylic alcohol **4Ad** was obtained from the corresponding (*Z*)-vinyl ether **3Ad**.

(Z)-1-Phenylhept-2-en-1-ol (4Ad).²⁵ Compound **4Ad** (57 mg, 81%, $Z/E = 89/11$) was obtained as an oil from **3Ad** (70 mg, 0.37 mmol, $Z/E = 91/9$), TMEDA (54 μ L, 0.36 mmol), and *n*-BuLi in hexane (1.76 mL, 1.65 M solution in hexane, 2.9 mmol). 1H NMR (400 MHz, $CDCl_3$): 0.92 (t, $J = 6.9$ Hz, 3H), 1.30–1.43 (m, 4H), 1.81 (d, $J = 2.7$ Hz, 1H), 2.14–2.30 (m, 2H), 5.52–5.59 (m, 3H), 7.24–7.80 (m, 5H). Selected data of (*E*)-isomer: 2.03–2.09 (m, 2H), 5.17 (d, $J = 6.9$ Hz, 1H), 5.67 (dd, $J = 15.6, 6.9$ Hz, 1H), 5.77 (dt, $J = 15.6, 6.4$ Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): 13.9, 22.3, 27.4, 31.7, 69.7, 125.9, 127.4, 128.5, 131.8, 132.4, 143.7.

■ ASSOCIATED CONTENT

📄 Supporting Information

Copies of 1H NMR and ^{13}C NMR spectra of products. The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.joc.5b00647.

■ AUTHOR INFORMATION

✉ Corresponding Author

*E-mail: ukaji@staff.kanazawa-u.ac.jp

Notes

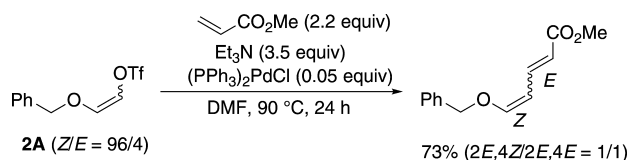
The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

This work was financially supported in part by a Grant-in-Aid for Scientific Research from the Japan Society for the Promotion of Science (JSPS).

REFERENCES

- (1) (a) Siau, W.-Y.; Zhang, Y.; Zhao, Y. *Top. Curr. Chem.* **2012**, 327, 33–58. (b) Oger, C.; Balas, L.; Durand, T.; Galano, J.-M. *Chem. Rev.* **2013**, 113, 1313–1350. Recent examples of stereoselective synthesis of (Z)-alkenes: (c) Zhuo, L.-G.; Yao, Z.-K.; Yu, Z.-X. *Org. Lett.* **2013**, 15, 4634–4637. (d) Chen, C.; Dugan, T. R.; Brennessel, W. W.; Weix, D. J.; Holland, P. L. *J. Am. Chem. Soc.* **2014**, 136, 945–955. (e) Singh, K.; Staig, S. J.; Weaver, J. D. *J. Am. Chem. Soc.* **2014**, 136, 5275–5278. (f) Bronner, S. M.; Herbert, M. B.; Patel, P. R.; Marx, V. M.; Grubbs, R. H. *Chem. Sci.* **2014**, 5, 4091–4098. (g) Koh, M. J.; Khan, R. K. M.; Torker, S.; Yu, M.; Mikus, M. S.; Hoveyda, A. H. *Nature* **2015**, 517, 181–186.
- (2) (a) Stang, P. J. *Acc. Chem. Res.* **1978**, 11, 107–114. (b) Stang, P. J.; Hanack, M.; Subramanian, L. R. *Synthesis* **1982**, 85–126. (c) Baraznenok, I. L.; Nenajdenko, V. G.; Balenkova, E. S. *Tetrahedron* **2000**, 56, 3077–3119. (d) Chassaing, S.; Specklin, S.; Weibel, J.-M.; Pale, P. *Tetrahedron* **2012**, 68, 7245–7273.
- (3) Examples of the reviews of cross-coupling reactions: (a) Miyaura, N.; Suzuki, A. *Chem. Rev.* **1995**, 95, 2457–2483. (b) *Handbook of Organopalladium Chemistry for Organic Synthesis*; Negishi, E., Ed.; John Wiley & Sons, Inc.: New York, 2002. (c) *Palladium-Catalyzed Coupling Reactions*; Molnár, Á., Ed.; Wiley-VCH: Weinheim, 2013. (d) *Metal-Catalyzed Cross-Coupling Reactions and More*; de Meijere, A., Bräse, S., Oestreich, M., Eds.; Wiley-VCH: Weinheim, 2014.
- (4) Cross-coupling reactions of vinyl triflates; reviews: (a) Scott, W. J.; McMurry, J. E. *Acc. Chem. Res.* **1988**, 21, 47–54. (b) Ritter, K. *Synthesis* **1993**, 735–762. (c) Cacchi, S. *Pure Appl. Chem.* **1996**, 68, 45–52. Recent examples: (d) Scheiper, B.; Bonnekessel, M.; Krause, H.; Fürstner, A. *J. Org. Chem.* **2004**, 69, 3943–3949. (e) Shirakawa, E.; Sato, T.; Imazaki, Y.; Kimura, T.; Hayashi, T. *Chem. Commun.* **2007**, 4513–4515. (f) Wu, X.-F.; Neumann, H.; Beller, M. *Angew. Chem., Int. Ed.* **2010**, 49, 5284–5288. (g) Saini, V.; Sigman, M. S. *J. Am. Chem. Soc.* **2012**, 134, 11372–11375. (h) Winkler, C. K.; Clay, D.; Davies, S.; O'Neill, P.; McDaid, P.; Debarge, S.; Stefflik, J.; Karmilowicz, M.; Wong, J. W.; Faber, K. *J. Org. Chem.* **2013**, 78, 1525–1533.
- (5) (a) Xie, H.; Shao, Y.; Becker, J. M.; Naider, F.; Gibbs, R. A. *J. Org. Chem.* **2000**, 65, 8552–8563. (b) Babinski, D.; Soltani, O.; Frantz, D. E. *Org. Lett.* **2008**, 10, 2901–2904. (c) Specklin, S.; Bertus, P.; Weibel, J.-M.; Pale, P. *J. Org. Chem.* **2008**, 73, 7845–7848.
- (6) Sosa, J. R.; Tudjarian, A. A.; Minehan, T. G. *Org. Lett.* **2008**, 10, 5091–5094.
- (7) Suero, M. G.; Bayle, E. D.; Collins, B. S. L.; Gaunt, M. J. *J. Am. Chem. Soc.* **2013**, 135, 5332–5335.
- (8) (a) Stang, P. J.; Treptow, W. *Synthesis* **1980**, 283–284. (b) Martínez, A. G.; Herrera, A.; Martínez, R.; Teso, E.; García, A.; Osio, J.; Pargada, L.; Unanue, R.; Subramanian, L. R.; Hanack, M. *J. Heterocycl. Chem.* **1988**, 25, 1237–1241. (c) Wright, M. E.; Pulley, S. R. *J. Org. Chem.* **1989**, 54, 2886–2889. (d) Sato, Y.; Watanabe, S.; Shibasaki, M. *Tetrahedron Lett.* **1992**, 33, 2589–2592. (e) Niwa, H.; Watanabe, M.; Inagaki, H.; Yamada, K. *Tetrahedron* **1994**, 50, 7385–7400.
- (9) Stang, P. J.; Mangum, M. G.; Fox, D. P.; Haak, P. *J. Am. Chem. Soc.* **1974**, 96, 4562–4569.
- (10) The stereoselective preparation of (Z)-tris(trimethylsilyl)silyl enol ether from propionaldehyde was reported: Boxer, M. B.; Yamamoto, H. *J. Am. Chem. Soc.* **2006**, 128, 48–49.
- (11) The “syn-effect” is herein defined as an effect which stabilizes the syn-conformation against the steric hindrance at the transition state.
- (12) Related representative studies on the “syn-effect”: (a) Hirata, T.; Sasada, Y.; Ohtani, T.; Asada, T.; Kinoshita, H.; Senda, H.; Inomata, K. *Bull. Chem. Soc. Jpn.* **1992**, 65, 75–96. (b) Guha, S. K.; Shibayama, A.; Abe, D.; Sakaguchi, M.; Ukaji, Y.; Inomata, K. *Bull. Chem. Soc. Jpn.* **2004**, 77, 2147–2157. (c) Takeda, N.; Chayama, T.; Takenaka, H.; Ukaji, Y.; Inomata, K. *Chem. Lett.* **2005**, 34, 1140–1141. (d) Inomata, K. *J. Synth. Org. Chem. Jpn.* **2009**, 67, 1172–1182. (e) Horii, S.; Ishimaru, I.; Ukaji, Y.; Inomata, K. *Chem. Lett.* **2011**, 40, 521–523. (f) Nakano, T.; Soeta, T.; Endo, K.; Inomata, K.; Ukaji, Y. *J. Org. Chem.* **2013**, 78, 12654–12661 and references cited therein.
- (13) Stereoselective productions of (Z)-alkenes by elimination or isomerization reactions were reported. (a) Margot, C.; Matsuda, H.; Schlosser, M. *Tetrahedron* **1990**, 46, 2425–2430. (b) Guillam, A.; Maddaluno, J.; Duhamel, L. *J. Chem. Soc., Chem. Commun.* **1996**, 1295–1296. (c) Guillam, A.; Toupet, L.; Maddaluno, J. *J. Org. Chem.* **1998**, 63, 5110–5122. (d) Tayama, E.; Sugai, S. *Synlett.* **2006**, 849–852. (e) Tayama, E.; Sugai, S.; Hara, M. *Tetrahedron Lett.* **2006**, 47, 7533–7535. (f) Pichon, N.; Harrison-Marchand, A.; Toupet, L.; Maddaluno, J. *J. Org. Chem.* **2006**, 71, 1892–1901. (g) Tayama, E.; Hashimoto, R. *Tetrahedron Lett.* **2007**, 48, 7950–7952. (h) Xu, L.; Regnier, T.; Lemiègre, L.; Cardinael, P.; Combret, J.-C.; Bouillon, J.-P.; Blanchet, J.; Rouden, J.; Harrison-Marchand, A.; Maddaluno, J. *Org. Lett.* **2008**, 10, 729–732. (i) Prantz, K.; Mulzer, J. *Angew. Chem., Int. Ed.* **2009**, 48, 5030–5033. (j) Song, Z.; Lei, Z.; Gao, L.; Wu, X.; Li, L. *Org. Lett.* **2010**, 12, 5298–5301. (k) Gan, Z.; Wu, Y.; Gao, L.; Sun, X.; Lei, J.; Song, Z.; Li, L. *Tetrahedron* **2012**, 68, 6928–6934. (l) Tayama, E.; Toma, Y. *Tetrahedron* **2015**, 71, 554–559 and references cited therein.
- (14) (a) Schöllkopf, U. *Angew. Chem., Int. Ed.* **1970**, 9, 763–773. (b) Rautenstrauch, V.; Büchi, G.; Wüest, H. *J. Am. Chem. Soc.* **1974**, 96, 2576–2580. (c) Marshall, J. A. In *Comprehensive Organic Synthesis*; Trost, B. M., Ed.; Pergamon Press: Oxford, 1991; Vol. 3, pp 979–981. (d) Tomooka, K.; Yamamoto, H.; Nakai, T. *Liebigs Ann./Recl.* **1997**, 1275–1281. (e) Tomooka, K. *J. Syn. Org. Chem. Jpn.* **2001**, 59, 322–330. (f) Giampietro, N. C.; Kampf, J. W.; Wolfe, J. P. *J. Am. Chem. Soc.* **2009**, 131, 12556–12557. (g) Giampietro, N. C.; Wolfe, J. P. *Angew. Chem., Int. Ed.* **2010**, 49, 2922–2924 and references cited therein.
- (15) Preference of syn-conformation of aldehydes was also pointed out. For example: (a) Wintner, C. E. *J. Chem. Educ.* **1987**, 64, 587–590. (b) Deslongchamps, G.; Deslongchamps, P. *Org. Biomol. Chem.* **2011**, 9, 5321–5333.
- (16) (a) McMurry, J. E.; Scott, W. J. *Tetrahedron Lett.* **1983**, 24, 979–982. (b) Scott, W. J.; Peña, M. R.; Swärd, K.; Stoessel, S. J.; Stille, J. K. *J. Org. Chem.* **1985**, 50, 2302–2308.
- (17) (a) Miyaura, N.; Yanagi, T.; Suzuki, A. *Synth. Commun.* **1981**, 11, 513–519. (b) Spivey, A. C.; Fekner, T.; Spey, S. E.; Adams, H. *J. Org. Chem.* **1999**, 64, 9430–9443.
- (18) (a) Colberg, J. C.; Rane, A.; Vaquer, J.; Soderquist, J. A. *J. Am. Chem. Soc.* **1993**, 115, 6065–6071. (b) Mjalli, A. M. M.; Polisetti, D. R.; Quada, J. C.; Yarragunta, R. R.; Andrews, R. C.; Xie, R.; Subramanian, G. *PCT Int. Appl.*, 2007089857.
- (19) Although the Heck reaction of the vinyl triflate **2A** with methyl acrylate was examined,³⁴ the serious isomerization occurred to give a ca. 1/1 mixture of the product.³⁵



- (20) (a) Sonogashira, K.; Tohda, Y.; Hagihara, N. *Tetrahedron Lett.* **1975**, 16, 4467–4470. (b) Li, C. C.; Xie, Z. X.; Zhang, Y. D.; Chen, J. H.; Yang, Z. *J. Org. Chem.* **2003**, 68, 8500–8504.

- (21) Oh-e, T.; Miyaura, N.; Suzuki, A. *J. Org. Chem.* **1993**, 58, 2201–2208.

- (22) (a) Tamao, K.; Sumitani, K.; Kumada, M. *J. Am. Chem. Soc.* **1972**, 94, 4374–4376. (b) Corriu, R. J. P.; Masse, J. P. *J. Chem. Soc., Chem. Commun.* **1972**, 144. (c) Tamao, K.; Sumitani, K.; Kiso, Y.; Zembayashi, M.; Fujioka, A.; Kodama, S.; Nakajima, I.; Minato, A.; Kumada, M. *Bull. Chem. Soc. Jpn.* **1976**, 49, 1958–1969. (d) Busacca, C. A.; Eriksson, M. C.; Fiaschi, R. *Tetrahedron Lett.* **1999**, 40, 3101–3104.

- (23) Examples of stereospecific transformation of allylic alcohols: (a) Katsuki, T. In *Comprehensive Asymmetric Catalysis*; Jacobsen, E. N., Pfaltz, A., Yamamoto, H., Eds.; Springer: Berlin, 1999; Chapter 18.1. (b) Adam, W.; Wirth, T. *Acc. Chem. Res.* **1999**, 32, 703–710. (c) Lebel, H.; Marcoux, J.-F.; Molinaro, C.; Charette, A. B. *Chem. Rev.* **2003**, 103,

977–1050. (d) Olivares-Romero, J. L.; Li, Z.; Yamamoto, H. *J. Am. Chem. Soc.* **2013**, *135*, 3411–3413.

(24) (Z)-2-En-4-yn-1-ols were useful precursors for furan synthesis: (a) Du, X.; Chen, H.; Liu, Y. *Chem.—Eur. J.* **2008**, *14*, 9495–9498.

(b) Du, X.; Song, F.; Lu, Y.; Chen, H.; Liu, Y. *Tetrahedron* **2009**, *65*, 1839–1845.

(25) Unique stereoselective synthesis of (Z)-allylic alcohols was reported: Jeon, S.-J.; Fisher, E. L.; Carroll, P. J.; Walsh, P. J. *J. Am. Chem. Soc.* **2006**, *128*, 9618–9619.

(26) Maulucci, N.; Izzo, I.; Bifulco, G.; Aliberti, A.; Cola, C. D.; Comegna, D.; Gaeta, C.; Napolitano, A.; Pizza, C.; Tedesco, C.; Flot, D.; Riccardis, F. D. *Chem. Commun.* **2008**, 3927–3929.

(27) Kamptmann, S. B.; Brückner, R. *Eur. J. Org. Chem.* **2013**, 6584–6600.

(28) Collins, I.; Caldwell, J.; Fonseca, T.; Donald, A.; Bavetsias, V.; Hunter, L.-J. K.; Garrett, M. D.; Rowlands, M. G.; Aherne, G. W.; Davies, T. G.; Berdini, V.; Woodhead, S. J.; Davis, D.; Seavers, L. C. A.; Wyatt, P. G.; Workman, P.; McDonald, E. *Bioorg. Med. Chem.* **2006**, *14*, 1255–1273.

(29) Mukherjee, S.; Kontokosta, D.; Patil, A.; Rallapalli, S.; Lee, D. J. *Org. Chem.* **2009**, *74*, 9206–9209.

(30) Ding, B.; Bentrude, W. G. *J. Am. Chem. Soc.* **2003**, *125*, 3248–3259.

(31) Banert, K.; Hagedorn, M.; Liedtke, C.; Melzer, A.; Schöffler, C. *Eur. J. Org. Chem.* **2000**, 257–267.

(32) Arai, N.; Azuma, K.; Nii, N.; Ohkuma, T. *Angew. Chem., Int. Ed.* **2008**, *47*, 7457–7460.

(33) Wu, H.-L.; Wu, P.-Y.; Uang, B.-J. *J. Org. Chem.* **2007**, *72*, 5935–5937.

(34) Scott, W. J.; Pefia, M. R.; Sward, K.; Stoessel, S. J.; Stille, J. K. *J. Org. Chem.* **1985**, *50*, 2302–2308.

(35) Lebold, T. P.; Gallego, G. M.; Marth, C. J.; Sarpong, R. *Org. Lett.* **2012**, *14*, 2110–2113.