Synthesis of 2-Alkoxy-5-methylenetetrahydropyrans: A Regioselective Ruthenium-Catalyzed C−C Coupling Reaction of Prop-2-yn-1-ols with Allyl Alcohol

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The carbon−carbon coupling of prop-2-yn-1-ols with allyl alcohol is achieved in the presence of the ruthenium(II) catalyst RuCl(cod)(C_5Me_5). The coupling reaction is highly regioselective and leads to the $HOCR_2C(=CH_2)CH_2CH_2CHO$ isomer and, after cyclization, to either 2-hydroxy- or 2-alkoxy-5-methylenetetrahydropyrans, at room temperature or at 80 °C, respectively. It is used for the synthesis of molecules containing two and three tetrahydropyran moieties. The study of a variety of prop-2-yn-1-ols has shown the influence of the substituent at the propargyl carbon on the regioselectivity of the C−C coupling. In the case of tertiary alcohols, the reaction leads to only one cyclic isomer, the 2-alkoxytetrahydropyran whereas with secondary alcohols, a linear isomer is also obtained. The tetrahydropyranols are easily oxidized into lactones.

Introduction

The power of ruthenium precatalysts is now recognized for the activation of simple unsaturated hydrocarbons substrates[1] and for selective transformations with atom economy.[2] Efficient to perform cyclopropanation reactions,[3] ruthenium-carbene[4,5] and ruthenium-allenylidene[6,7] catalysts have become the unique partners for diene[4,6] or enyne[5,7] ring closing metathesis reactions. Alternatively, the catalytic activation of inert (sp^2)CH bonds with a ruthenium species leads to the functionalization of arenes and alkenes.[8] A variety of new methods of carbon−carbon bond formation involve the activation of alkynes with ruthenium precursors[9] such as the coupling with allylic alcohols,[10−12] alkenes,[13] or cyclic olefins,[14] allowing the selective synthesis of γ,δ-unsaturated ketones,[11] aldehydes[12] or 1,5-diketones,[15] dienes,[13] polycyclic compounds,[14] or butenolides.[16] 1,6- and 1,7-Enynes can be intramolecularly rearranged into alkenylcycloolefins[17a] or cyclopentenones.[17b,c] In these reactions, the ruthenium activation of terminal alkynes takes place either via a

* Corresponding author. Phone: 33 2 99 28 62 80. Fax: 33 2 99 28 69 39. E-mail: pierre.dixneuf@univ-rennes1.fr.

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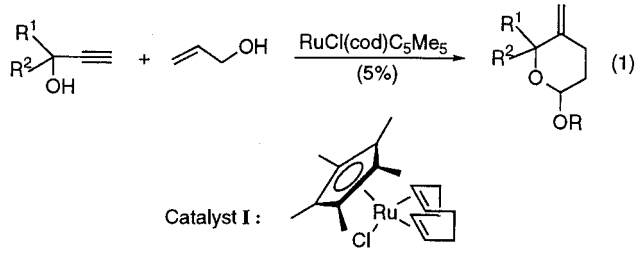
ruthenium vinylidene species[10,18] or a ruthenacycle intermediate.[11−16]

The tetrahydropyran skeleton is the key structure of several intermediates for the synthesis of natural products,[19] and 2-alkoxy-5-methylenetetrahydropyrans have been used to prepare 3-hydroxypyran-4-ones, flavoring components,[20] aggregation pheromones,[21] tricothecanes,[22] and precursors of the cytotoxic and antitumor active vernolepin.[23] On the basis of our initial discovery that the ruthenium-catalyzed coupling of alkynes with allyl alcohol leads to branched γ,δ-unsaturated aldehydes,[12] it could be predicted that the attachment of a hydroxy group at the α carbon of the C≡CH bond would lead to a tetrahydropyran skeleton. We now describe, following our preliminary report,[24] a novel, general method to prepare new 2-alkoxy-5-methylenetetrahydropyrans, based on the highly regioselective C−C coupling of prop-2-yn-1-ols with allyl alcohol, in the presence of catalytic amounts of RuCl(cod)(C_5Me_5), according to eq 1.

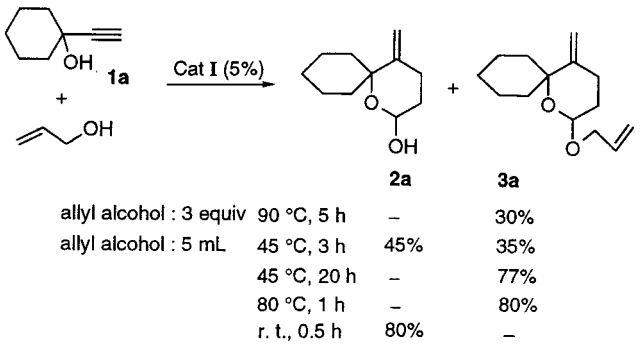


Results and Discussion

Ruthenium(II)-Catalyzed Carbon−Carbon Coupling of Prop-2-yn-1-ols with Allyl Alcohol. The reaction of alkynes with allyl alcohol in the presence of (C_5Me_5)Ru(II) or (C_5Me_5)Ru(IV) precatalysts has led to the formation of γ,δ-unsaturated aldehydes.[12] In the case of terminal alkynes, the regioselectivity of the carbon−carbon coupling did not exceed 85% for the branched isomer except for the bulky alkyne *t*-BuC≡CH. Our search to improve the regioselectivity led us to study the catalytic activation of propargylic alcohols in the presence of allyl alcohol and discover a new, very convenient way to produce 5-methylenetetrahydropyrans.

The reaction of 1-ethynylcyclohexanol **1a** and 3 equiv of allyl alcohol, in the presence of 5 mol % of RuCl(cod)-(C_5Me_5) catalyst **I**[25] (cod = cycloocta-1,5-diene), without solvent, was first attempted at 90 °C. A reaction slowly took place and led to the formation of the 2-(allyloxy)-tetrahydropyran **3a** isolated in 30% yield after 5 h

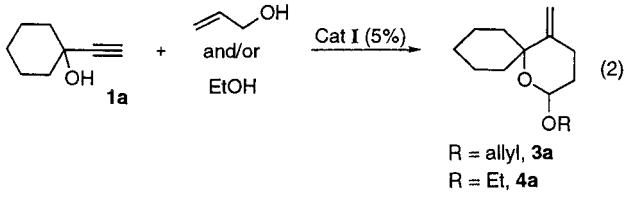
Scheme 1



allyl alcohol : 3 equiv	90 °C, 5 h	–	30%
allyl alcohol : 5 mL	45 °C, 3 h	45%	35%
	45 °C, 20 h	–	77%
	80 °C, 1 h	–	80%
	r. t., 0.5 h	80%	–

(Scheme 1). However, when a large excess of allyl alcohol was used (5 mL, 30 equiv), the conversion of the prop-2-yn-1-ol **1a** was much faster, and the reaction performed at 45 °C afforded a mixture of hemiacetal **2a** and 2-allylacetal **3a**. The ratio **3a**/**2a** increased with the reaction time, and the selective formation of the mixed acetal **3a** (77%) was obtained after 20 h at 45 °C. Actually, the temperature is an important reaction parameter for the chemoselectivity: the mixed acetal **3a** was formed in 80% yield after 1 h at 80 °C, whereas, only the hemiacetal **2a** (80%) was formed when the reaction was performed at 20 °C for 30 min. These results showed that the hemiacetal **2a** was first selectively produced and that further heating in an excess of allyl alcohol selectively led to the 2-allylacetal **3a**.

The competition of formation of 2-ethylacetal **4a** versus that of 2-allylacetal **3a** was studied in allyl alcohol/ethanol mixtures (eq 2). At room temperature, the reaction took place significantly more slowly with addition of ethanol, and the conversion of the prop-2-yn-1-ol was not complete. The hemiacetal **2a** was only obtained but with low yields. At 80 °C, a mixture of mixed acetals **3a** and **4a** was produced, and the ratio **4a**/**3a** increased with the addition of ethanol until a ratio ethanol/allyl alcohol 4/1 was reached. Under these conditions, **4a** and **3a** were obtained in 65 and 13% yield, respectively.



Thus, an excess of neat allyl alcohol with 5 mol % of RuCl(cod)(C_5Me_5) as catalyst precursor gave the best conditions in the formation of **2a** (rt) or **3a** (80 °C) for which a *100% regioselectivity* was observed by contrast to simple terminal alkynes. These conditions were selected to study the activation of various prop-2-yn-1-ols.

Catalyzed Formation of 5-Methylenetetrahydropyrans from Tertiary Prop-2-yn-1-ols. The above reaction conditions were applied to a variety of tertiary prop-2-yn-1-ols and produced selectively either the corresponding 2-hydroxy-5-methylenetetrahydropyrans **2** at room temperature or 2-(allyloxy)-5-methylenetetrahydropyrans **3** at 80 °C, respectively (Table 1). It is noteworthy that the tertiary prop-2-yn-1-ols allow a high regioselective C−C coupling leading only to the branched isomer.

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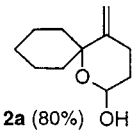
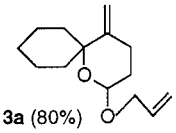
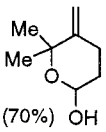
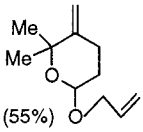
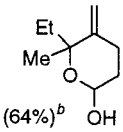
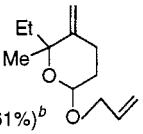
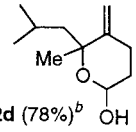
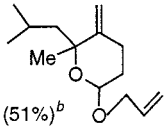
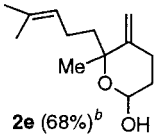
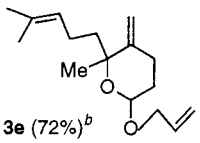
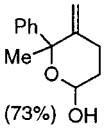
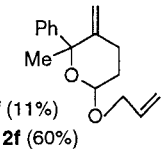
Table 1. Formation of 5-methylenetetrahydropyrans 2 and 3 from tertiary prop-2-yn-1-ols[a]

$(R^1)(R^2)C(OH)$-C≡CH		r. t.		80 °C	
	R^1, R^2	t (h)	Products (yield)	t (h)	Products (yield)
1a	-$(CH_2)_5$-	0.5	 **2a** (80%)	1	 **3a** (80%)
1b	Me, Me	2	 **2b** (70%)	1	 **3b** (55%)
1c	Me, Et	2	 **2c** (64%)[b]	4	 **3c** (61%)[b]
1d	Me, CH_2CHMe_2	2	 **2d** (78%)[b]	5	 **3d** (51%)[b]
1e	Me, $(CH_2)_2CH$=CMe_2	2	 **2e** (68%)[b]	3	 **3e** (72%)[b]
1f	Me, Ph	3	 **2f** (73%)	5	 **3f** (11%) + **2f** (60%)

[a] Isolated yields after silica gel chromatography. [b] Diastereomeric ratio of 60/40 determined by ^{1}H NMR.

The 2-alkoxy-5-methylenetetrahydropyrans were formed in 51−80% yield for reaction times of 0.5−5 h. The achiral derivative **1b** selectively afforded **2b** (70%) or **3b** (55%). Bulkier alkyl groups (**1d**,**e**) or an aryl group (**1f**) showed no influence on the efficiency of the regioselective C−C coupling reaction. However, from the phenyl derivative **1f**, the tetrahydropyranol **2f** was obtained as the major product, either at 20 °C (3 h) in 73% yield, or at 80 °C (5 h) in 60% yield in addition to only 11% of **3f**.

When unsymmetrically substituted derivatives **1c**,**f** were used, the hemiacetalization cyclization created a second asymmetric center, and the two stereoisomers were obtained in the ratio 60/40 for **2c**−**e** derivatives. Their corresponding acetals **3c**−**e** were also formed in the same stereoisomeric ratio. This ratio corresponds to the six-membered anomer ratio usually obtained for sugar derivatives. However, from the phenyl derivative **1f**, ^{1}H and ^{13}C NMR indicated only one stereoisomer **2f**, showing that the steric hindrance of the phenyl group plays an important role in this selectivity. Indeed, NOE experiments showed the relative trans arrangement of the phenyl group and the OH group of **2f**. The ortho aromatic protons were identified by ^{1}H NMR and irradiated, and the effect on the ^{1}H NMR signals of the alcohol proton and anomeric proton was studied. This irradiation produced a 5% increase of the anomeric proton signal whereas the alcohol proton signal was not modified.

Since the prop-2-yn-1-ol **1f** produced only one stereoisomer it was chosen as a model, to study multifunctional molecules. The diol **1g** and the triol **1h**, readily synthesized from 1,4-diacetylbenzene and 1,3,5-triacetylbenzene, respectively, have been studied toward this coupling reaction. The reaction of the diol **1g**, in 5 mL of allyl alcohol, at room temperature for 3 h, in the presence of 10 mol % of RuCl(cod)(C_5Me_5) catalyst led to the bis-(tetrahydropyranyl)benzene **2g** as the major product isolated in 65% yield, after separation by chromatography over silica (Scheme 2). No stereoisomers of **2g** could be detected by ^{13}C NMR (50 MHz). We observed the signals of only one product. Under similar conditions, the reaction of the triol **1h**, in the presence of 15 mol % of ruthenium catalyst precursor, led to a mixture of several products from which the tris(tetrahydropyranyl)benzene **2h** was isolated by chromatography in 33% yield after 15 h at room temperature. In this case, ^{13}C NMR indicated the presence of stereoisomers.

Catalyzed Reaction of Allyl Alcohol with Secondary Prop-2-yn-1-ols. By contrast to tertiary alcohols, when the reaction was performed with secondary prop-2-yn-1-ols **1i** (R = *t*-Bu), **1j** (R = Ph), and **1k** (R = Et),

Scheme 2

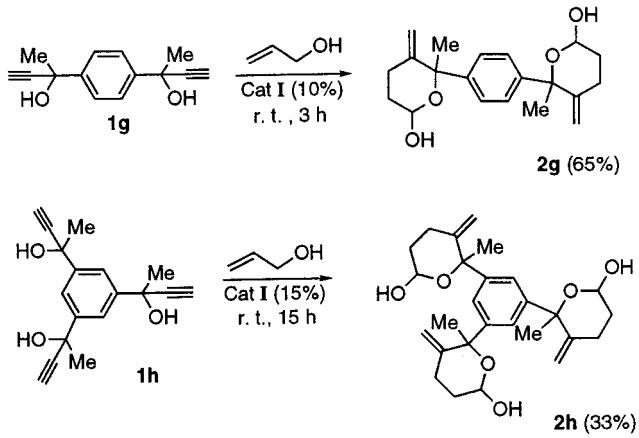
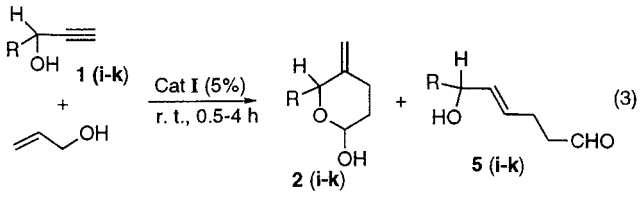


Table 2. Catalytic Coupling of Secondary Prop-2-yn-1-ols with Allyl Alcohol[a]

Prop-2-yn-1-ol (R)	t (h)	yield[b] 2 + 5	regioselectivity 2/5
1i (*t*-Bu)	4	80%	78/22
1j (Ph)	2	94%	75/25
1k (Et)	0.5	40%	70/30

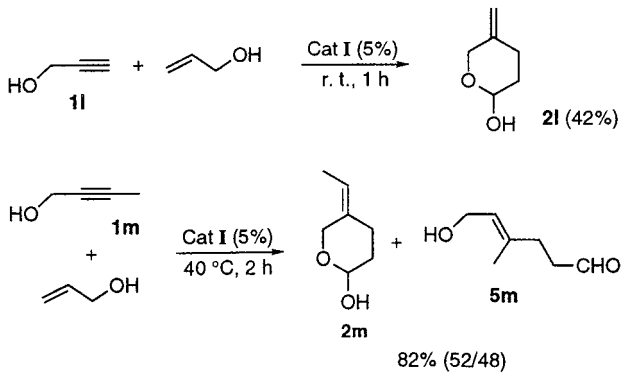
[a] Reaction conditions : **1** (2.5 mmol) in allyl alcohol (5 mL) was treated with [RuCl(cod)(C_5Me_5)] (0.125 mmol, 5 mol%) at room temperature. [b] Isolated yields after silica gel chromatography.

the regioselectivity decreased (eq 3). Actually, at room temperature, the branched isomer, leading to the tetrahydropyranol **2**, was still favored but the linear trans isomer **5**, which did not cyclize, was also obtained.



To study this selectivity, we attempted comparative reactions with the three secondary prop-2-yn-1-ols (**1i**−**k**) (Table 2). For reaction times of 0.5−4 h at room temperature, we obtained coupling products in excellent yields (80−94%) with large substituents (R = *t*-Bu, Ph) and in low yield (40%) with R = Et. On the other hand, in each case, the same regioselectivity was approximately obtained with a major branched isomer **2**/**5** ≈ 75/25. The bulkiness of R group did not seem determining for this regioselectivity since the branched/linear isomer **2**/**5** ratio reached 78/22 for the bulkier *t*-Bu group, 75/25 for the phenyl group, and 70/30 for the less bulky ethyl group. It is noteworthy that the less functionalized *tert*-butylacetylene upon reaction with allyl alcohol under similar catalytic conditions led to 100% of the branched aldehyde *t*-BuC(=CH_2)CH_2CH_2CHO.[12] In the present case, more important seems to be the difference between the secondary and the tertiary prop-2-yn-1-ols, as the presence of one hydrogen atom on the propargyl carbon allows the formation of the linear isomer **5**. These products **2** and **5** correspond to the C−C coupling of the allyl alcohol with both carbon atoms of the C≡C bond of derivatives **1**. Derivative **2** arises from the coupling with carbon C_3 and **5** from that with carbon C_2. The trans stereochemistry of the latter and the 1,6 position of the hydroxy and formyl groups inhibit the cyclization into a hemiacetal.

Scheme 3



Catalyzed Reaction of Allyl Alcohol with Primary Prop-2-yn-1-ols. The influence of the substitution at the propargyl carbon was studied using primary prop-2-yn-1-ols. The reaction was performed with the propynyl alcohol **1l**, in 5 mL of allyl alcohol, at room temperature, in the presence of 5 mol % of RuCl(cod)(C_5Me_5) catalyst. We observed the sole formation of the branched isomer, the tetrahydropyranol **2l**, which was isolated in 42% yield only, even if the conversion of the propynol was complete after 1 h of reaction (Scheme 3). In this case, the unusual presence of an insoluble dark product in the reaction mixture was also detected.

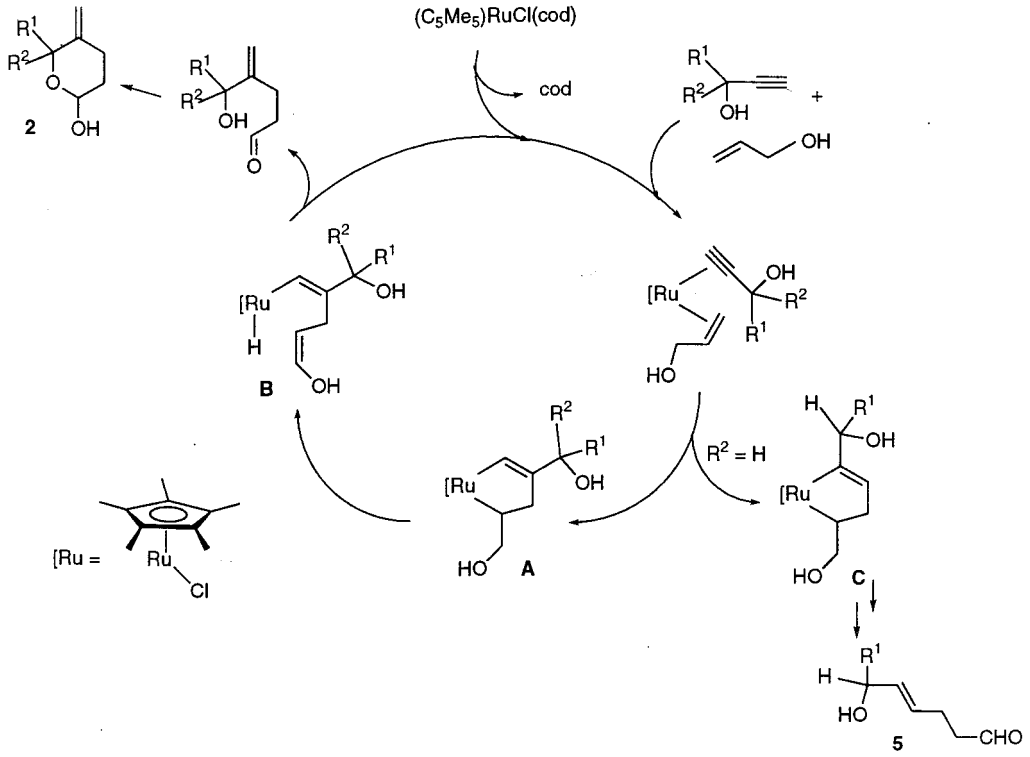
The reaction with a primary alcohol containing a disubstituted triple bond, the but-2-yn-1-ol **1m**, was carried out. This disubstitution significantly slowed the reactivity of the prop-2-yn-1-ol: 85% of conversion was reached after 7 h at room temperature. Two products **2m** and **5m** were isolated in 65% yield with a regioselectivity of isomers branched **2m**/linear **5m** corresponding to a ratio 52/48 (Scheme 3). The reaction performed at 40 °C led to better yields, as, after 2 h, the products **2m** and **5m** were isolated in 82% yield with the same regioselectivity. These results confirm that the presence of two hydrogen atoms at the propargyl carbon increases the formation of the linear isomer.

Mechanism of Catalyzed Prop-2-yn-1-ol/Allyl Alcohol C−C Coupling. We already reported that, for the coupling of alkynes with allyl alcohol,[12] the ruthenium(II) complex RuCl(cod)(C_5Me_5) appeared to be the best catalyst precursor to produce the branched isomer, as the major product (up to 85%). The performance of the reaction with disubstituted alkynes precluded a mechanism via vinylidene intermediate.[18] A regioselective oxidative coupling of both the C≡C and C=C bonds of the reagents seems the most likely process to account for that reaction and the present one (Scheme 4). Such an oxidative coupling of C≡C and C=C bonds at a ruthenium site has first been suggested by Mitsudo et al.[26] and then by Trost[11] for the coupling of alkynes with substituted allylic alcohols.

A ruthenium allenylidene intermediate (Ru=C=C=CR_2) is usually produced by metal activation of a terminal prop-2-yn-1-ol by ruthenium(II) species following by water elimination.[27] Thus, the reaction is specific for terminal triple bonds. In the present case, this interme-

(26) Mitsudo, T. A.; Kokuryo, K.; Shinsugi, T.; Nakagawa, Y.; Watanabe, Y.; Takegami, Y. *J. Org. Chem.* **1979**, *44*, 4492−4496.

Scheme 4



diate can be ruled out. As expected for an oxidative coupling mechanism, the disubstituted prop-2-yn-1-ol MeC≡CCH$_2$OH **1m**, which cannot lead to an allenylidene-ruthenium moiety, is coupled with allyl alcohol to give the tetrahydropyranol **2m** and the linear derivative **5m** with 82% yield at 40 °C.

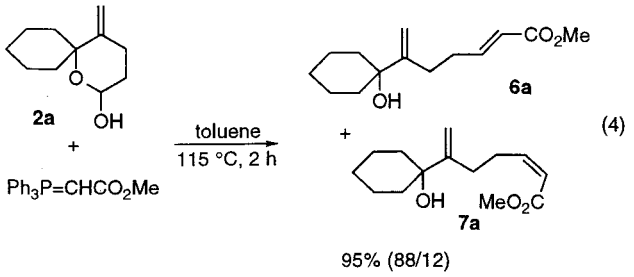
It is known that RuCl(cod)(C_5R_5) complexes[11−16] easily loose their cod ligand in the presence of unsaturated substrates, thus offering two vacant coordination sites for the fixation of two unsaturated bonds. By contrast, in the presence of a phosphine, a single vacant coordination site would be offered and favor the formation of a ruthenium vinylidene intermediate, in the presence of a terminal alkyne.[10,18] Thus, the coordination of the triple bond of the prop-2-yn-1-ol and the double bond of the allyl alcohol to the ruthenium center is expected to displace the cod ligand and to lead to the oxidative coupling into a ruthenacyclopentene **A**. The electron richness of the (C_5Me_5)(Cl)Ru(II) moiety is also expected to favor the oxidative coupling at the ruthenium site (Ru(II) → Ru(IV)) and to account for the occurrence of the reaction at room temperature. A favored β-elimination of one hydrogen atom of the exocyclic methylene group should lead to the alkenyl hydrido ruthenium species **B**. The latter, on reductive elimination, should form a branched γ,δ-unsaturated aldehyde which cyclizes into the six-membered hemiacetal **2**. Analogously, the minor species **C** corresponding to the reverse regioselective coupling should lead to the linear aldehyde **5** which cannot cyclize into a hemiacetal due to the trans position of the alkene substituents.

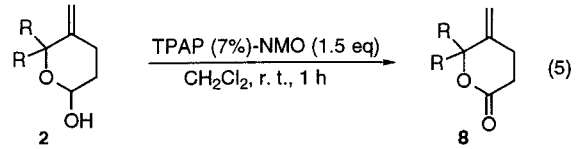
It is noteworthy that the regioselectivity of C−C coupling of alkynes with allylic alcohols depends on the nature of the catalyst precursor. The use of the catalyst RuCl(cod)(C_5H_5) has already been reported by Trost et al.[11] for the synthesis of γ,δ-unsaturated ketones, via the C−C coupling of alkynes with 1-substituted allylic alcohols. This catalyst preferentially led to the formation of linear derivatives. According to the nature of the allylic alcohol substituent, the selectivity in the formation of linear/branched isomers could reach the 3/1 ratio. By contrast the bulkier, more electron-rich complex RuCl(cod)(C_5Me_5), associated with the small allyl alcohol, favored the formation of the branched γ,δ-unsaturated aldehydes.[12] In the latter case it is likely that the regioselective formation of the branched isomer is due to the steric hindrance of the C_5Me_5 ligand with respect to that of the C_5H_5 ligand. In the case of prop-2-yn-1-ols **1**, the bulkiness of both C_5Me_5 group and C(R^1)(R^2)OH substituent of the alkyne **1** should favor the formation of the intermediate **A** rather than **C**. The better regioselectivity of this reaction is influenced by the substitution at the propargyl carbon: actually, only the tertiary prop-2-yn-1-ols led to the sole formation of the branched isomer **2**. On the other hand, the presence of one or two hydrogen atoms at the propargyl carbon could allow the formation of one intermediate of type **C**, with a weak steric interaction between the bulky C_5Me_5 and the CHROH groups, leading to the formation of the linear isomer **5** (Scheme 4).

Reactivity of 5-Methylenetetrahydropyranols 2. As the 5-methylenetetrahydropyranols **2** are hemiacetals, they are involved in an equilibrium with the open hydroxy-aldehyde form. As a general rule, this equilibrium is strongly shifted toward the six-membered cyclic form. The potential of the aldehyde functionality of **2** was studied in a Wittig reaction. The reaction of the tetrahydropyranol **2a** with 1 equiv of phosphorus ylide Ph_3P=C-HCO_2Me in boiling toluene for 2 h afforded the corresponding alkenes **6a** and **7a** isolated in 95% yield as a

(27) Touchard, D.; Pirio, N.; Dixneuf, P. H. *Organometallics* **1995**, *14*, 4920−4928 and references therein.

E/*Z* mixture (88/12) (eq 4) showing the potential of **2a** as a masked aldehyde.





tetrahydropyranol **2** (R, R)	Yield
2a (-$(CH_2)_5$-)	80%
2b (Me, Me)	80%

As γ- and δ-lactones derived from carbohydrates are useful precursors for the synthesis of natural products,[28] the tetrahydropyranols **2** were submitted to oxidation in order to prepare γ-methylene-δ-valerolactones. We first attempted to oxidize the alcohol function with manganese oxide, but the tetrahydropyranol **2a** was recovered unchanged after 16 h at room temperature or at 60 °C. Protected glycopyranose derivatives have been oxidized into lactone with several oxidants such as dimethyl sulfoxide activated by oxalyl chloride,[29] pyridinium dichromate,[30] and 4-methylmorpholine *N*-oxide (NMO) in the presence of tetra-*n*-propylammonium per-ruthenate (TPAP).[31] Only the treatment of **2a** with 7 mol % of TPAP, in the presence of 1.5 equiv of NMO as co-oxidant and 4 Å molecular sieves, in dichloromethane for 1 h at room temperature, afforded **8a** in 80% yield (eq 5). The same conditions applied to the tetrahydropyranol **2b** led to the γ-methylene-δ-valerolactone **8b** in 80% yield also.

Conclusion

This one-pot ruthenium catalyzed regioselective C−C coupling reaction of two simple unsaturated hydrocarbon molecules, followed by cyclization, takes place with atom economy. Such a high regioselectivity to form a branched isomer from the coupling of C≡C and C=C bonds seems unprecedented. It offers a new direct route to a variety of functional tetrahydropyran derivatives, and we have shown their potential for the access to δ-valerolactones and functional dienes. This reaction illustrates a new example of the dramatic influence of the nature of the ruthenium catalyst, associated to that of the unsaturated substrate, on the regioselectivity of the C−C coupling reaction.

(28) (a) Bhat, K. L.; Chen, S. Y.; Joullie, M. *Heterocycles* **1985**, *23*, 691−729. (b) Hanessian, S.; Ugolini, A. *Carbohydr. Res.* **1984**, *130*, 261−269.

(29) Mancuso, A. J.; Swern, D. *Synthesis* **1981**, 165−185.

(30) Czernecki, S.; Georgoulis, C.; Stevens, C. L.; Vijayakumaran, K. *Tetrahedron Lett.* **1985**, *26*, 1699−1702.

(31) Benhaddou, R.; Czernecki, S.; Farid, W.; Ville, G.; Xie, J.; Zegar, A. *Carbohydr. Res.* **1994**, *260*, 243−250.

Experimental Section

All catalytic reactions were carried out under inert atmosphere in Schlenk tubes. Chemicals were obtained commercially and used as supplied. The complex RuCl(cod)(C_5Me_5) was prepared according to reported method.[25] Products were isolated by silica gel (70−230 mesh) column chromatography. Elemental analyses were performed by "Le Service de Microanalyse du CNRS", Lyon, France and high-resolution mass spectra by "Le Centre Régional de Mesures Physiques de l'Ouest", Université de Rennes 1, Rennes, France.

General Procedure for the Catalytic Reaction. Propargylic alcohol (2.5 mmol) was added to a mixture of ruthenium complex RuCl(cod)(C_5Me_5) (0.125 mmol) and allyl alcohol (or mixture of allyl alcohol and ethanol) (5 mL). The mixture was stirred at room temperature or heated at 80 °C for 0.5−5 h. The solvent was evaporated under vacuum. The products were isolated after column chromatography over silica gel (30 g) with pentane/Et_2O mixtures as eluent. The compounds were analyzed by NMR (^{1}H and ^{13}C), IR, and mass spectrum or elemental analysis.

5-Methylene-6-spirocyclohexanetetrahydropyran-2-ol (2a): IR (film) ν/cm^{-1} 3395, 3086, 1645; ^{1}H NMR δ (200 MHz, $CDCl_3$) 5.03 (1H, m), 4.68 (1H, s), 4.67 (1H, s), 4.20 (1H, d, J = 6.7 Hz), 2.36−2.25 (2H, m), 1.93−1.38 (10H, m), 1.18−1.09 (2H, m); ^{13}C NMR δ (50 MHz, $CDCl_3$) 149.93, 107.06, 90.49, 76.41, 35.85, 34.31, 32.92, 28.00, 25.64, 21.29, 20.95. Anal. Calcd for $C_{11}H_{18}O_2$: C, 72.49; H, 9.95. Found: C, 72.29; H, 10.11.

6-(Allyloxy)-3-methylene-2-spirocyclohexanetetrahydropyran (3a): IR (film) ν/cm^{-1} 3086, 3023, 1645; ^{1}H NMR δ (200 MHz, $CDCl_3$) 5.91 (1H, dddd, J = 17.2 Hz, J = 10.6 Hz, J = 6.5 Hz, J = 5.0 Hz), 5.27 (1H, dm, J = 17.2 Hz), 5.15 (1H, dm, J = 10.6 Hz), 4.80 (1H, dd, J = 8.4 Hz, J = 3.4 Hz), 4.74 (1H, sl), 4.73 (1H, sl), 4.40 (1H, ddt, J = 12.9 Hz, J = 5.0 Hz, J = 1.5 Hz), 4.06 (1H, ddt, J = 12.9 Hz, J = 6.5 Hz, J = 1.5 Hz), 2.40−2.33 (2H, m), 2.1−1.5 (10H, m), 1.24−1.20 (2H, m); ^{13}C NMR δ (50 MHz, $CDCl_3$) 150.66, 134.55, 116.70, 106.96, 95.44, 76.05, 69.11, 36.40, 33.17, 32.63, 28.04, 25.81, 21.49, 21.38. Anal. Calcd for $C_{14}H_{22}O_2$: C, 75.63; H, 9.97. Found: C, 75.37; H, 10.05.

6-Ethoxy-3-methylene-2-spirocyclohexanetetrahydropyran (4a): IR (film) ν/cm^{-1} 3086, 1645; ^{1}H NMR δ (200 MHz, $CDCl_3$) 4.74 (1H, m), 4.70 (1H, s), 4.68 (1H, s), 3.96 (1H, dq, J = 9.4 Hz, J = 7.1 Hz), 3.46 (1H, dq, J = 9.4 Hz, J = 7.1 Hz), 2.32−2.27 (2H, m), 2.1−1.4 (10H, m), 1.21−1.11 (2H, m), 1.17 (3H, t, J = 7.1 Hz); ^{13}C NMR δ (50 MHz, $CDCl_3$) 150.68, 106.91, 95.97, 75.91, 64.01, 36.36, 32.96, 32.86, 28.25, 25.87, 21.47, 21.34, 15.09. HRMS calcd for $C_{11}H_{16}O$ ($M^+ - C_2H_5OH$) 164.1201, found 164.1194.

6,6-Dimethyl-5-methylenetetrahydropyran-2-ol (2b): IR (film) ν/cm^{-1} 3388, 3086, 1645; ^{1}H NMR δ (200 MHz, $CDCl_3$) 5.13 (1H, m), 4.72 (1H, s), 4.68 (1H, s), 4.48 (1H, sl), 2.37−2.31 (2H, m), 1.92−1.86 (1H, m), 1.58−1.50 (1H, m), 1.38 (3H, s), 1.29 (3H, s); ^{13}C NMR δ (50 MHz, $CDCl_3$) 149.34, 107.27, 91.39, 76.28, 33.91, 28.55, 27.72, 25.89. Anal. Calcd for $C_8H_{14}O_2$: C, 67.57; H, 9.92. Found: C, 66.88; H, 9.80.

6-(Allyloxy)-2,2-dimethyl-3-methylenetetrahydropyran (3b): IR (film) ν/cm^{-1} 3086, 3011, 1645; ^{1}H NMR δ (200 MHz, $CDCl_3$) 5.90 (1H, dddd, J = 17.3 Hz, J = 10.3 Hz, J = 6.3 Hz, J = 5.0 Hz), 5.27 (1H, dm, J = 17.3 Hz), 5.15 (1H, dm, J = 10.3 Hz), 4.85 (1H, dd, J = 5.4 Hz, J = 3.7 Hz), 4.76 (1H, sl), 4.72 (1H, m), 4.30 (1H, ddt, J = 13.0 Hz, J = 5.0 Hz, J = 1.5 Hz), 4.00 (1H, ddt, J = 13.0 Hz, J = 6.3 Hz, J = 1.5 Hz), 2.59−2.48 (1H, m), 2.32−2.22 (1H, m), 1.9−1.6 (2H, m), 1.44 (3H, s), 1.34 (3H, s); ^{13}C NMR δ (50 MHz, $CDCl_3$) 148.78, 132.62, 114.61, 104.81, 94.40, 73.62, 66.14, 30.36, 26.93, 25.28, 24.94. Anal. Calcd for $C_{11}H_{18}O_2$: C, 72.49; H, 9.95. Found: C, 72.62; H, 10.38.

6-Ethyl-6-methyl-5-methylenetetrahydropyran-2-ol (2c): IR (film) ν/cm^{-1} 3388, 3086, 1645; ^{1}H NMR δ (200 MHz, $CDCl_3$) two diastereoisomers a/b (60/40) isomer a 5.13 (1H, m), 4.75 (1H, s), 4.69 (1H, s), 4.31 (1H, sl), 2.5−2.2 (2H, m), 2.0−1.4 (4H, m), 1.29 (3H, s), 0.76 (3H, t, J = 7.4 Hz) isomer b 5.13 (1H, m), 4.75 (1H, s), 4.64 (1H, s), 4.20 (1H, sl), 2.5−2.2 (2H,

m), 2.0−1.4 (4H, m), 1.22 (3H, s), 0.83 (3H, t, J = 7.4 Hz); ^{13}C NMR δ (50 MHz, $CDCl_3$) isomer a 148.06, 108.51, 91.01, 79.29, 33.91, 29.72, 28.27, 25.29, 8.07 isomer b 148.59, 107.99, 91.43, 78.88, 33.30, 33.22, 27.23, 24.09, 8.14. HRMS calcd for $C_8H_{13}O_2$ ($M^+ - CH_3$) 141.0915, found 141.0915.

6-(Allyloxy)-2-ethyl-2-methyl-3-methylenetetrahydropyran (3c): IR (film) ν/cm^{-1} 3086, 3010, 1645, 1616; ^{1}H NMR δ (200 MHz, $CDCl_3$) two diastereoisomers a/b (60/40) isomer a 5.92 (1H, m), 5.27 (1H, ddt, J = 17.3 Hz, J = 1.8 Hz, J = 1.4 Hz), 5.15 (1H, ddt, J = 10.3 Hz, J = 1.8 Hz, J = 1.5 Hz), 4.85 (1H, t, J = 3.7 Hz), 4.79 (1H, d, J = 1.5 Hz), 4.71 (1H, sl), 4.36−4.27 (1H, m), 4.00 (1H, ddt, J = 12.9 Hz, J = 6.3 Hz, J = 1.5 Hz), 2.3−2.05 (2H, m), 2.0−1.75 (4H, m), 1.35 (3H, s), 0.87 (3H, t, J = 7.4 Hz) isomer b 5.92 (1H, m), 5.27 (1H, ddt, J = 17.3 Hz, J = 1.8 Hz, J = 1.4 Hz), 5.15 (1H, ddt, J = 10.3 Hz, J = 1.8 Hz, J = 1.5 Hz), 4.82 (1H, t, J = 2.2 Hz), 4.78 (1H, d, J = 1.5 Hz), 4.69 (1H, sl), 4.36−4.27 (1H, m), 4.00 (1H, ddt, J = 12.9 Hz, J = 6.3 Hz, J = 1.5 Hz), 2.3−2.05 (2H, m), 2.0−1.75 (4H, m), 1.26 (3H, s), 0.84 (3H, t, J = 7.7 Hz); ^{13}C NMR δ (50 MHz, $CDCl_3$) isomer a 149.77, 134.79, 116.84, 107.89, 96.16, 78.31, 68.46, 32.34, 32.17, 27.98, 26.45, 7.99 isomer b 149.69, 134.79, 116.75, 108.12, 96.57, 78.81, 68.50, 33.03, 32.10, 26.97, 23.92, 8.61. HRMS calcd for $C_{11}H_{17}O_2$ ($M^+ - CH_3$) 181.1228, found 181.1234.

6-Methyl-5-methylene-6-(2-methylpropyl)tetrahydropyran-2-ol (2d): IR (film) ν/cm^{-1} 3402, 3086, 1645; ^{1}H NMR δ (200 MHz, $CDCl_3$) two diastereoisomers a/b (60/40) isomer a 5.12 (1H, m), 4.74 (1H, sl), 4.72 (1H, s), 3.02 (1H, sl), 2.5−2.2 (2H, m), 2.0−1.4 (5H, m), 1.35 (3H, s), 0.90 (6H, d, J = 6.6 Hz) isomer b 5.12 (1H, m), 4.74 (1H, sl), 4.67 (1H, s), 2.89 (1H, sl), 2.5−2.2 (2H, m), 2.0−1.4 (5H, m), 1.26 (3H, s), 0.83 (6H, d, J = 6.5 Hz); ^{13}C NMR δ (50 MHz, $CDCl_3$) isomer a 149.33, 108.47, 91.13, 79.38, 45.88, 34.29, 28.62, 26.70, 24.62, 24.51, 24.36 isomer b 149.48, 108.07, 91.59, 79.26, 49.39, 33.48, 27.38, 25.35, 25.04, 24.84, 24.24. HRMS calcd for $C_{10}H_{17}O_2$ ($M^+ - CH_3$) 169.1228, found 169.1240.

6-(Allyloxy)-2-methyl-3-methylene-2-(2-methylpropyl)-tetrahydropyran (3d): IR (film) ν/cm^{-1} 3086, 3010, 1645; ^{1}H NMR δ (200 MHz, $CDCl_3$) two diastereoisomers a/b (60/40) isomer a 5.85 (1H, m), 5.21 (1H, dm, J = 17.2 Hz), 5.08 (1H, dm J = 10.4 Hz), 4.82 (1H, dd, J = 7.6 Hz, J = 3.8 Hz), 4.71 (1H, sl), 4.67 (1H, sl), 4.30−4.21 (1H, m), 3.98−3.91 (1H, m), 2.5−2.15 (2H, m), 1.95−1.4 (5H, m), 1.34 (3H, s), 0.90 (6H, d, J = 6.8 Hz) isomer b 5.85 (1H, m), 5.21 (1H, dm, J = 17.2 Hz), 5.08 (1H, dm, J = 10.4 Hz), 4.82 (1H, dd, J = 7.6 Hz, J = 3.8 Hz), 4.73 (1H, sl), 4.67 (1H, sl), 4.30−4.21 (1H, m), 3.98−3.91 (1H, m), 2.5−2.15 (2H, m), 1.95−1.4 (5H, m), 1.26 (3H, s), 0.86 (6H, d, J = 6.6 Hz) ; ^{13}C NMR δ (50 MHz, $CDCl_3$) isomer a 150.64, 134.80, 116.69, 107.69, 96.11, 78.68, 68.45, 47.28, 32.17, 28.20, 27.33, 24.82, 24.75 isomer b 150.30, 134.74, 116.77, 108.05, 96.24, 78.93, 68.31, 49.06, 32.51, 27.28, 25.01, 24.39, 24.21. HRMS calcd for $C_{13}H_{21}O_2$ ($M^+ - CH_3$) 209.1541, found 209.1536.

6-Methyl-5-methylene-6-(4-methylpent-3-enyl)tetrahydropyran-2-ol (2e): IR (film) ν/cm^{-1} 3405, 3086, 1639, 1631; ^{1}H NMR δ (200 MHz, $CDCl_3$) two diastereoisomers a/b (60/40) isomer a 5.11 (1H, m), 5.05−4.99 (1H, m), 4.76 (1H, m), 4.71 (1H, sl), 3.26 (1H, d, J = 6.2 Hz), 2.5−2.2 (2H, m), 2.05−1.4 (6H, m), 1.61 (6H, s), 1.33 (3H, s) isomer b 5.11 (1H, m), 5.05−4.99 (1H, m), 4.76 (1H, sl), 4.68 (1H, sl), 3.14 (1H, d, J = 5.1 Hz), 2.5−2.2 (2H, m), 2.05−1.4 (6H, m), 1.53 (6H, s), 1.26 (3H, s); ^{13}C NMR δ (50 MHz, $CDCl_3$) isomer a 148.42, 131.61, 124.06, 108.61, 91.22, 78.80, 37.47, 34.05, 28.28, 26.03, 25.62, 22.58, 17.59 isomer b 148.85, 131.25, 124.58, 108.11, 91.65, 78.46, 40.93, 33.34, 27.21, 25.62, 24.76, 22.55, 17.56. HRMS calcd for $C_7H_{11}O_2$ ($M^+ - C_6H_{11}$) 127.0599, found 127.1580.

6-(Allyloxy)-2-methyl-3-methylene-2-(4-methylpent-3-enyl)tetrahydropyran (3e): IR (film) ν/cm^{-1} 3079, 3015, 1645; ^{1}H NMR δ (200 MHz, $CDCl_3$) two diastereoisomers a/b (60/40) isomer a 5.93 (1H, m), 5.27 (1H, dm, J = 17.0 Hz), 5.15 (1H, dm, J = 10.3 Hz), 5.09 (1H, m), 4.86 (1H, dd, J = 7.1 Hz, J = 3.5 Hz), 4.79 (1H, m), 4.73 (1H, sl), 4.37−4.27 (1H, m), 4.05−3.97 (1H, m), 2.6−2.2 (2H, m), 2.05−1.5 (6H, m), 1.67 (3H, s), 1.66 (3H, s), 1.38 (3H, s) isomer b 5.93 (1H, m), 5.27 (1H, dm, J = 17.0 Hz), 5.15 (1H, dm, J = 10.3 Hz), 5.09 (1H, m), 4.86 (1H, dd, J = 7.1 Hz, J = 3.5 Hz), 4.79 (1H, m), 4.71 (1H, sl), 4.37−4.27 (1H, m), 4.05−3.97 (1H, m), 2.6−2.2 (2H, m), 2.05−1.5 (6H, m), 1.59 (3H, s), 1.58 (3H, s), 1.30 (3H, s); ^{13}C NMR δ (50 MHz, $CDCl_3$) isomer a 149.75, 134.71, 131.43, 124.41, 116.73, 107.81, 96.20, 77.91, 68.47, 38.78, 32.05, 27.88, 26.71, 25.65, 22.35, 17.60 isomer b 149.87, 134.71, 131.13, 124.65, 116.71, 107.99, 96.43, 78.22, 68.38, 40.53, 32.29, 27.00, 25.65, 24.51, 22.88, 17.60. HRMS calcd for $C_{13}H_{21}O_2$ ($M^+ - C_3H_5O$) 192.5110, found 192.5114.

6-Methyl-5-methylene-6-phenyltetrahydropyran-2-ol (2f): IR (film) ν/cm^{-1} 3381, 3058, 1645; ^{1}H NMR δ (300 MHz, $CDCl_3$) 7.35−7.12 (5H, m), 5.09 (1H, sl), 5.06 (1H, s), 4.83 (1H, m), 4.01 (1H, sl), 2.40−2.33 (1H, m), 2.27−2.16 (1H, m), 1.94−1.87 (1H, m), 1.71−1.60 (1H, m), 1.58 (3H, s); ^{13}C NMR δ (75 MHz, $CDCl_3$) 146.49, 143.59, 128.51, 127.03, 125.60, 111.60, 91.81, 80.91, 35.04, 30.72, 29.90. HRMS calcd for $C_{13}H_{16}O_2$ (M^+) 204.1150, found 204.1152.

6-(Allyloxy)-2-methyl-3-methylene-2-phenyltetrahydropyran (3f): IR (film) ν/cm^{-1} 3086, 1652; ^{1}H NMR δ (300 MHz, $CDCl_3$) 7.35−7.16 (5H, m), 5.94 (1H, dddd, J = 17.2 Hz, J = 10.5 Hz, J = 6.4 Hz, J = 5.1 Hz), 5.31 (1H, dm, J = 17.2 Hz), 5.17 (1H, m), 5.15 (1H, m), 5.10 (1H, sl), 4.59 (1H, dd, J = 9.5 Hz, J = 2.5 Hz), 4.50 (1H, ddt, J = 12.7 Hz, J = 5.1 Hz, J = 1.5 Hz), 4.11 (1H, ddt, J = 12.7 Hz, J = 6.4 Hz, J = 1.3 Hz), 2.34−2.28 (1H, m), 2.23−2.10 (1H, m), 1.78−1.72 (1H, m), 1.68−1.53 (1H, m), 1.53 (3H, s).

1,4-Bis(2-hydroxy-6-methyl-5-methylenetetrahydropyran-6-yl)benzene (2g): IR (film) ν/cm^{-1} 3426, 3086, 1648; ^{1}H NMR δ (200 MHz, $(CD_3)_2CO$) 7.42−7.26 (4H, m), 5.33 (2H, d, J = 6.5 Hz), 5.17 (2H, d, J = 1.6 Hz), 5.15 (2H, sl), 4.86−4.80 (2H, m), 2.42−2.12 (4H, m), 1.86−1.53 (4H, m), 1.50 (6H, s); ^{13}C NMR δ (50 MHz, $(CD_3)_2CO$) 147.86, 143.11, 125.73, 110.30, 91.34, 79.74, 35.07, 30.61, 30.19. HRMS calcd for $C_{20}H_{26}O_4$ (M^+) 330.1831, found 330.1835.

1,3,5-Tris(2-hydroxy-6-methyl-5-methylenetetrahydropyran-6-yl)benzene (2h): IR (film) ν/cm^{-1} 3440, 1652; ^{1}H NMR δ (200 MHz, $CDCl_3$) 7.29−7.23 (3H, m), 5.13 (3H, sl), 5.09 (3H, sl), 4.85−4.75 (3H, m), 3.9 (3H, m), 2.43−2.08 (6H, m), 1.91−1.80 (6H, m), 1.53 (9H, s); ^{13}C NMR δ (50 MHz, $CDCl_3$) two diastereoisomers a/b isomer a 146.35, 144.57, 121.77, 111.72, 91.75, 81.13, 34.64, 30.93, 29.89 isomer b 146.45, 144.79, 121.64, 111.72, 91.75, 80.92, 34.93, 30.80, 29.67. HRMS calcd for $C_{27}H_{34}O_5$ ($M^+ - H_2O$) 438.2406, found 438.2411.

5-Methylene-6-(1,1-dimethylethyl)tetrahydropyran-2-ol (2i): IR (film) ν/cm^{-1} 3395, 3079, 1652; ^{1}H NMR δ (200 MHz, $CDCl_3$) two diastereoisomers a/b (60/40) isomer a 5.30 (1H, m), 4.92 (1H, m), 4.72 (1H, sl), 4.00 (1H, s), 3.25 (1H, d, J = 7.7 Hz), 2.23−2.15 (2H, m), 2.13−2.03 (1H, m), 1.60−1.49 (1H, m), 0.90 (9H, s) isomer b 4.90 (1H, m), 4.80 (1H, m), 4.69 (1H, d, J = 1.8 Hz), 3.85 (1H, d, J = 8.5 Hz), 3.70 (1H, d, J = 1.8 Hz), 2.52−2.35 (1H, m), 2.13−2.03 (1H, m), 1.94−1.82 (1H, m), 1.76−1.64 (1H, m), 0.91 (9H, s); ^{13}C NMR δ (50 MHz, $CDCl_3$) isomer a 145.31, 110.40, 91.56, 80.35, 35.02, 33.01, 28.67, 26.59 isomer b 144.98, 111.05, 94.22, 85.61, 34.79, 33.24, 29.39, 26.28. HRMS calcd for $C_{10}H_{16}O$ ($M^+ - H_2O$) 152.1201, found 152.1200.

(*E*)-6-Hydroxy-7-dimethyloct-4-enal (5i): IR (film) ν/cm^{-1} 3423, 3020, 2868, 2727, 1722, 1680; ^{1}H NMR δ (200 MHz, $CDCl_3$) 9.71 (1H, t, J = 1.7 Hz), 5.55 (2H, m), 3.63 (1H, d, J = 6.4 Hz), 2.49 (2H, m), 2.36 (2H, m), 1.75 (1H, sl), 0.82 (9H, s; ^{13}C NMR δ (50 MHz, $CDCl_3$) 201.93, 131.21, 130.59, 80.56, 43.06, 34.70, 25.58, 24.78.

5-Methylene-6-phenyltetrahydropyran-2-ol (2j): IR (film) ν/cm^{-1} 3395, 3080, 3030, 1625, 1600, 1585, 1455; ^{1}H NMR δ (300 MHz, $CDCl_3$) two diastereoisomers a/b (60/40) isomer a 7.3 (5H, m), 5.48 (1H, s), 5.32 (1H, m), 4.84 (1H, s), 4.20 (1H, d, J = 1.0 Hz), 3.59 (1H, sl), 2.78−2.59 (1H, m), 2.4−2.2 (1H, m), 1.93−1.78 (2H, m) isomer b 7.3 (5H, m), 4.92 (2H, m), 4.82 (1H, s), 4.13 (1H, d, J = 1.2 Hz), 3.94 (1H, sl), 2.51−2.41 (1H, m), 2.4−2.2 (1H, m), 2.07−1.93 (1H, m), 1.72−1.51 (1H, m); ^{13}C NMR δ (50 MHz, $CDCl_3$) isomer a 146.71, 139.12, 128.13, 127.72, 127.65, 111.21, 91.95, 74.66, 32.23, 27.43 isomer b 145.68, 139.56, 128.07, 127.78, 127.65, 111.88, 96.39, 80.02,

34.12, 30.99. HRMS calcd for $C_{12}H_{12}O$ ($M^+ - H_2O$) 172.0888, found 172.0889.

(*E*)-6-Hydroxy-6-phenylhex-4-enal (5j): IR (film) ν/cm^{-1} 3438, 3031, 2852, 2722, 1719, 1677, 1620, 1590, 1493, 1452; ^{1}H NMR δ (200 MHz, $CDCl_3$) 9.68 (1H, t, J = 1.4 Hz), 7.50−7.22 (5H, m), 5.68 (2H, m), 5.09 (1H, d, J = 4.3 Hz), 3.55 (1H, sl), 2.49 (2H, m), 2.34 (2H, m); ^{13}C NMR δ (50 MHz, $CDCl_3$) 201.99, 142.91, 133.50, 129.49, 128.46, 126.58, 126.08, 74.63, 42.78, 24.48.

6-Ethyl-5-methylenetetrahydropyran-2-ol (2k): IR (film) ν/cm^{-1} 3407, 3085, 1652; ^{1}H NMR δ (200 MHz, $CDCl_3$) two diastereoisomers a/b (60/40) isomer a 5.27 (1H, t, J = 3.5 Hz), 4.79 (1H, sl), 4.73 (1H, s), 4.25 (1H, t, J = 6.5 Hz), 3.15 (1H, sl), 2.5−2.35 (1H, m), 2.3−2.1 (1H, m), 2.0−1.5 (4H, m), 0.93 (3H, t, J = 7.4 Hz) isomer b 4.91 (1H, dd, J = 8.5 Hz, J = 2.0 Hz), 4.79 (1H, sl), 4.78 (1H, sl), 3.74 (1H, t, J = 6.4 Hz), 3.5 (1H, sl), 2.5−2.35 (1H, m), 2.3−2.1 (1H, m), 2.0−1.5 (4H, m), 0.97 (3H, t, J = 7.5 Hz); ^{13}C NMR δ (50 MHz, $CDCl_3$) isomer a 146.21, 107.49, 91.48, 72.95, 32.67, 27.64, 24.49, 10.21 isomer b 144.92, 108.08, 95.68, 77.78, 34.54, 30.51, 25.04, 10.44. HRMS calcd for $C_8H_{14}O_2$ (M^+) 142.0994, found 142.0993.

(*E*)-6-Hydroxyoct-4-enal (5k): IR (film) ν/cm^{-1} 3370, 3050, 2870, 2730, 1723, 1672; ^{1}H NMR δ (200 MHz, $CDCl_3$) 9.73 (1H, t, J = 1.5 Hz), 5.49 (2H, m), 4.32 (1H, sl), 3.94 (1H, q, J = 6.4 Hz), 2.51 (2H, m), 2.36 (2H, m),1.72−1.64 (2H, m), 0.85 (3H, t, J = 7.5 Hz); ^{13}C NMR δ (50 MHz, $CDCl_3$) 201.89, 134.13, 129.31, 74.06, 43.07, 30.06, 24.65, 9.64. HRMS calcd for $C_8H_{14}O_2$ (M^+) 142.0994, found 142.0996.

5-Methylenetetrahydropyran-2-ol (2l): IR (film) ν/cm^{-1} 3381, 3072, 1659; ^{1}H NMR δ (200 MHz, $CDCl_3$) 5.07 (1H, m), 4.78 (1H, sl), 4.77 (1H, sl), 4.37 (1H, d, J = 12.4 Hz), 4.03 (1H, sl), 3.94 (1H, d, J = 12.4 Hz), 2.55−2.46 (1H, m), 2.25−2.17 (1H, m), 1.88−1.81 (1H, m), 1.74−1.66 (1H, m); ^{13}C NMR δ (50 MHz, $CDCl_3$) 142.60, 109.38, 93.06, 66.49, 32.59, 27.50. Anal. Calcd for $C_6H_{10}O_2$: C, 63.14; H, 8.83. Found: C, 63.10; H, 8.72.

2-(Allyloxy)-5-methylenetetrahydropyran (3l): ^{1}H NMR δ (200 MHz, $CDCl_3$) 5.86 (1H, m), 5.22 (1H, dm, J = 17.2 Hz), 5.09 (1H, dm, J = 10.3 Hz), 4.72 (1H, m), 4.72 (1H, s), 4.71 (1H, s), 4.23 (1H, d, J = 12.4 Hz), 4.2−3.9 (2H, m), 3.81 (1H, d, J = 12.4 Hz), 2.57−2.41 (1H, m), 2.19−2.07 (1H, m), 1.79−1.71 (2H, m).

(*Z*)-Ethylidenetetrahydropyran-2-ol (2m): IR (film) ν/cm^{-1} 3395, 1680; ^{1}H NMR δ (200 MHz, $CDCl_3$) 5.21 (1H, q, J = 6.9 Hz), 5.00 (1H, m), 4.45 (1H, sl), 4.41 (1H, d, J = 12.8 Hz), 4.01 (1H, d, J = 12.8 Hz), 2.43−2.30 (1H, m), 2.14−2.01 (1H, m), 1.86−1.71 (1H, m), 1.66−1.53 (1H, m), 1.52 (3H, d, J = 6.9 Hz); ^{13}C NMR δ (50 MHz, $CDCl_3$) 133.03, 118.60, 93.63, 60.64, 32.90, 28.87, 12.45. HRMS calcd for $C_7H_{10}O$ ($M^+ - H_2O$) 110.0732, found 110.0728.

(*E*)-6-Hydroxy-4-methylhex-4-enal (5m): IR (film) ν/cm^{-1} 3381, 3010, 2854, 2734, 1722, 1673; ^{1}H NMR δ (200 MHz, $CDCl_3$) 9.69 (1H, t, J = 1.7 Hz), 5.37−5.29 (1H, m), 4.10 (1H, sl), 4.06 (2H, d, J = 6.7 Hz), 2.50 (2H, tm, J = 7.6 Hz), 2.28 (2H, t, J = 7.5 Hz), 1.60 (3H, s); ^{13}C NMR δ (50 MHz, $CDCl_3$) 202.24, 136.87, 124.28, 58.87, 41.61, 31.31, 16.24. HRMS calcd for $C_7H_{10}O$ ($M^+ - H_2O$) 110.0732, found 110.0738.

Procedure for the Wittig Reaction. The tetrahydropyranol **2a** (5 mmol) was added to a mixture of phosphorus ylide $Ph_3P{=}CHCO_2Me$ (5 mmol) and toluene (5 mL). The mixture was heated at 115 °C for 2 h. After cooling, diethyl ether (5 mL) was added, and the mixture was filtered through a layer of silica gel. The filtrate was evaporated under vacuum, and the products were isolated after column chromatography over silica gel (75:25 pentane−Et_2O).

Methyl (*E*)-6-(1-hydroxyspirocyclohexane)hepta-2,6-dienoate (6a): IR (film) ν/cm^{-1} 3488, 3093, 3021, 1732, 1654, 1639; ^{1}H NMR δ (200 MHz, $CDCl_3$) 6.90 (1H, dt, J = 15.7 Hz, J = 6.5 Hz), 5.75 (1H, dt, J = 15.7 Hz, J = 1.5 Hz), 5.05 (1H, s), 4.71 (1H, s), 3.61 (3H, s), 2.34−2.25 (2H, m), 2.20−2.14 (2H, m), 1.70 (1H, s), 1.56−1.13 (10H, m); ^{13}C NMR δ (50 MHz, $CDCl_3$) 166.90, 154.48, 149.02, 120.84, 108.26, 73.53, 51.19, 36.01, 31.28, 28.95, 25.43, 21.77.

Methyl (*Z*)-6-(1-hydroxyspirocyclohexane)hepta-2,6-dienoate (7a): IR (film) ν/cm^{-1} 3448, 3089, 3033, 1719, 1647; ^{1}H NMR δ (200 MHz, $CDCl_3$) 6.20 (1H, dt, J = 11.5 Hz, J = 7.4 Hz), 5.74 (1H, dt, J = 11.5 Hz, J = 1.6 Hz), 5.08 (1H, s), 4.79 (1H, sl), 3.65 (3H, s), 3.05 (1H, sl), 2.35−2.17 (4H, m), 1.64−1.20 (10H, m).

Procedure for the Oxidation Reaction. To a solution of tetrahydropyranol **2** (5 mmol) in CH_2Cl_2 (40 mL) were added 4 Å molecular sieves (1.36 g) and 4-methylmorpholine *N*-oxide (878 mg, 7.5 mmol). After stirring at room temperature for 10 min, TPAP (122 mg, 0.35 mmol) was added, and the progress of the reaction was monitored by GC. After completion of the oxidation (1 h), the mixture was diluted with CH_2Cl_2 (20 mL) and washed successively with 5% Na_2SO_3 in brine (15 mL), brine (15 mL), and saturated $CuSO_4$ (15 mL). The organic layer was dried ($MgSO_4$), concentrated under reduced pressure, and chromatographed on a column of silica gel (85:15 pentane−Et_2O).

5-Methylene-6-spirocyclohexanetetrahydropyran-2-one (8a): IR (film) ν/cm^{-1} 3085, 1735, 1637; ^{1}H NMR δ (200 MHz, $CDCl_3$) 4.90 (1H, s), 4.87 (1H, s), 2.46 (4H, s), 1.87−1.43 (9H, m), 1.2−1.05 (1H, m); ^{13}C NMR δ (50 MHz, $CDCl_3$) 171.30, 147.02, 109.80, 84.53, 37.57, 30.79, 27.35, 24.89, 21.02. HRMS calcd for $C_{11}H_{16}O_2$ (M^+) 180.2490, found 180.2495.

6,6-Dimethyl-5-methylenetetrahydropyran-2-one (8b): IR (film) ν/cm^{-1} 3093, 1738, 1651; ^{1}H NMR δ (200 MHz, $CDCl_3$) 4.91 (2H, sl), 2.49 (4H, s), 1.45 (6H, s); ^{13}C NMR δ (50 MHz, $CDCl_3$) 171.22, 146.42, 109.88, 84.14, 30.84, 29.27, 27.13. HRMS calcd for $C_8H_{12}O_2$ (M^+) 140.1836, found 140.1846.

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Supporting Information Available: ^{1}H and ^{13}C NMR of compounds **4a**, **2c**, **3c**, **2d**, **3d**, **2e**, **3e**, **2f**, **2g**, **2h**, **2i**, **5i**, **2j**, **5j**, **2k**, **5k**, **2m**, **5m**, **6a**, **8a**, **8b** and ^{1}H NMR of compounds **3f**, **3l**, **7a**. This material is available free of charge via the Internet at http://pubs.acs.org.

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