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Asymmetric Synthesis of Azepine-Fused Cyclobutanes from Yne-Methylenecyclopropanes Involving Cyclopropanation/C−C Cleavage/Wagner−Meerwein Rearrangement and Reaction Mechanism

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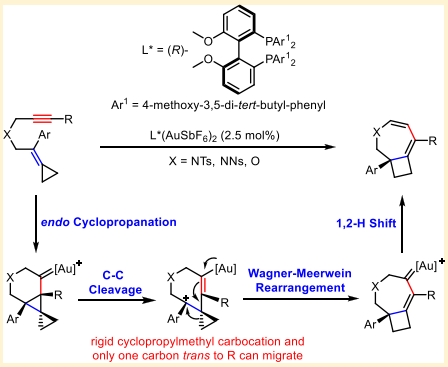
Supporting Information

ABSTRACT: Ring expansion of in situ generated cyclopropylmethyl cations via Wagner−Meerwein rearrangement to cyclobutanes is widely used in synthesis. However, the cyclopropylmethyl cations generated are planar, which would lead to loss of chiral information in the case of chiral precursors, making an asymmetric version of such ring expansion difficult. In the present work, a gold(I)-catalyzed asymmetric cyclopropanation/C−C cleavage/Wagner−Meerwein rearrangement of easily affordable yne-methylenecyclopropanes (1,6-yne-MCPs) has been developed to synthesize 3-azabicyclo[5.2.0]nonadiene, a bicyclic 7/4 ring (azepine fused with cyclobutane) with a bridgehead aryl substituent. This reaction overcomes the challenging loss of chirality from the Wagner−Meerwein rearrangement. Density functional theory calculations indicate that the chirality of the final product comes from the first cyclopropanation step in this reaction. The chirality in the resultant cyclopropane is lost in the following C−C cleavage step, generating rigid, planar cyclopropylmethyl carbocation intermediate. Then, only one carbon of the cyclopropyl group in the cyclopropylmethyl carbocation intermediate can migrate via ring expansion in the Wagner−Meerwein rearrangement process, and consequently, the chirality in the cyclopropane generated in the first step is transferred to the final product.



INTRODUCTION

Many natural products with significant biological and medicinal activities have cyclobutane motif.[1] Therefore, significant efforts have been devoted by many chemists to develop methods to synthesize cyclobutanes.[2] Developing more synthetic methods to cyclobutanes, especially their asymmetric versions are highly required so that synthetic chemists can have more tools in their efficient target-, diversity-, and function-oriented syntheses.

A widely used method to access four-membered rings is the ring expansion of in situ generated cyclopropylmethyl cations via the Wagner−Meerwein rearrangement.[3] One of the efficient ways of generating cyclopropylmethyl cations is using methylenecyclopropanes (MCPs) as precursors.[4−8] The MCP ring expansion can be directly triggered by transition-metal (such as Pt, Pd, and Au) coordination to the alkene part of MCPs.[5] Another way to achieve ring expansion is through cycloisomerization by connecting MCP with alkynes. For example, in 2008, a gold-catalyzed cycloisomerization of 1,6-yne-MCPs to four-membered carbocycle-embedded polycyclic compounds via a key cyclopropylmethyl carbocation intermediate was accomplished by Toste (Scheme 1a).[6] In 2014, a series of gold-catalyzed cycloisomerizations of 1,5-yne-MCPs through MCP expansions were also reported by Gagné,[7] one representative example[7a] of which is shown in Scheme 1b. Recently, Shi has found that 1,7-yne-MCPs can be converted to two different cycloisomerization products by using two different gold catalysts, in which a ring expansion of cyclopropylmethyl carbocation intermediate was also involved (Scheme 1c).[8] One drawback of the ring expansion of MCPs is that these reactions are difficult to be advanced to their asymmetric versions.[9−12] The main reason is that these reactions generate planar achiral cyclopropylmethyl carbocation intermediates, which then undergo ring expansion via the Wagner−Meerwein rearrangement to give racemic four-membered products. This could be the reason why only moderate enantioselectivity has been realized when Gagné and co-workers developed the asymmetric version of their reaction shown in Scheme 1b.[7a]

Here, we report our advance in this field, a new MCP ring expansion to form 3-azabicyclo[5.2.0]nonadienes enantioselectively. This reaction not only provides a new way to four-membered rings, but also leads to the challenging seven-membered heterocycles, in this case the azepine derivatives (fused with the four-membered rings), which are widely found

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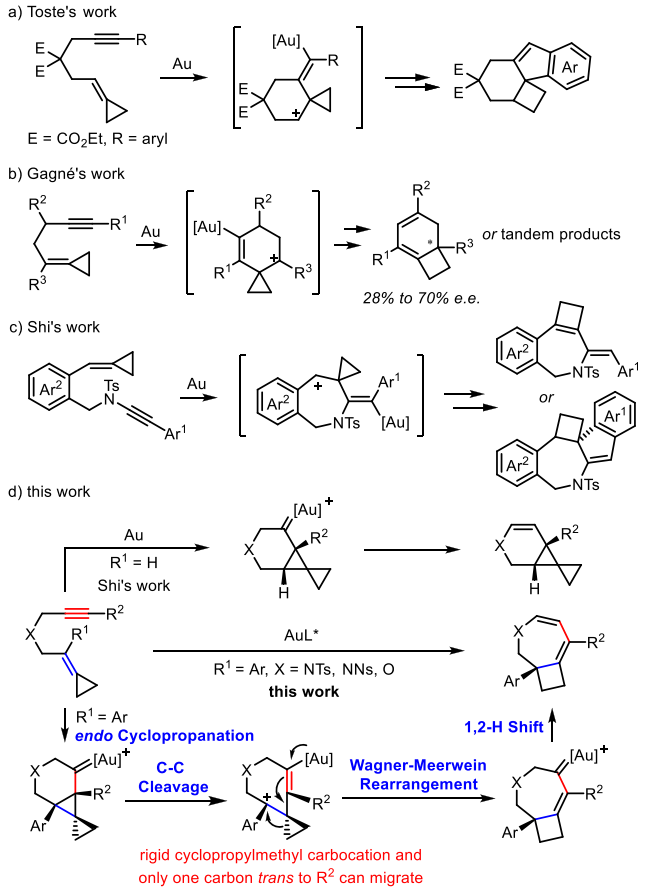
Scheme 1. Ring Expansions of MCPs via Wagner−Meerwein Rearrangement



in a variety of bioactive natural products and pharmaceutically important compounds.[13] Furthermore, we achieved the asymmetric version of this 7/4 ring synthesis by overcoming the "planar cyclopropylmethyl carbocation" challenge mentioned above. In addition to reporting the development of our asymmetric cyclization/rearrangement reaction, we also present here the reaction mechanism, especially as to how the chirality from the first cyclopropanation step is transferred (and not lost) to the final product in the Wagner−Meerwein rearrangement. We point out here that, for R^1 = H, the reaction in Scheme 1d gave cyclopropanation products, as demonstrated by Shi and co-workers.[14] Therefore, a computational understanding of the different reaction patterns for R^1 = H and Ar groups in Scheme 1d has also been presented in this paper.

RESULTS AND DISCUSSION

We discovered the present synthesis of azepine-fused cyclobutanes serendipitously when we tried to develop a transition-metal-catalyzed [m + n + o] reaction using 1,6-yne-MCP **1i** as the precursor of the cyclization synthon (see this in Table 2, which has been discussed later in the paper). We found that, under the catalysis of Au (Shi's conditions[14]), **1i** did not afford the cyclopropanation product that was our desired product for metal-catalyzed cycloaddition, instead a bicyclic 7/4 product was formed, as shown in Scheme 1d. Then, we realized that the aryl group could be the key to the synthesis of this challenging and important azepine-fused cyclobutane skeleton with a bridgehead aryl group, starting from easily prepared 1,6-yne-MCP. Therefore, we decided to develop this reaction as a general method to synthesize bicyclic 7/4 compounds as our research project.

Reaction Optimizations. First, we screened reaction conditions for the present reaction by using nitrogen-tethered MCP **1a** as the model substrate. The reaction was initially tested in 1,2-dichloroethane (DCE) by using a commercially available Au(I) salt as the catalyst. To our delight, the expected 3-azabicyclo[5.2.0]nonadiene **2a** was obtained in 97% yield (Table 1, entry 1). Structure of product **2a** was further confirmed by the X-ray crystal analysis.[15] If the reaction time was reduced to 1 h, mostly starting material remained. We also tested newly prepared Au catalyst with either JohnPhos or ^{t}BuXPhos ligand, observing that the reaction gave comparable yields of **2a** (Table 1, entries 2 and 3). It was also worth mentioning that a simpler triphenylphosphine (PPh_3) ligand could be used in this transformation (Table 1, entry 4). With these observations in hand, we next studied whether this reaction could be advanced to its asymmetric version, even though previous reports of such rearrangement had encountered limited success.[10−12] We chose L1 (*O*,*O*′-(*S*)-(1,1′-dinaphthyl-2,2′-diyl)-*N*,*N*-di-*i*-propyl-phosphoramidite) as the chiral ligand, which had previously proven to be efficient in asymmetric gold-catalyzed cycloisomerization of 1,6-enynes.[16] The reaction of **1a** using L1 as chiral ligand gave the target product, but the e.e. was just 7% (Table 1, entry 5). We then tested the reaction using the gold catalyst and L2 ((*R*)-4-MeO-3,5-(*t*-Bu)$_2$-MeOBIPHEP) ligand,[16b,17] finding that the reaction afforded **2a** product in 97% yield and 78% e.e. (Table 1, entry 6). Through screening counter anions of the catalysts (Table 1, entries 7−11) and reaction solvents (Table 1, entries 12−15), we found that a combination of hexafluoroantimonate anion and toluene solvent gave the best results: 96% reaction yield and 96% e.e. (Table 1, entry 14).

Reaction Scope. With the optimized reaction conditions (Table 1, entry 14) in hand, we then carried out reaction of **1a** in a larger scale. We found that in 0.2 mmol scale, product **2a** was obtained in 99% yield and 99% e.e. (Table 2, entry 1). Moreover, **2a** could be also synthesized in gram scale, with the same yield and e.e. value (see Experimental Section). After that, we studied the scope of the present cascade reaction. We found that substrates bearing electron-donating substituents on aryl rings linked to the alkene motif (**1b** and **1c**) could also give rise to products **2b** and **2c** in high yields and enantiomeric excess values, respectively (Table 2, entries 2 and 3). For substrate **1d** with an electron-withdrawing CF_3 group in the aryl ring, the reaction only gave a complex mixture under asymmetric conditions (Table 2, entry 4). We found that this substrate gave cyclopropanation product (±)-**3d**[14] when no chiral ligand was used (using (MeCN)Au(JohnPhos)SbF_6 as the catalyst in DCE solvent; Table 2, entry 4).

We then investigated substituent effects in the alkyne moiety of yne-MCPs. We found substrates **1e−h**, in which the aryl rings had either electron-donating or electron-withdrawing substituents, had high reactivities, and gave excellent enantioselectivities (Table 2, entries 5−8). The absolute configuration of **2** was determined by X-ray structure of **2h** in 99% e.e., which had an R configuration.[18] Substrates **1i−k** (Table 2, entries 9−11) with alkene substituents in the alkyne moiety of yne-MCPs also gave corresponding products in high yields (from 68 to 85%) and enantiomeric excess values (from 90 to 97%). To our surprise, no reaction took place for **1l** in which the alkyne moiety was substituted by an ester group

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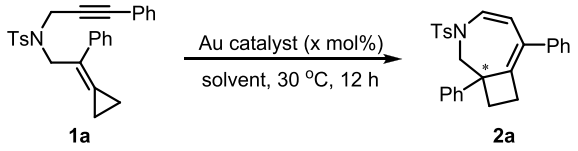
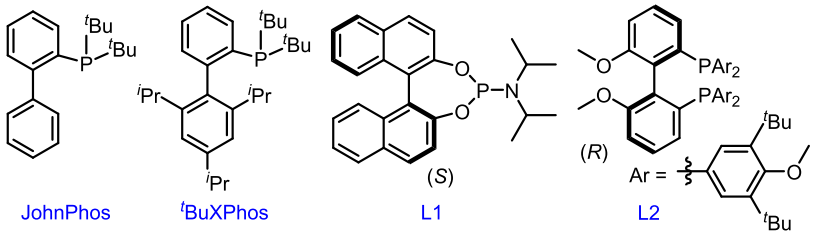
Table 1. Optimization of Reaction Conditions[a]



1a 2a

Entry	Au catalyst	x	solvent	yield	e.e.
1	(MeCN)Au(JohnPhos)SbF_6	5	DCE	97 %	-
2	Au(JohnPhos)SbF_6	5	DCE	95 %	-
3	Au(^{t}BuXPhos)SbF_6	5	DCE	96 %	-
4	Au(PPh_3)SbF_6	5	DCE	96 %	-
5	Au(L1)SbF_6	5	DCE	94 %	7 %
6	L2(AuSbF_6)$_2$	2.5	DCE	97 %	78 %
7	L2(AuBAr_4^F)$_2$	2.5	DCE	N. R.	-
8	L2(AuOTf)$_2$	2.5	DCE	mixture [b]	-
9	L2(AuNTf_2)$_2$	2.5	DCE	mixture [c]	-
10	L2(AuBF_4)$_2$	2.5	DCE	94 %	47 %
11	L2(AuPF_6)$_2$	2.5	DCE	mixture [d]	-
12	L2(AuSbF_6)$_2$	2.5	DCM	98 %	85 %
13	L2(AuSbF_6)$_2$	2.5	THF	N. R.	-
14	**L2(AuSbF_6)$_2$**	**2.5**	**Toluene**	**96 %**	**96 %**
15	L2(AuSbF_6)$_2$	2.5	MeCN	N. R.	-



[a]Reaction conditions: 0.1 mmol **1a**, 2.5 or 5 mol % Au catalyst, solvent (0.05 M), 30 °C, 12 h. [b]A mixture of the substrate and product with a ratio of 0.17/1. [c]A mixture of the substrate and product with a ratio of 0.45/1. [d]A mixture of the substrate and product with a ratio of 2.8/1.

(Table 2, entry 12). In this case, most **1l** could be recovered back after 12 h of reaction under standard reaction conditions. It was interesting to note that when the R group in the substrate was a methyl group, a mixture of 7/4 compound **2m** and cyclopropanation product **3m** was obtained, with a ratio of 1.3/1 and in 86% total yield (Table 2, entry 13). Moreover, this reaction showed low enantioselectivities because **2m** and **3m** had 27 and 64% e.e., respectively.[19] We then studied substrates with different tethers. For both the nitrogen-tethered yne-MCP with a *para*-nitrobenzenesulfonyl-protecting group (**1n**) and the oxygen-tethered yne-MCP (**1o**), the desired cyclization/rearrangement products **2n** (84% yield, 82% e.e.) and **2o** (47% yield, 43% e.e.) were obtained (Table 2, entries 14 and 15). It was reported that the tether in the similar gold-catalyzed cycloisomerization cannot be NBoc, and we did not test such substrates.[20] For some reactions to give solid products (**2a**, **2c**, **2e**, and **2f**), we directly measured enantiomeric excess values of the reaction mixture once reactions finished and found that these results were the same as those enantiomeric excess values from the purified solid products. This indicates that the high enantioselectivity of the present reactions were not artifacts from the purified products.

Computational Investigation. To gain more insights into the mechanism and chirality transfer processes in this cyclopropanation/rearrangement reaction, density functional theory (DFT) calculations at the PCM(toluene)/M06-2X/6-311+G(d,p) (SDD for Au)//B3LYP/6-31G(d) (SDD for Au) level[21−23] have been executed. We first chose yne-MCP **1a** to investigate its reaction mechanism. The *para*-toluenesulfonyl-protecting group in **1a** and the ligand in the Au(I) catalyst

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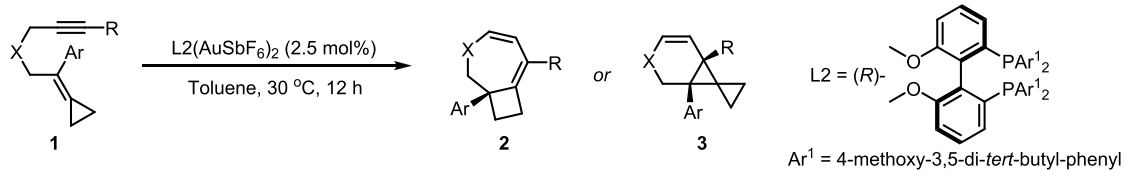
Table 2. Reaction Scope[a]



Entry	Substrate	Product [b]	Entry	Substrate	Product [b]
1	**1a**, Ar = Ph	**2a**, 99 %, 99 % e.e.	9 [d]	**1i**, $R^1 = R^2 = H$	**2i**, 82 %, 90 % e.e.
2	**1b**, Ar = 4-MeC_6H_4	**2b**, 99 %, 98 % e.e.	10	**1j**, R^1 = Me, R^2 = H	**2j**, 68 %, 97 % e.e.
3	**1c**, Ar = 4-$MeOC_6H_4$	**2c**, 97 %, 97 % e.e.	11 [e]	**1k**, R^1 = H, R^2 = Me	**2k**, 85 %, 97 % e.e.
4	**1d**, Ar = 4-$CF_3C_6H_4$	**3d**, mixture (89 % [c])	12	**1l**, R = CO_2Me	N. R.
5	**1e**, R = 4-MeC_6H_4	**2e**, 96 %, 98 % e.e.	13 [e, f]	**1m**, R = Me	**2m** + **3m**: 86 % **2m** / **3m** = 1.3 / 1 **2m**: 27 % e.e. **3m**: 64 % e.e.
6	**1f**, R = 4-$MeOC_6H_4$	**2f**, 96 %, 99 % e.e.	14	**1n**	**2n**, 84 %, 82 % e.e.
7	**1g**, R = 4-$CF_3C_6H_4$	**2g**, 93 %, 99 % e.e.			
8	**1h**, R = 4-BrC_6H_4	**2h**, 95 %, 99 % e.e.	15	**1o**, Ar = 4-$MeOC_6H_4$	**2o**, 47 %, 43 % e.e.

[a]Reaction conditions: 0.2 mmol **1**, 2.5 mol % L2$(AuSbF_6)_2$, toluene (0.05 M), 30 °C, 12 h. [b]Isolated yields and enantiomeric excess (e.e.) values were determined by high-performance liquid chromatography (HPLC). [c]When (MeCN)Au(JohnPhos)SbF_6 and 1,2-dichloroethane (DCE) were used, (±)-**3d** was obtained in 89% yield. [d]1 h. [e]3 h. [f]0.6 mmol scale (0.05 M). N.R. = no reaction.

used were simplified as a smaller methanesulfonyl group and trimethylphosphine, respectively. The energy profile (Figure 1a) was drawn based on the relative Gibbs free energies in toluene solution ($\Delta G_{sol\text{-}Toluene}$). Other computed values such as enthalpies are given in the Supporting Information. The first step of the catalytic cycle is the well-known endo cycloisomerization of 1,6-enyne,[24] starting from a complex of Au(I) catalyst and substrate (**INT1-Ph**) to give **INT2-Ph** via a cyclopropanation transition state **TS1-Ph**. This step is an endergonic process of 5.2 kcal/mol with a computed activation free energy of 19.6 kcal/mol. The newly formed tricyclic intermediate **INT2-Ph** with an elongated carbon−carbon (C−C) bond length of 2.19 Å can be regarded as a nonclassical carbocation (Figure 1b), considering that C1−C2−C5 in this intermediate does not form a regular cyclopropane structure (this intermediate could also be regarded as a C1 cation). The two phenyl groups in this intermediate are in a cis configuration. Then, this C1−C5 bond in **INT2-Ph** easily breaks up via **TS3-Ph** to generate a ring-expanded intermediate **INT4-Ph** with an activation free energy of 4.0 kcal/mol. We have to mention here that **TS3-Ph** has a computed imaginary frequency of 52.9 cm^{-1}, suggesting that this corresponds a rotation of Ph group at C1 position [intrinsic reaction coordinate (IRC) could not be run here] so that the C1−C5 bond can be further broken to give **INT4-Ph**. We can locate both reactant and product in this step by geometry optimizations of structures with slightly changed C1−C5 distances that are shorter or greater than 2.48 Å. In the

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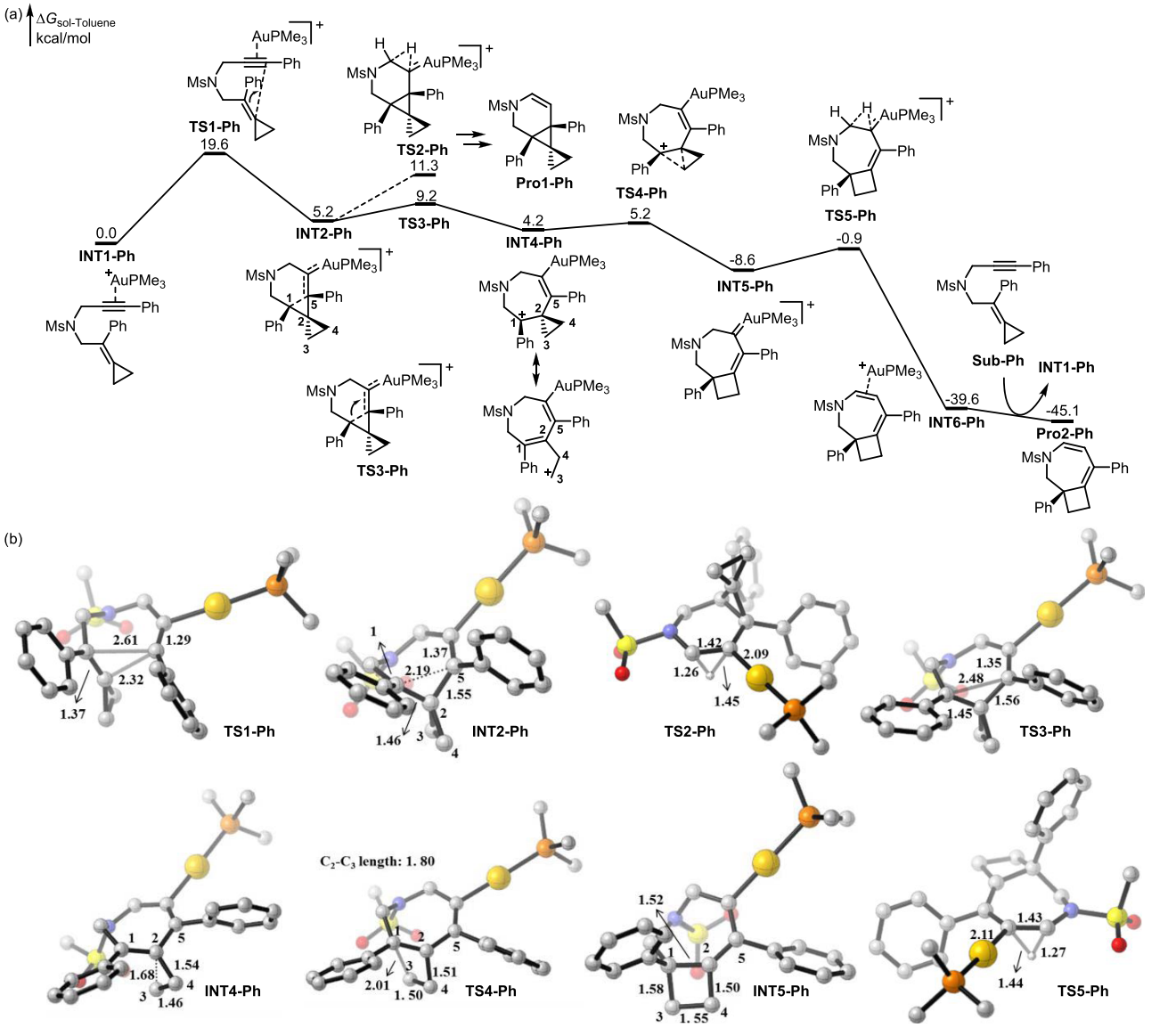

Figure 1. Computed energy surface for the reaction of **1a** and the key structures of several stationary points (bond distances in angstrom, and most hydrogen atoms in (b) are omitted for clarification).

later discussion of **TS3-H** in Figure 2, we can see a real C1−C5 bond breaking by IRC with the computed imaginary frequency of 409.4 cm^{-1}.

Intermediate **INT4-Ph**, which is also a nonclassical carbocation, is a special cyclopropylmethyl carbocation with memory of chirality (see discussion below).[25] In this intermediate, C1 carbon is planar, sp^2-hybridized, suggesting this carbon has lost its chirality from **INT2-Ph**, in which C1 is sp^3-hybridized (C5 is weakly connected to C1). But the cyclopropane characteristic in **INT4-Ph** is almost lost because its C2−C3 bond is 1.68 Å (see Figure 1 for atom labeling). **INT4-Ph** can also be regarded as a homoallylic cation if we consider that C1−C2 has double-bond character. Therefore, C1−C2 and the aryl group linked to C1 form a plane and C3 is at the bottom of this plane. Since the following step is the Wagner−Meerwein rearrangement, only C3 migration (not C4, see below) can occur and the chirality from **INT2-Ph** is retained in **INT5-Ph**. Therefore, we can call **INT4-Ph** is a carbocation with memory of chirality. (Here, we mean that the chiral center at C1 is kept from **INT2-Ph** to **INT5-Ph**, even though this carbon temporarily becomes planar without chirality in the intermediate between **INT2-Ph** and **INT5-Ph**.) The computed activation free energy for the carbocation rearrangement from **INT4-Ph** to **INT5-Ph**, is only 1.0 kcal/mol.[26] There is another possibility that intermediate **INT4-Ph** could form the C2−C3 bond and break the C2−C4 bond to form another homoallylic cation at C4, but this homoallylic cation rearrangement is prohibited sterically by the phenyl group adjacent to C2 and can be excluded for consideration (see more discussion in the Supporting Information).

After that, a [1,2]-hydride shift converts **INT5-Ph** to **INT6-Ph**, which is a complex of Au(I) catalyst and product, with an activation free energy of 7.7 kcal/mol. The [1,2]-hydride shift step is exergonic by 31.0 kcal/mol. The final product **Pro2-Ph** is liberated after an exchange reaction of **INT6-Ph** with substrate, which is slightly exergonic by 5.5 kcal/mol. In general, the cyclopropanation step is the rate-determining step and the enantioselectivity is determined here. This newly constructed chiral center is then retained completely in the subsequent Wagner−Meerwein rearrangement.

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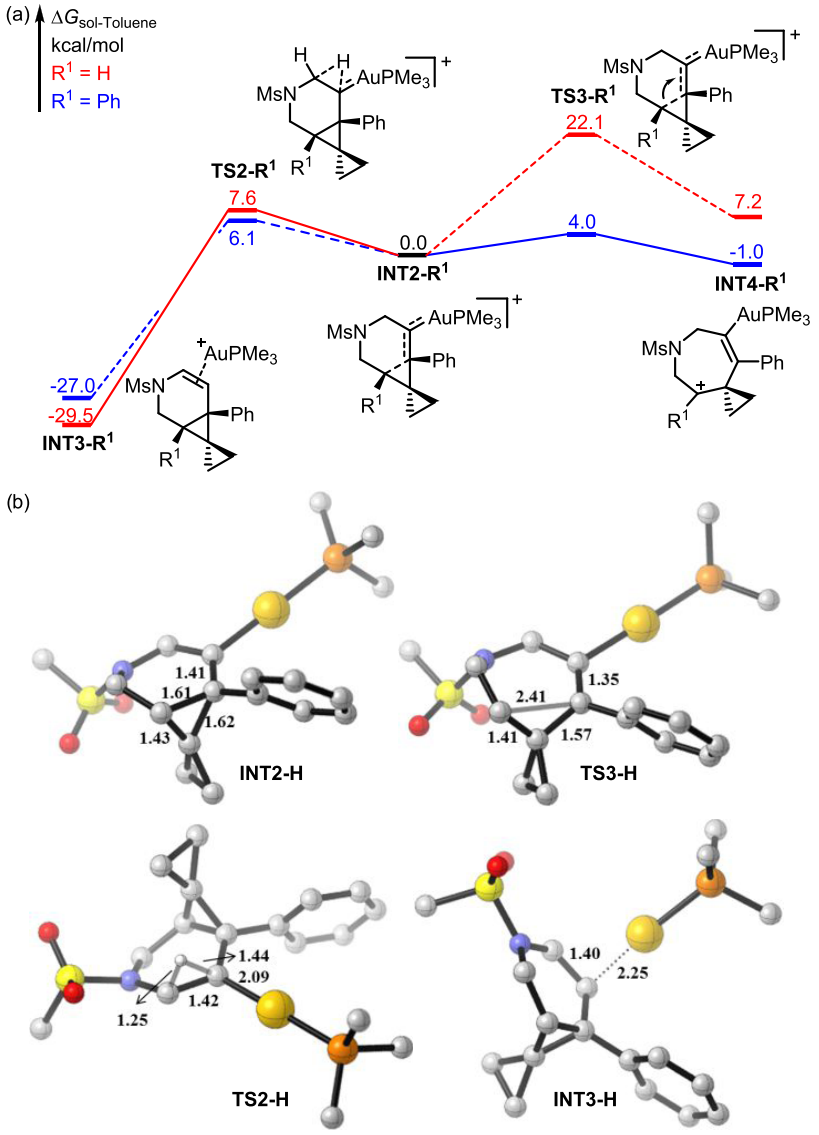

Figure 2. Ring expansion vs [1,2]-hydride shift for R^1 = Ph and R^1 = H (bond distances in angstrom, and most hydrogen atoms in (b) are omitted for clarification).

Ring Expansion vs [1,2]-Hydride Shift. Here we explain why cyclopropanation product, which was observed by Shi,[14] was not generated in the present system. Our calculations indicated that the direct [1,2]-hydride shift in **INT2-Ph**, giving a tricyclic product **Pro1-Ph**, has a higher activation free energy compared to the irreversible C−C bond cleavage and migration in Figure 2a,b (6.1 vs 4.0 kcal/mol). Therefore, the formation of cyclopropanation product is disfavored, which agrees with our experiments. We computed the case for R^1 = H, the Shi system, finding that the C−C bond cleavage is now requiring an activation free energy of 22.1 kcal/mol, while the [1,2]-hydride shift to give cyclopropanation product is still easy with a computed activation free energy of 7.6 kcal/mol. Certainly, the C−C bond cleavage in Shi's case generates a secondary carbocation and is disfavored. While for yne-MCP with R^1 = Ar group, this cation can be stabilized by the aromatic substituent and the C−C bond cleavage is easy and needs only 4.0 kcal/mol. Therefore, the stabilization of the carbocation by aryl ring is the key reason for the different reaction patterns for Shi's work and the present work.

Chemoselectivities for Reactions of 1d and 1m. Now let us discuss the substituent effect found in substrates **1d** and **1m** to answer the question regarding less or no generation of 7/4 products (Table 2). Since both chemoselectivity determination reactions (through ring expansion and [1,2]-hydride shift) arise from the same intermediate, we simply compare these two transition states here. Chemoselectivity for the reaction of **1d** was first investigated. As shown in Figure 3a, substrate **1d** also gives a nonclassical cation intermediate **INT2-CF_3Ph**. The electron-withdrawing CF_3 group in the aryl ring has an influence on this nonclassical cation intermediate, in which a shorter elongated C−C bond of 2.14 Å is observed in **INT2-CF_3Ph** compared to **INT2-Ph** (Figure 3b). This means that more cationic character is localized in the former species than that in the latter species. This can explain the [1,2]-hydride shift here is easier (3.5 kcal/mol here compared to 7.6 kcal/mol for **INT2-Ph**). Comparing to a phenyl group in **INT4-Ph**, this electron-withdrawing CF_3 group also has less stabilization on the cation intermediate **INT4-CF_3Ph** (−0.7 kcal/mol of **INT4-CF_3Ph** from **INT2-CF_3Ph** vs −1.0 kcal/mol of **INT4-Ph** from **INT2-Ph** in $\Delta G_{\text{sol-Toulene}}$). This makes the

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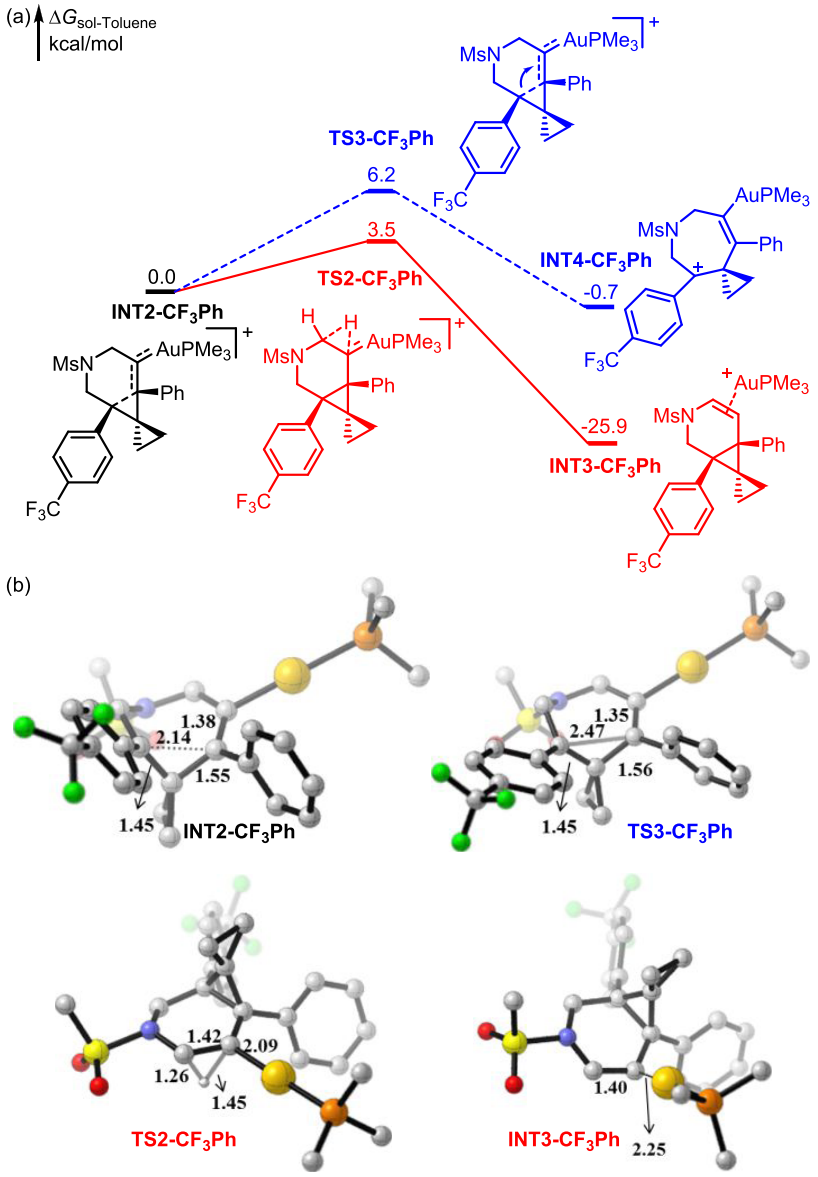

Figure 3. Chemoselectivity for the reaction of **1d** (bond distances in angstrom, and most hydrogen atoms in (b) are omitted for clarification).

expansion step become more difficult (its transition state is destabilized to some extent) than the direct [1,2]-hydride shift (6.2 kcal/mol of **TS3-CF$_3$Ph** vs 3.5 kcal/mol of **TS2-CF$_3$Ph** in $\Delta G_{\text{sol-Toulene}}^{\ddagger}$), which can explain that only product **3d** is obtained.

We also studied the reaction of substrate **1m** in Figure 4a, which gave a mixture of two products **2m** and **3m** with a ratio of 1.3/1. As shown in Figure 4b, a nonclassical cation intermediate **INT2-Me** with a shorter elongated C−C bond of 2.15 Å is found comparing to **INT2-Ph**. We proposed that the present system with Me group could lose some conjugation with the carbene moiety compared to that in the previous system with Ph group, making C1−C5 become shorter and the carbene part in this intermediate have more positive charge. Therefore, [1,2]-hydride shift is also easier here (3.9 vs 7.6 kcal/mol for **INT2-Ph**). This shorter C−C bond also makes the ring expansion of **INT2-Me** (through **TS3-Me**) slightly more difficult than the direct [1,2]-hydride shift (through **TS2-Me**). Moreover, the computed energy difference of **TS2-Me** and **TS3-Me** (**TS3-Me** − **TS2-Me**) in $\Delta G_{\text{sol-Toulene}}^{\ddagger}$ is only 1.6 kcal/mol, suggesting that both products can be generated. This is consistent with the experiment that a mixture of **2m** and **3m** was observed.

CONCLUSIONS

In conclusion, we have developed an efficient asymmetric synthetic method to azepine-fused cyclobutanes with bridgehead aryl substitutions, through a gold-catalyzed tandem cyclopropanation/C−C cleavage/Wagner−Meerwein rearrangement of yne-MCPs. DFT calculations reveal that the chirality is built in the cyclopropanation step. This chirality is temporarily lost in the followed C−C cleavage reaction to form planar cyclopropylmethyl carbocation. But this intermediate has very rigid structure and can only allow one carbon (not two) of the cyclopropyl group to migrate in the followed Wagner−Meerwein rearrangement. Consequently, chirality is regenerated in the Wagner−Meerwein rearrangement. The overall outcome of this C−C cleavage and Wagner−Meerwein rearrangement is that the chirality from cyclopropanation step is transferred to the final Wagner−Meerwein rearrangement

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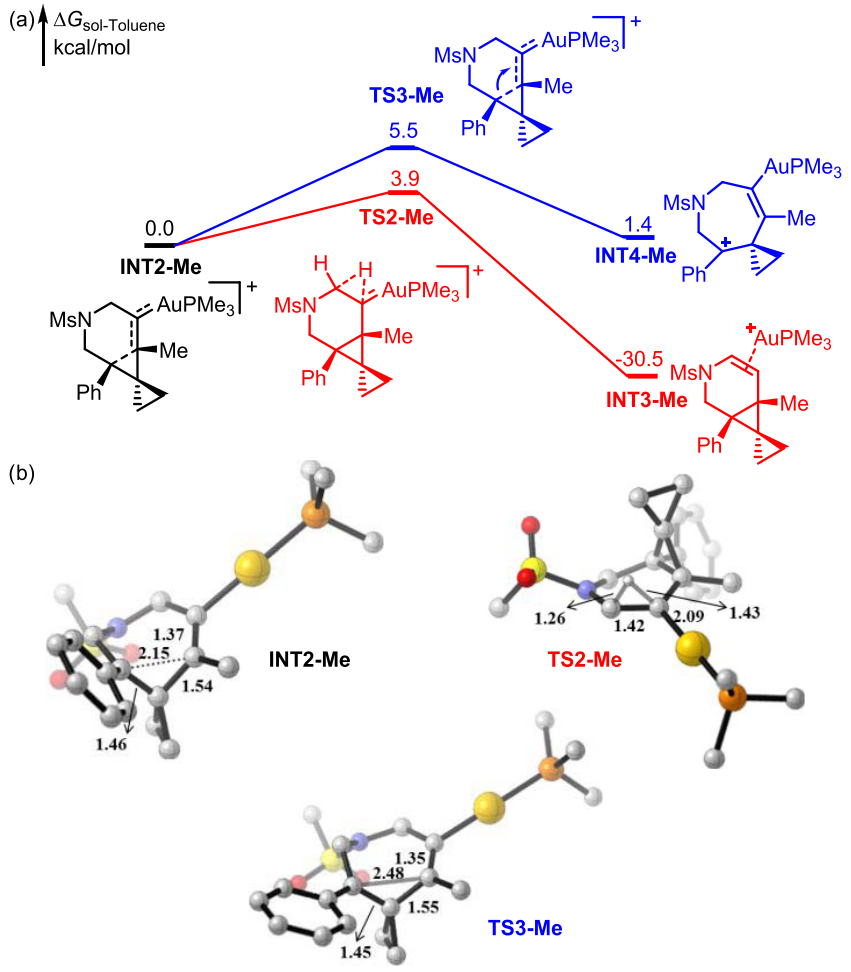

Figure 4. Chemoselectivity for the reaction of **1m** (bond distances in angstrom, and most hydrogen atoms in (b) are omitted for clarification).

product. Such a process can be regarded as chirality-memorized Wagner−Meerwein rearrangement, even though the chirality of generated cyclopropane in the first step has been lost temporarily in the formed planar cyclopropylmethyl carbocation.

EXPERIMENTAL SECTION

Computational Methods. All calculations were performed with the Gaussian 09 program.[27] Geometry optimizations of all minima and transition structures were carried out using the hybrid B3LYP functional[23] with the SDD[28] basis set and pseudopotential for Au and the 6-31+G(d)[22] basis set for the other atoms. The keyword "5D" was used to specify that five d-type orbitals were used for all elements in the calculations. Frequency calculations at the same level were performed to confirm that each stationary point was either a minimum or a transition structure and to evaluate its zero-point energy and the thermal corrections at 298 K. To improve the calculation accuracy, single-point energy calculations were carried out using the M06-2X[21,29] functional with the SDD basis set and pseudopotential for Au and the 6-311+G(d,p)[22] basis set for the other atoms. Because experiments were performed in toluene (asymmetric product synthesis) and dichloroethane (DCE, racemic product synthesis), solvation energies in both solvents were taken into consideration. Solvation energies ($\Delta G_{solvation}$) were single-point energy differences in toluene and DCE from those in the gas phase, respectively. Single-point energies in toluene (ε = 2.3741) and DCE (ε = 10.125) were evaluated by default IEFPCM[30] calculations. Gibbs free energies in solutions were obtained from sums of the large basis set gas-phase single-point energies, solvation energies ($\Delta G_{solvation}$), and the gas-phase Gibbs free energy corrections (at 298 K). The energy profile was drawn according to Gibbs free energies in the toluene solution ($\Delta G_{sol\text{-}Toluene}$). Gibbs free energies in the DCE solution ($\Delta G_{sol\text{-}DCE}$), Gibbs free energies, and enthalpies in the gas phase (ΔG_{gas} and ΔH_{gas}) have been all given in the Supporting Information. The computed structures were illustrated using CYLview.[31] Most hydrogen atoms in computed structures are omitted for clarity.

General Methods. Air- and moisture-sensitive reactions were carried out in oven and flame-dried glassware sealed with rubber septa under a positive pressure of dry nitrogen. Similarly, sensitive liquids and solutions were transferred via syringe. Reactions were stirred using Teflon-coated magnetic stir bars. Elevated temperatures were maintained using thermostat-controlled silicone oil baths. Organic solutions were concentrated using a Büchi rotary evaporator with a desktop vacuum pump. Tetrahydrofuran (THF) and toluene were distilled from sodium and benzophenone prior to use. DCE was superdry (water ≤ 30 ppm), which could be purchased from J&K. Synthetic reagents were purchased from J&K and Acros Organics and used without further purification, unless otherwise indicated. Analytical thin-layer chromatography (TLC) was performed with 0.25 mm silica gel G plates with a 254 nm fluorescent indicator. The TLC plates were visualized by ultraviolet light and treatment with phosphomolybdic acid stain or $KMnO_4$ stain followed by gentle heating. Purification of products was accomplished by flash chromatography on silica gel, and the purified compounds show a single spot by analytical TLC. NMR spectra were measured on Bruker ARX 400 (^{1}H NMR at 400 MHz, ^{13}C NMR at 101 MHz) nuclear magnetic resonance spectrometers. Data for ^{1}H NMR spectra were reported as follows: chemical shift (ppm), referenced to residual

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solvent peak ($CDCl_3$ = δ 7.26 ppm, CD_2Cl_2 = δ 5.32 ppm, $(CD_3)_2SO$ = δ 2.50 ppm; s = singlet, brs = broad singlet, d = doublet, t = triplet, q = quartet, dd = doublet of doublets, dt = doublet of triplets, ddd = doublet of doublet of doublets, ddt = doublet of doublet of triplets, dm = doublet of multiplet, m = multiplet), coupling constant (Hz), and integration. Data for $^{13}C\{^1H\}$ NMR were reported in terms of chemical shift (ppm) relative to residual solvent peak ($CDCl_3$ = δ 77.16 ppm, CD_2Cl_2 = δ 53.84 ppm, $(CD_3)_2SO$ = δ 39.52 ppm). Infrared spectra were recorded on a Mettler Toledo ReactIR iC10 system with a SiComp probe and were reported in wavenumbers (cm^{-1}). High-resolution mass spectra (HRMS) were recorded on a Bruker Apex IV FTMS mass spectrometer [electrospray ionization (ESI) or electron ionization (EI)] with an FT-ICR analyzer. The enantiomer excesses (e.e.) of the products were determined by chiral HPLC analysis using Varian Prostar 210. Optical rotations were measured on PerkinElmer model 341LC Polarimeter at 20 °C with visible light (λ = 589 nm) and 100 mm length cuvette.

For General Synthesis of Substrates, See Scheme S1, Reaction 1. *N-(2-Cyclopropylidene-2-phenylethyl)-4-methyl-N-(3-phenylprop-2-yn-1-yl)benzenesulfonamide (**1a**, Scheme S1, Reaction 1).* To a stirred solution of 4-methyl-*N*-(3-phenylprop-2-yn-1-yl)benzenesulfonamide (**S1**)[32] (571.7 mg, 2.0 mmol), 2-cyclopropylidene-2-phenylethan-1-ol (**S2**)[33] (337.7 mg, 2.1 mmol) and PPh_3 (787.8 mg, 3.0 mmol) in THF (12 mL) was added diisopropyl azodiformate (DIAD, 604.7 mg, 3.0 mmol) at 0 °C. The reaction was gradually allowed to warm to room temperature, monitored by TLC, and stirred for 2 h. Upon completion, the reaction mixture was concentrated and the crude product was purified by flash column chromatography on silica gel [eluted with petroleum ether (PE)/dichloromethane (DCM), 6:1] to afford **1a** (575.8 mg, 67%): white solid, m.p. = 141−143 °C, TLC R_f = 0.39 [PE/ethyl acetate (EA), 5:1]; ^1H NMR (400 MHz, CD_2Cl_2) δ 7.86−7.75 (m, 4H), 7.42−7.35 (m, 2H), 7.32−7.23 (m, 6H), 7.02 (d, J = 7.0 Hz, 2H), 4.51 (s, 2H), 4.11 (s, 2H), 2.31 (s, 3H), 1.53−1.48 (m, 2H), 1.25−1.19 (m, 2H); $^{13}C\{^1H\}$ NMR (101 MHz, $CDCl_3$) δ 143.6, 137.2, 135.6, 131.5, 129.6, 128.5, 128.4, 128.25, 128.21, 128.16, 127.4, 126.4, 122.5, 120.9, 85.8, 82.1, 49.6, 36.2, 21.5, 5.8, 1.6; IR (neat) 3055, 2974, 2920, 1598, 1490, 1444, 1347, 1306, 1288, 1162, 1118, 1093, 1040, 1026 cm^{-1}; HRMS (ESI) calcd for $C_{27}H_{26}NO_2S$ ($[M + H]^+$) 428.1679, found 428.1678.

*N-(2-Cyclopropylidene-2-(p-tolyl)ethyl)-4-methyl-N-(3-phenylprop-2-yn-1-yl)benzenesulfonamide (**1b**, Scheme S1, Reaction 1).* To a stirred solution of **S1**[32] (256.1 mg, 0.9 mmol), 2-cyclopropylidene-2-(*p*-tolyl)ethan-1-ol (**S3**)[33] (164.9 mg, 1.0 mmol), and PPh_3 (355.8 mg, 1.4 mmol) in THF (6 mL) was added DIAD (272.7 mg, 1.4 mmol) at 0 °C. The reaction was gradually allowed to warm to room temperature, monitored by TLC, and stirred for 12 h. Upon completion, the reaction mixture was concentrated and the crude product was purified by flash column chromatography on silica gel (eluted with PE/DCM, 4:1) to afford **1b** (284.3 mg, 72%): white solid, m.p. = 144−146 °C, TLC R_f = 0.38 (PE/EA, 5:1); ^1H NMR (400 MHz, CD_2Cl_2) δ 7.80 (d, J = 8.2 Hz, 2H), 7.70 (d, J = 8.2 Hz, 2H), 7.32−7.23 (m, 5H), 7.20 (d, J = 8.0 Hz, 2H), 7.01 (dd, J = 8.0, 1.5 Hz, 2H), 4.49 (s, 2H), 4.10 (s, 2H), 2.36 (s, 3H), 2.31 (s, 3H), 1.50−1.44 (m, 2H), 1.23−1.17 (m, 2H); $^{13}C\{^1H\}$ NMR (101 MHz, CD_2Cl_2) δ 144.2, 137.5, 135.9, 134.8, 131.7, 129.9, 129.3, 128.7, 128.5, 128.3, 127.5, 126.6, 122.7, 121.1, 85.8, 82.3, 49.9, 36.4, 21.5, 21.3, 5.7, 1.6; IR (neat) 3033, 2972, 2920, 1597, 1514, 1490, 1449, 1347, 1246, 1188, 1161, 1116, 1093, 1034, 991 cm^{-1}; HRMS (ESI) calcd for $C_{28}H_{28}NO_2S$ ($[M + H]^+$) 442.1835, found 442.1833.

*N-(2-Cyclopropylidene-2-(4-methoxyphenyl)ethyl)-4-methyl-N-(3-phenylprop-2-yn-1-yl)benzenesulfonamide (**1c**, Scheme S1, Reaction 1).* To a stirred solution of **S1**[32] (342.3 mg, 1.2 mmol), 2-cyclopropylidene-2-(4-methoxyphenyl)ethan-1-ol (**S4**)[33] (239.6 mg, 1.3 mmol), and PPh_3 (473.1 mg, 1.8 mmol) in THF (8 mL) was added DIAD (363.5 mg, 1.8 mmol) at 0 °C. The reaction was gradually allowed to warm to room temperature, monitored by TLC, and stirred for 6 h. Upon completion, the reaction mixture was concentrated and the crude product was purified by flash column chromatography on silica gel (eluted with PE/DCM, 3:1) to afford **1c** (381.9 mg, 70%): white solid, m.p. = 139−140 °C, TLC R_f = 0.39 (PE/EA, 5:1); ^1H NMR (400 MHz, CD_2Cl_2) δ 7.83−7.74 (m, 4H), 7.32−7.22 (m, 5H), 7.05−6.98 (m, 2H), 6.96−6.90 (m, 2H), 4.48 (s, 2H), 4.10 (s, 2H), 3.82 (s, 3H), 2.31 (s, 3H), 1.50−1.43 (m, 2H), 1.22−1.16 (m, 2H); $^{13}C\{^1H\}$ NMR (101 MHz, CD_2Cl_2) δ 159.3, 144.2, 135.9, 131.7, 130.3, 129.9, 128.7, 128.5, 128.3, 127.9, 126.4, 122.7, 120.6, 114.0, 85.9, 82.3, 55.6, 50.0, 36.3, 21.5, 5.7, 1.6; IR (neat) 3048, 2972, 2920, 2836, 1607, 1575, 1514, 1490, 1454, 1443, 1427, 1346, 1330, 1298, 1250, 1183, 1162, 1117, 1093, 1070, 1029, 990 cm^{-1}; HRMS (ESI) calcd for $C_{28}H_{28}NO_3S$ ($[M + H]^+$) 458.1784, found 458.1785.

*2-((tert-Butyldiphenylsilyl)oxy)-1-(4-(trifluoromethyl)phenyl)-ethan-1-one (**S6**, Scheme S1, Reaction 2).* Magnesium (1.68 g, 69.1 mmol) and a piece of iodine crystal were placed in flame-dried glassware. To the mixture was added dropwise 1-bromo-4-(trifluoromethyl)benzene (9.7 mL, 69.3 mmol) in dry THF (70 mL), and the mixture was stirred at room temperature for about 30 min to generate the Grignard reagent. To a stirred solution of 2-((*tert*-butyldiphenylsilyl)oxy)-*N*-methoxy-*N*-methylacetamide (**S5**)[34] (7.04 g, 19.7 mmol) in THF (52 mL) was added dropwise the newly prepared Grignard reagent at 0 °C. The reaction was gradually allowed to warm to room temperature, monitored by TLC, and stirred for 1 h. The reaction was quenched at 0 °C with saturated NH_4Cl (100 mL) and extracted with ether (50 mL × 3). The combined organic phase was washed with brine and dried over Na_2SO_4, then filtered and concentrated. The crude product was purified by flash column chromatography on silica gel (eluted with PE/EA, 50:1) to afford **S6** (7.93 g, 91%): light yellow oil, TLC R_f = 0.84 (PE/EA, 5:1); ^1H NMR (400 MHz, $CDCl_3$) δ 7.94 (d, J = 8.1 Hz, 2H), 7.76−7.64 (m, 6H), 7.49−7.37 (m, 6H), 4.90 (s, 2H), 1.11 (s, 9H); $^{13}C\{^1H\}$ NMR (101 MHz, $CDCl_3$) δ 196.3, 137.8, 135.7, 134.6 (q, J = 32.6 Hz), 132.8, 130.2, 128.5, 128.0, 125.7 (q, J = 3.6 Hz), 123.7 (q, J = 272.8 Hz), 68.0, 26.8, 19.4; IR (neat) 3073, 3052, 3000, 2957, 2931, 2859, 1714, 1589, 1513, 1472, 1428, 1412, 1392, 1377, 1362, 1326, 1286, 1225, 1170, 1134, 1112, 1067, 1017, 983 cm^{-1}; HRMS (ESI) calcd for $C_{25}H_{29}F_3NO_2Si$ ($[M + NH_4]^+$) 460.1914, found 460.1916.

*2-Cyclopropylidene-2-(4-(trifluoromethyl)phenyl)ethan-1-ol (**S8**, Scheme S1, Reaction 3).* To a flame-dried glassware containing NaH (1.72 g, 43.0 mmol, 60% in oil) and cyclopropyltriphenylphosphonium bromide (16.48 g, 43.0 mmol) was added THF (37 mL) at room temperature. After being stirred for 10 h at 65 °C, a solution of **S6** (7.92 g, 17.9 mmol) in THF (18 mL) was added. The reaction was monitored by TLC and stirred for 1 h at the same temperature. Then, the resulting mixture was quenched with water (60 mL) and extracted with ether (30 mL × 3). The combined organic phase was washed with brine and dried over Na_2SO_4, then filtered and concentrated. The residue was purified by flash column chromatography on silica gel (eluted with PE) to afford crude *tert*-butyl(2-cyclopropylidene-2-(4-(trifluoromethyl)phenyl)ethoxy)diphenylsilane (**S7**), which was then used in the next step. To a stirred solution of **S7** in THF (28 mL) was added tetrabutylammonium fluoride trihydrate (4.99 g, 15.8 mmol). The reaction was monitored by TLC and stirred for 3.5 h at room temperature. Then, the resulting mixture was quenched with water (50 mL) and extracted with ether (30 mL × 3). The combined organic phase was washed with brine and dried over Na_2SO_4, then filtered and concentrated. The residue was purified by flash column chromatography on silica gel (eluted with PE/EA, 5:1) to afford **S8** (461.8 mg, 11% over two steps): light yellow solid, m.p. = 76−78 °C, TLC R_f = 0.21 (PE/EA, 5:1); ^1H NMR (400 MHz, $CDCl_3$) δ 7.80 (d, J = 8.2 Hz, 2H), 7.61 (d, J = 8.2 Hz, 2H), 4.74 (s, 2H), 1.59 (brs, 1H), 1.52−1.47 (m, 2H), 1.34−1.26 (m, 2H); $^{13}C\{^1H\}$ NMR (101 MHz, $CDCl_3$) δ 141.6, 128.9 (q, J = 32.3 Hz), 127.2, 126.3, 125.9, 125.4 (q, J = 3.7 Hz), 124.4 (q, J = 271.7 Hz), 64.7, 4.7, 0.9; IR (neat) 3289, 2949, 1614, 1574, 1469, 1409, 1361, 1325, 1231, 1171, 1145, 1112, 1073, 1051, 1011, 978 cm^{-1}; HRMS (EI) calcd for $C_{12}H_{11}F_3O$ ($M^{\cdot+}$) 228.0756, found 228.0754.

*N-(2-Cyclopropylidene-2-(4-(trifluoromethyl)phenyl)ethyl)-4-methyl-N-(3-phenylprop-2-yn-1-yl)benzenesulfonamide (**1d**, Scheme S1, Reaction 1).* To a stirred solution of **S1**[32] (395.1 mg,

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1.4 mmol), **S8** (315.0 mg, 1.4 mmol), and PPh_3 (544.4 mg, 2.1 mmol) in THF (9 mL) was added DIAD (416.9 mg, 2.1 mmol) at 0 °C. The reaction was gradually allowed to warm to room temperature, monitored by TLC, and stirred for 11 h. Upon completion, the reaction mixture was concentrated and the crude product was purified by flash column chromatography on silica gel (eluted with PE/DCM, 5:1) to afford **1d** (346.0 mg, 50%): white solid, m.p. = 153−156 °C, TLC R_f = 0.44 (PE/EA, 5:1); ^{1}H NMR (400 MHz, CD_2Cl_2) δ 8.02 (d, J = 8.2 Hz, 2H), 7.85 (d, J = 8.2 Hz, 2H), 7.68 (d, J = 8.3 Hz, 2H), 7.45−7.18 (m, 5H), 7.15−6.97 (m, 2H), 4.58 (s, 2H), 4.15 (s, 2H), 2.34 (s, 3H), 1.65−1.50 (m, 2H), 1.38−1.23 (m, 2H); ^{13}C{^{1}H} NMR (101 MHz, CD_2Cl_2) δ 144.4, 141.4 (q, J = 0.8 Hz), 135.7, 131.9, 131.7, 130.0, 129.0 (q, J = 32.3 Hz), 128.8, 128.6, 128.4, 127.0, 125.5 (q, J = 3.7 Hz), 124.9 (q, J = 271.9 Hz), 122.6, 120.4, 86.2, 82.0, 49.8, 36.5, 21.5, 6.0, 1.9; IR (neat) 2955, 2918, 2850, 1735, 1613, 1598, 1491, 1457, 1427, 1408, 1377, 1343, 1325, 1184, 1165, 1125, 1080, 1067, 1031, 1015, 961 cm^{-1}; HRMS (ESI) calcd for $C_{28}H_{25}F_3NO_2S$ ([M + H]$^+$) 496.1553, found 496.1554.

*N-(2-Cyclopropylidene-2-phenylethyl)-4-methyl-N-(3-(p-tolyl)-prop-2-yn-1-yl)benzenesulfonamide (**1e**, Scheme S1, Reaction 1).* To a stirred solution of 4-methyl-*N*-(3-(*p*-tolyl)prop-2-yn-1-yl)-benzenesulfonamide (**S9**)[32] (299.7 mg, 1.0 mmol), **S2**[33] (160.3 mg, 1.0 mmol), and PPh_3 (393.8 mg, 1.5 mmol) in THF (7 mL) was added DIAD (301.1 mg, 1.5 mmol) at 0 °C. The reaction was gradually allowed to warm to room temperature, monitored by TLC, and stirred for 12 h. Upon completion, the reaction mixture was concentrated and the crude product was purified by flash column chromatography on silica gel (eluted with PE/DCM, 3:1) to afford **1e** (304.6 mg, 69%): white solid, m.p. = 171−173 °C, TLC R_f = 0.50 (PE/EA, 5:1); ^{1}H NMR (400 MHz, CD_2Cl_2) δ 7.87−7.77 (m, 4H), 7.43−7.36 (m, 2H), 7.33−7.25 (m, 3H), 7.07 (d, J = 8.0 Hz, 2H), 6.92 (d, J = 8.0 Hz, 2H), 4.52 (s, 2H), 4.11 (s, 2H), 2.34 (s, 3H), 2.33 (s, 3H), 1.54−1.47 (m, 2H), 1.26−1.19 (m, 2H); ^{13}C{^{1}H} NMR (101 MHz, CD_2Cl_2) δ 144.1, 139.0, 137.7, 136.0, 131.6, 129.9, 129.2, 128.7, 128.6, 128.4, 127.5, 126.7, 121.2, 119.6, 86.0, 81.5, 49.8, 36.5, 21.6, 21.5, 5.8, 1.7; IR (neat) 3025, 2965, 2919, 2863, 1593, 1500, 1444, 1335, 1220, 1158, 1097, 1032, 981 cm^{-1}; HRMS (ESI) calcd for $C_{28}H_{28}NO_2S$ ([M + H]$^+$) 442.1835, found 442.1834.

*N-(2-Cyclopropylidene-2-phenylethyl)-N-(3-(4-methoxyphenyl)-prop-2-yn-1-yl)-4-methylbenzenesulfonamide (**1f**, Scheme S1, Reaction 1).* To a stirred solution of *N*-(3-(4-methoxyphenyl)prop-2-yn-1-yl)-4-methylbenzenesulfonamide (**S10**)[32] (365.0 mg, 1.2 mmol), **S2**[33] (176.2 mg, 1.1 mmol), and PPh_3 (445.9 mg, 1.7 mmol) in THF (7 mL) was added DIAD (324.7 mg, 1.6 mmol) at 0 °C. The reaction was gradually allowed to warm to room temperature, monitored by TLC, and stirred for 12 h. Upon completion, the reaction mixture was concentrated and the crude product was purified by flash column chromatography on silica gel (eluted with PE/DCM, 2:1) to afford **1f** (302.0 mg, 60%): white solid, m.p. = 144−146 °C, TLC R_f = 0.33 (PE/EA, 5:1); ^{1}H NMR (400 MHz, CD_2Cl_2) δ 7.86−7.76 (m, 4H), 7.41−7.35 (m, 2H), 7.34−7.24 (m, 3H), 7.02−6.91 (m, 2H), 6.82−6.73 (m, 2H), 4.50 (s, 2H), 4.10 (s, 2H), 3.79 (s, 3H), 2.35 (s, 3H), 1.53−1.47 (m, 2H), 1.26−1.18 (m, 2H); ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$) δ 159.7, 143.5, 137.2, 135.8, 132.9, 129.6, 128.5, 128.2, 128.1, 127.4, 126.4, 121.0, 114.6, 113.9, 85.7, 80.6, 55.4, 49.5, 36.3, 21.6, 5.7, 1.6; IR (neat) 3047, 2969, 2922, 2842, 1603, 1506, 1452, 1341, 1293, 1249, 1161, 1100, 1032 cm^{-1}; HRMS (ESI) calcd for $C_{28}H_{28}NO_3S$ ([M + H]$^+$) 458.1784, found 458.1785.

*N-(2-Cyclopropylidene-2-phenylethyl)-4-methyl-N-(3-(4-(trifluoromethyl)phenyl)prop-2-yn-1-yl)benzenesulfonamide (**1g**, Scheme S1, Reaction 1).* To a stirred solution of 4-methyl-*N*-(3-(4-(trifluoromethyl)phenyl)prop-2-yn-1-yl)benzenesulfonamide (**S11**)[32] (388.7 mg, 1.1 mmol), **S2**[33] (185.9 mg, 1.2 mmol), and PPh_3 (432.7 mg, 1.6 mmol) in THF (7 mL) was added DIAD (323.3 mg, 1.6 mmol) at 0 °C. The reaction was gradually allowed to warm to room temperature, monitored by TLC, and stirred for 5 h. Upon completion, the reaction mixture was concentrated and the crude product was purified by flash column chromatography on silica gel (eluted with PE/DCM, 5:1) to afford **1g** (428.1 mg, 79%): white solid, m.p. = 142−145 °C, TLC R_f = 0.46 (PE/EA, 5:1); ^{1}H NMR (400 MHz, CD_2Cl_2) δ 7.88−7.77 (m, 4H), 7.53 (d, J = 8.1 Hz, 2H), 7.43−7.36 (m, 2H), 7.34−7.25 (m, 3H), 7.14 (d, J = 8.1 Hz, 2H), 4.53 (s, 2H), 4.15 (s, 2H), 2.30 (s, 3H), 1.55−1.47 (m, 2H), 1.24−1.17 (m, 2H); ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$) δ 143.7, 137.0, 135.6, 131.7, 130.2 (q, J = 32.8 Hz), 129.6, 128.5, 128.22, 128.16, 127.5, 126.4, 126.2, 125.2 (q, J = 3.7 Hz), 123.9 (q, J = 272.1 Hz), 120.9, 85.0, 84.5, 49.7, 36.1, 21.5, 5.8, 1.5; IR (neat) 3057, 2953, 2921, 1743, 1615, 1597, 1498, 1451, 1422, 1405, 1344, 1324, 1290, 1162, 1128, 1106, 1092, 1067, 1042, 1027, 1017, 988 cm^{-1}; HRMS (ESI) calcd for $C_{28}H_{25}F_3NO_2S$ ([M + H]$^+$) 496.1553, found 496.1553.

*N-(3-(4-Bromophenyl)prop-2-yn-1-yl)-N-(2-cyclopropylidene-2-phenylethyl)-4-methylbenzenesulfonamide (**1h**, Scheme S1, Reaction 1).* To a stirred solution of *N*-(3-(4-bromophenyl)prop-2-yn-1-yl)-4-methylbenzenesulfonamide (**S12**)[32] (437.1 mg, 1.2 mmol), **S2**[33] (193.4 mg, 1.2 mmol), and PPh_3 (474.4 mg, 1.8 mmol) in THF (8 mL) was added DIAD (362.5 mg, 1.8 mmol) at 0 °C. The reaction was gradually allowed to warm to room temperature, monitored by TLC, and stirred for 16 h. Upon completion, the reaction mixture was concentrated and the crude product was purified by flash column chromatography on silica gel (eluted with PE/DCM, 3:1) to afford **1h** (501.3 mg, 82%): white solid, m.p. = 163−165 °C, TLC R_f = 0.60 (PE/EA, 5:1); ^{1}H NMR (400 MHz, CD_2Cl_2) δ 7.85−7.77 (m, 4H), 7.43−7.35 (m, 4H), 7.32−7.24 (m, 3H), 6.95−6.83 (m, 2H), 4.50 (s, 2H), 4.10 (s, 2H), 2.33 (s, 3H), 1.53−1.47 (m, 2H), 1.23−1.17 (m, 2H); ^{13}C{^{1}H} NMR (101 MHz, CD_2Cl_2) δ 144.2, 137.7, 135.9, 133.2, 131.8, 129.9, 128.70, 128.66, 128.4, 127.6, 126.7, 122.8, 121.7, 121.2, 84.9, 83.7, 49.9, 36.4, 21.6, 5.8, 1.7; IR (neat) 2955, 2918, 2870, 2850, 1597, 1499, 1485, 1451, 1420, 1377, 1342, 1328, 1292, 1166, 1159, 1117, 1090, 1069, 1041, 1029, 1011 cm^{-1}; HRMS (ESI) calcd for $C_{27}H_{25}BrNO_2S$ ([M + H]$^+$) 506.0784, found 506.0783.

*N-(2-Cyclopropylidene-2-phenylethyl)-4-methyl-N-(pent-4-en-2-yn-1-yl)benzenesulfonamide (**1i**, Scheme S1, Reaction 1).* To a stirred solution of 4-methyl-*N*-(pent-4-en-2-yn-1-yl)-benzenesulfonamide (**S13**)[35] (283.7 mg, 1.2 mmol), **S2**[33] (193.2 mg, 1.2 mmol), and PPh_3 (474.8 mg, 1.8 mmol) in THF (8 mL) was added DIAD (362.7 mg, 1.8 mmol) at 0 °C. The reaction was gradually allowed to warm to room temperature, monitored by TLC, and stirred for 16 h. Upon completion, the reaction mixture was concentrated and the crude product was purified by flash column chromatography on silica gel (eluted with PE/EA, 50:1) to afford **1i** (346.1 mg, 76%): white solid, m.p. = 112−115 °C, TLC R_f = 0.47 (PE/EA, 5:1); ^{1}H NMR (400 MHz, $(CD_3)_2SO$) δ 7.77 (d, J = 8.2 Hz, 2H), 7.73 (d, J = 7.6 Hz, 2H), 7.43 (d, J = 8.2 Hz, 2H), 7.40−7.33 (m, 2H), 7.31−7.24 (m, 1H), 5.55 (dd, J = 17.3, 11.2 Hz, 1H), 5.42 (dd, J = 11.2, 2.3 Hz, 1H), 5.23 (dd, J = 17.3, 2.3 Hz, 1H), 4.35 (s, 2H), 3.95 (d, J = 1.1 Hz, 2H), 2.40 (s, 3H), 1.57−1.46 (m, 2H), 1.21−1.12 (m, 2H); ^{13}C{^{1}H} NMR (101 MHz, $(CD_3)_2SO$) δ 143.5, 137.1, 134.8, 129.6, 128.6, 128.2, 127.74, 127.69, 127.0, 126.0, 120.1, 116.3, 84.1, 82.8, 49.2, 35.8, 21.0, 5.0, 1.1; IR (neat) 2918, 1768, 1711, 1598, 1495, 1450, 1345, 1289, 1161, 1092, 1021, 971, 902 cm^{-1}; HRMS (ESI) calcd for $C_{23}H_{24}NO_2S$ ([M + H]$^+$) 378.1522, found 378.1524.

*N-(2-Cyclopropylidene-2-phenylethyl)-4-methyl-N-(4-methylpent-4-en-2-yn-1-yl)benzenesulfonamide (**1j**, Scheme S1, Reaction 1).* To a stirred solution of 4-methyl-*N*-(4-methylpent-4-en-2-yn-1-yl)benzenesulfonamide (**S14**)[36] (298.5 mg, 1.2 mmol), **S2**[33] (192.1 mg, 1.2 mmol), and PPh_3 (474.3 mg, 1.8 mmol) in THF (8 mL) was added DIAD (362.2 mg, 1.8 mmol) at 0 °C. The reaction was gradually allowed to warm to room temperature, monitored by TLC, and stirred for 9 h. Upon completion, the reaction mixture was concentrated and the crude product was purified by flash column chromatography on silica gel (eluted with PE/EA, 20:1) to afford **1j** (278.9 mg, 60%): white solid, m.p. = 103−105 °C, TLC R_f = 0.53 (PE/EA, 5:1); ^{1}H NMR (400 MHz, CD_2Cl_2) δ 7.85−7.71 (m, 4H), 7.41−7.31 (m, 4H), 7.30−7.24 (m, 1H), 5.13−5.05 (m, 1H), 4.95−4.85 (m, 1H), 4.44 (s, 2H), 4.01 (s, 2H), 2.42 (s, 3H), 1.68−1.55 (m, 3H), 1.52−1.46 (m, 2H), 1.25−1.17 (m, 2H); ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$) δ 143.5, 137.2, 135.7, 129.6, 128.5, 128.2, 128.0, 127.4, 126.4, 126.1, 121.9, 121.0, 87.0, 81.2, 49.4, 36.1, 23.1, 21.6, 5.7, 1.5;

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IR (neat) 3051, 2957, 2919, 1603, 1496, 1454, 1343, 1292, 1159, 1094, 1031 cm^{-1}; HRMS (ESI) calcd for $C_{24}H_{26}NO_2S$ ($[M + H]^+$) 392.1679, found 392.1678.

*4-Methyl-N-(5-methylhex-4-en-2-yn-1-yl)benzenesulfonamide (**S16**, Scheme S1, Reaction 4).* CuI (285.6 mg, 1.50 mmol) and $Pd(PPh_3)_4$ (563.4 mg, 0.49 mmol) were dissolved in pyrrolidine (8 mL). 1-Bromo-2-methylprop-1-ene (2.1 mL, 20.5 mmol) was added to the resulting solution at 0 °C. After stirring for 5 min, 4-methyl-*N*-(prop-2-yn-1-yl)benzenesulfonamide (**S15**)[37] (2.09 g, 10.0 mmol) in THF (8 mL) was added to the solution at 0 °C. The reaction was gradually allowed to warm to 25 °C. The reaction was monitored by TLC and stirred for 18 h. Upon completion, 2 M HCl solution (50 mL) was added to quench the reaction. The resulting mixture was extracted with ether (50 mL × 3), and the combined organic phase was washed with brine, dried over Na_2SO_4, then filtered and concentrated. The crude product was purified by flash column chromatography on silica gel (eluted with PE/EA, 10:1) to afford **S16** (1.21 g, 46%): yellow solid, m.p. = 69−72 °C, TLC R_f = 0.25 (PE/EA, 5:1); ^1H NMR (400 MHz, $CDCl_3$) δ 7.78 (d, J = 8.2 Hz, 2H), 7.30 (d, J = 8.2 Hz, 2H), 5.03 (s, 1H), 4.64 (t, J = 5.4 Hz, 1H), 3.97 (d, J = 5.4 Hz, 2H), 2.42 (s, 3H), 1.74 (s, 3H), 1.70 (s, 3H); $^{13}C\{^1H\}$ NMR (101 MHz, $CDCl_3$) δ 149.8, 143.7, 136.8, 129.8, 127.5, 104.2, 85.0, 83.0, 34.1, 24.8, 21.6, 21.0; IR (neat) 3280, 3035, 2921, 2853, 1595, 1432, 1323, 1244, 1153, 1089, 1047 cm^{-1}; HRMS (ESI) calcd for $C_{14}H_{18}NO_2S$ ($[M + H]^+$) 264.1053, found 264.1049.

*N-(2-Cyclopropylidene-2-phenylethyl)-4-methyl-N-(5-methylhex-4-en-2-yn-1-yl)benzenesulfonamide (**1k**, Scheme S1, Reaction 1).* To a stirred solution of **S16** (290.0 mg, 1.1 mmol), **S2**[33] (175.6 mg, 1.1 mmol), and PPh_3 (434.6 mg, 1.7 mmol) in THF (7 mL) was added DIAD (330.6 mg, 1.6 mmol) at 0 °C. The reaction was gradually allowed to warm to room temperature, monitored by TLC, and stirred for 4 h. Upon completion, the reaction mixture was concentrated and the crude product was purified by flash column chromatography on silica gel (eluted with PE/EA, 50:1) to afford **1k** (274.4 mg, 61%): light yellow solid, m.p. = 110−113 °C, TLC R_f = 0.54 (PE/EA, 5:1); ^1H NMR (400 MHz, CD_2Cl_2) δ 7.83−7.71 (m, 4H), 7.40−7.34 (m, 2H), 7.32 (d, J = 8.0 Hz, 2H), 7.29−7.24 (m, 1H), 4.95 (t, J = 1.2 Hz, 1H), 4.43 (s, 2H), 4.04 (d, J = 1.2 Hz, 2H), 2.42 (s, 3H), 1.73 (s, 3H), 1.59 (s, 3H), 1.51−1.44 (m, 2H), 1.23−1.15 (m, 2H); $^{13}C\{^1H\}$ NMR (101 MHz, CD_2Cl_2) δ 149.0, 144.0, 137.9, 136.1, 129.8, 128.6, 128.5, 128.3, 127.5, 126.7, 121.4, 104.6, 84.09, 84.08, 49.7, 36.6, 24.7, 21.6, 21.0, 5.6, 1.8; IR (neat) 3035, 2976, 2911, 2872, 1637, 1597, 1496, 1451, 1400, 1380, 1346, 1331, 1308, 1290, 1241, 1206, 1186, 1162, 1114, 1093, 1038, 1026, 1001, 989 cm^{-1}; HRMS (ESI) calcd for $C_{25}H_{28}NO_2S$ ($[M + H]^+$) 406.1835, found 406.1831.

*Methyl 4-((N-(2-Cyclopropylidene-2-phenylethyl)-4-methylphenyl)sulfonamido)but-2-ynoate (**1l**, Scheme S1, Reaction 5).* To a stirred solution of **S15**[37] (328.7 mg, 1.6 mmol), **S2**[33] (252.0 mg, 1.6 mmol), and PPh_3 (618.0 mg, 2.4 mmol) in THF (10 mL) was added DIAD (476.6 mg, 2.4 mmol) at 0 °C. The reaction was gradually allowed to warm to room temperature, monitored by TLC, and stirred for 6 h. Upon completion, the reaction mixture was concentrated and the residue was purified by flash column chromatography on silica gel (eluted with PE/EA, 20:1) to afford crude *N*-(2-cyclopropylidene-2-phenylethyl)-4-methyl-*N*-(prop-2-yn-1-yl)benzenesulfonamide (**S17**), which was then used in the next step. To a stirred solution of **S17** in THF (4 mL) was added dropwise *n*-BuLi (0.8 mL, 2.4 M in hexane) at −78 °C. The reaction was stirred at −78 °C for 1 h, and then methyl chloroformate (0.5 mL, 6.5 mmol) was added dropwise at the same temperature. The reaction was gradually allowed to warm to room temperature, monitored by TLC, and stirred for 12 h. The reaction was quenched with saturated $NaHCO_3$ (10 mL) and extracted with ether (5 mL × 3). The combined organic phase was washed with brine and dried over Na_2SO_4, then filtered and concentrated. The crude product was purified by flash column chromatography on silica gel (eluted with PE/EA, 10:1) to afford **1l** (244.4 mg, 38% over two steps): white solid, m.p. = 120−123 °C, TLC R_f = 0.24 (PE/EA, 5:1); ^1H NMR (400 MHz, CD_2Cl_2) δ7.83−7.68 (m, 4H), 7.40−7.33 (m, 4H), 7.30−7.25 (m, 1H), 4.43 (s, 2H), 4.02 (s, 2H), 3.67 (s, 3H), 2.45 (s, 3H), 1.55−1.44 (m, 2H), 1.26−1.19 (m, 2H); $^{13}C\{^1H\}$ NMR (101 MHz, CD_2Cl_2) δ 153.2, 144.7, 137.4, 135.2, 130.1, 129.3, 128.7, 128.2, 127.7, 126.6, 120.9, 80.9, 77.3, 53.0, 50.1, 35.6, 21.7, 5.8, 1.7; IR (neat) 2955, 2920, 2851, 2238, 1716, 1597, 1496, 1457, 1377, 1349, 1254, 1186, 1162, 1092, 1062, 1038, 939 cm^{-1}; HRMS (ESI) calcd for $C_{23}H_{27}N_2O_4S$ ($[M + NH_4]^+$) 427.1686, found 427.1688.

*N-(But-2-yn-1-yl)-N-(2-cyclopropylidene-2-phenylethyl)-4-methylbenzenesulfonamide (**1m**, Scheme S1, Reaction 1).* To a stirred solution of *N*-(but-2-yn-1-yl)-4-methylbenzenesulfonamide (**S18**)[38] (268.4 mg, 1.2 mmol), **S2**[33] (191.9 mg, 1.2 mmol), and PPh_3 (475.8 mg, 1.8 mmol) in THF (8 mL) was added DIAD (360.9 mg, 1.8 mmol) at 0 °C. The reaction was gradually allowed to warm to room temperature, monitored by TLC, and stirred for 12 h. Upon completion, the reaction mixture was concentrated and the crude product was purified by flash column chromatography on silica gel (eluted with PE/EA, 20:1) to afford **1m** (326.0 mg, 74%): white solid, m.p. = 125−128 °C, TLC R_f = 0.52 (PE/EA, 5:1); ^1H NMR (400 MHz, CD_2Cl_2) δ 7.80−7.73 (m, 4H), 7.39−7.33 (m, 4H), 7.29−7.23 (m, 1H), 4.39 (s, 2H), 3.83 (q, J = 2.1 Hz, 2H), 2.45 (s, 3H), 1.51−1.45 (m, 2H), 1.47 (t, J = 2.1 Hz, 3H), 1.24−1.18 (m, 2H); $^{13}C\{^1H\}$ NMR (101 MHz, CD_2Cl_2) δ 143.9, 137.9, 136.1, 129.6, 128.6, 128.5, 128.4, 127.5, 126.7, 121.4, 82.0, 71.9, 49.6, 36.1, 21.6, 5.6, 3.2, 1.7; IR (neat) 3054, 2957, 2921, 2852, 1598, 1497, 1453, 1378, 1347, 1306 1289, 1247, 1185, 1162, 1093, 1040, 1025, 989 cm^{-1}; HRMS (ESI) calcd for $C_{22}H_{24}NO_2S$ ($[M + H]^+$) 366.1522, found 366.1529.

*4-Nitro-N-(pent-4-en-2-yn-1-yl)benzenesulfonamide (**S20**, Scheme S1, Reaction 6).* CuI (22.9 mg, 0.12 mmol) and $Pd(PPh_3)_4$ (52.1 mg, 0.045 mmol) were dissolved in Et_2NH (1.55 mL). Bromoethene (6.0 mL, 1.0 M in THF) was added to the resulting solution at 0 °C. After stirring for 5 min, 4-nitro-*N*-(prop-2-yn-1-yl)benzenesulfonamide (**S19**)[37] (720.3 mg, 3.0 mmol) in THF (5 mL) was added to the solution at 0 °C. The reaction was gradually allowed to warm to room temperature. The reaction was monitored by TLC and stirred for 14 h. Upon completion, water (30 mL) was added to quench the reaction. The resulting mixture was extracted with ether (20 mL × 3) and the combined organic phase was washed with brine, dried over Na_2SO_4, then filtered and concentrated. The crude product was purified by flash column chromatography on silica gel (eluted with PE/DCM, 1:1) to afford **S20** (505.9 mg, 63%): light yellow solid, m.p. = 105−107 °C, TLC R_f = 0.37 (PE/EA, 3:1); ^1H NMR (400 MHz, $CDCl_3$) δ 8.35 (d, J = 8.8 Hz, 2H), 8.11 (d, J = 8.8 Hz, 2H), 5.55−5.43 (m, 1H), 5.43−5.29 (m, 2H), 4.99 (t, J = 5.9 Hz, 1H), 4.07 (dd, J = 5.9, 1.5 Hz, 2H); $^{13}C\{^1H\}$ NMR (101 MHz, $CDCl_3$) δ 150.3, 146.0, 128.9, 128.5, 124.4, 115.8, 84.1, 83.2, 33.8; IR (neat) 3263, 3104, 1607, 1541, 1428, 1351, 1315, 1162, 1089, 1057, 1012, 978, 929 cm^{-1}; HRMS (ESI) calcd for $C_{11}H_{11}N_2O_4S$ ($[M + H]^+$) 267.0434, found 267.0433.

*N-(2-Cyclopropylidene-2-phenylethyl)-4-nitro-N-(pent-4-en-2-yn-1-yl)benzenesulfonamide (**1n**, Scheme S1, Reaction 1).* To a stirred solution of **S20** (292.8 mg, 1.1 mmol), **S2**[33] (175.9 mg, 1.1 mmol), and PPh_3 (433.4 mg, 1.7 mmol) in THF (7 mL) was added DIAD (332.2 mg, 1.6 mmol) at 0 °C. The reaction was gradually allowed to warm to room temperature, monitored by TLC, and stirred for 6 h. Upon completion, the reaction mixture was concentrated and the crude product was purified by flash column chromatography on silica gel (eluted with PE/DCM, 2:1) to afford **1n** (397.3 mg, 88%): white solid, m.p. = 132−135 °C, TLC R_f = 0.44 (PE/EA, 5:1); ^1H NMR (400 MHz, $CDCl_3$) δ 8.38−8.32 (m, 2H), 8.12−8.06 (m, 2H), 7.78−7.72 (m, 2H), 7.41−7.35 (m, 2H), 7.31−7.26 (m, 1H), 5.46−5.33 (m, 2H), 5.26 (dd, J = 16.4, 3.1 Hz, 1H), 4.46 (s, 2H), 4.08 (d, J = 1.1 Hz, 2H), 1.54−1.48 (m, 2H), 1.23−1.17 (m, 2H); $^{13}C\{^1H\}$ NMR (101 MHz, $CDCl_3$) δ 150.3, 144.4, 136.8, 129.4, 129.0, 128.6, 128.0, 127.6, 126.3, 124.1, 120.4, 115.9, 84.9, 82.1, 49.7, 36.2, 5.7, 1.6; IR (neat) 3105, 3053, 2978, 2968, 1607, 1536, 1498, 1476, 1453, 1426, 1401, 1348, 1330, 1315, 1288, 1240, 1191, 1164, 1105, 1091, 1044, 1027, 1010, 982, 944, 900 cm^{-1}; HRMS (ESI) calcd for $C_{22}H_{21}N_2O_4S$ ($[M + H]^+$) 409.1217, found 409.1217.

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*1-(1-Cyclopropylidene-2-((3-phenylprop-2-yn-1-yl)oxy)ethyl)-4-methoxybenzene (**1o**, Scheme S1, Reaction 7).* To a stirred solution of NaH (319.9 mg, 8.0 mmol, 60% in oil) and *n*-Bu_4NI (369.2 mg, 1.0 mmol) in DMF (2 mL) was added dropwise **S4**[33] (190.4 mg, 1.0 mmol) in DMF (3 mL) at 0 °C. The reaction was stirred at 0 °C for 30 min, then (3-bromoprop-1-yn-1-yl)benzene (**S21**)[39] (680.9 mg, 3.5 mmol) was added dropwise at the same temperature. The reaction was gradually allowed to warm to room temperature, monitored by TLC, and stirred for 2 h. The reaction was quenched with water (60 mL) and extracted with ether (30 mL × 3). The combined organic phase was washed with brine and dried over Na_2SO_4, then filtered and concentrated. The crude product was purified by flash column chromatography on silica gel (eluted with PE/EA, 70:1) to afford **1o** (173.0 mg, 57%): yellow oil (some impurities could be found in the final product, but all efforts to purify it failed), TLC R_f = 0.62 (PE/EA, 5:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.75−7.69 (m, 2H), 7.48−7.44 (m, 2H), 7.34−7.31 (m, 3H), 6.92−6.88 (m, 2H), 4.72 (s, 2H), 4.37 (s, 2H), 3.82 (s, 3H), 1.53−1.47 (m, 2H), 1.29−1.24 (m, 2H); $^{13}C\{^1H\}$ NMR (101 MHz, $CDCl_3$) δ 158.8, 131.9, 131.0, 128.5, 128.4, 127.3, 125.1, 123.0, 122.8, 113.8, 86.3, 85.6, 71.3, 57.2, 55.4, 5.4, 1.0; IR (neat) 2956, 2921, 2870, 2850, 1512, 1492, 1461, 1378, 1249, 1181, 1081 cm^{-1}; HRMS (ESI) calcd for $C_{21}H_{21}O_2$ ([M + H]$^+$) 305.1536, found 305.1541.

Racemic Product Synthesis, General Procedure A (5 mol % Catalyst). Under nitrogen, the commercially available (MeCN)Au(JohnPhos)SbF_6 (7.8 mg, 10.1 μmol) was added to flame-dried glassware containing **1** (0.2 mmol). Anhydrous DCE (4.0 mL) was added, and the glassware was then immersed into an oil bath at 30 °C. The reaction was monitored by TLC. Upon completion, the reaction mixture was purified by flash column chromatography on silica gel to afford (±)-**2** or (±)-**3**.

Here we did not include the detailed experimental results for all substrates except for **1d**. A summary of the results is given in the Supporting Information.

*(±)-(1S,6S)-6-Phenyl-3-tosyl-1-(4-(trifluoromethyl)phenyl)-3-azaspiro[bicyclo[4.1.0]heptane-7,1′-cyclopropan]-4-ene ((±)-**3d**).* Following general procedure A, 99.8 mg of **1d** was used, and the reaction time was 12 h. After flash column chromatography on silica gel (eluted with PE/EA, 50:1), 89.0 mg (±)-**3d** was obtained in 89% yield. (±)-**3d**: white solid, m.p. = 65−68 °C, TLC R_f = 0.53 (PE/EA, 5:1); ^{1}H NMR (400 MHz, CD_2Cl_2) δ 7.77 (d, J = 8.3 Hz, 2H), 7.44−7.34 (m, 4H), 7.16−7.00 (m, 7H), 6.90 (d, J = 8.4 Hz, 1H), 5.65 (d, J = 8.4 Hz, 1H), 4.08 (d, J = 11.5 Hz, 1H), 3.14 (d, J = 11.5 Hz, 1H), 2.47 (s, 3H), 1.62 (ddd, J = 9.2, 5.5, 5.5 Hz, 1H), 1.40 (ddd, J = 9.2, 5.5, 5.5 Hz, 1H), 1.03 (ddd, J = 9.2, 5.5, 5.5 Hz, 1H), 0.89 (ddd, J = 9.2, 5.5, 5.5 Hz, 1H); $^{13}C\{^1H\}$ NMR (101 MHz, CD_2Cl_2) δ 144.6, 142.6 (q, J = 0.8 Hz), 140.0, 135.5, 130.8, 130.4, 129.0 (q, J = 32.2 Hz), 128.4, 128.0, 127.5, 126.2, 125.2 (q, J = 3.6 Hz), 124.6 (q, J = 272.0 Hz), 123.4, 112.5, 47.1, 43.5, 31.4, 29.4, 21.7, 7.6, 5.3; IR (neat) 2956, 2923, 2851, 1735, 1645, 1618, 1599, 1494, 1459, 1399, 1348, 1325, 1283, 1167, 1124, 1110, 1069, 1018, 980, 956 cm^{-1}; HRMS (ESI) calcd for $C_{28}H_{25}F_3NO_2S$ ([M + H]$^+$) 496.1553, found 496.1549.

Asymmetric Product Synthesis, General Procedure B (2.5 mol % Catalyst). Preparation of solution of cationic Au(I) catalyst: Anhydrous toluene (4.0 mL) was added to a mixture of $L2Au_2Cl_2$[40] (8.1 mg, 5.0 μmol, L2 = (*R*)-4-MeO-3,5-(*t*-Bu)$_2$-MeOBIPHEP) and $AgSbF_6$ (4.1 mg, 11.9 μmol) under nitrogen. The mixture was stirred at room temperature for 30 min. The resulting suspension was left to stand until the formed AgCl precipitated. The supernatant was used in Au(I)-catalyzed cyclization/rearrangement reactions as the catalyst precursor. General procedure of Au(I)-catalyzed cyclization/rearrangement reaction: Under nitrogen, the above Au(I)$^+$ solution (4.0 mL) was added to flame-dried glassware containing **1** (0.2 mmol) in an oil bath at 30 °C. The reaction was monitored by TLC. Upon completion, the reaction mixture was purified by flash column chromatography on silica gel to afford **2** or **3**.

The R configuration of each product was proposed by analogy to that from the absolute configuration of **2h**, which was confirmed by its X-ray structure.

*(R)-1,6-Diphenyl-3-tosyl-3-azabicyclo[5.2.0]nona-4,6-diene (**2a**).* Following general procedure B, 85.6 mg of **1a** was used, and the reaction time was 12 h. After flash column chromatography on silica gel (eluted with PE/EA, 20:1), 85.1 mg of **2a** was obtained in 99% yield and 99% e.e., as determined by HPLC analysis (chiral OD-H, hexane/*i*-PrOH = 90/10, 1.0 mL/min, 220 nm, 25 °C), t_r, 9.26 min (minor), 11.35 min (major); α = −209.7° (c = 0.49, $CHCl_3$). **2a**: white solid, m.p. = 62−65 °C, TLC, R_f = 0.49 (PE/EA, 5:1); ^{1}H NMR (400 MHz, CD_2Cl_2) δ 7.37 (d, J = 8.1 Hz, 2H), 7.35−7.23 (m, 10H), 7.21 (d, J = 8.1 Hz, 2H), 6.66 (d, J = 10.6 Hz, 1H), 5.29 (d, J = 10.6 Hz, 1H), 4.47 (dd, J = 12.1, 1.6 Hz, 1H), 3.19 (d, J = 12.1 Hz, 1H), 3.12 (ddd, J = 16.0, 9.6, 9.6 Hz, 1H), 2.51 (ddd, J = 16.0, 8.4, 3.5 Hz, 1H), 2.40 (s, 3H), 2.37−2.26 (m, 2H); $^{13}C\{^1H\}$ NMR (101 MHz, $CDCl_3$) δ 145.4, 143.6, 142.6, 140.0, 136.0, 130.0, 129.8, 128.6, 128.3, 127.7, 127.3, 127.1, 127.0, 126.82, 126.80, 106.5, 59.5, 55.2, 31.4, 29.0, 21.7; IR (neat) 2922, 2852, 1631, 1350, 1329, 1199, 1145, 1091, 1056, 984 cm^{-1}; HRMS (ESI) calcd for $C_{27}H_{26}NO_2S$ ([M + H]$^+$) 428.1679, found 428.1678.

Gram-Scale Reaction to 2a. Following a similar procedure (the reaction scale was 2.5 mmol) of general procedure B, 1.0695 g of **1a** was used, and the reaction time was 12 h. After flash column chromatography on silica gel (eluted with PE/EA, 20:1), 1.0578 g of **2a** was obtained in 99% yield and 99% e.e., as determined by HPLC analysis.

*(R)-6-Phenyl-1-(p-tolyl)-3-tosyl-3-azabicyclo[5.2.0]nona-4,6-diene (**2b**).* Following general procedure B, 88.2 mg of **1b** was used, and the reaction time was 12 h. After flash column chromatography on silica gel (eluted with PE/EA, 20:1), 87.6 mg of **2b** was obtained in 99% yield and 98% e.e., as determined by HPLC analysis (chiral OD-H, hexane/*i*-PrOH = 90/10, 1.0 mL/min, 220 nm, 25 °C), t_r, 7.42 min (minor), 9.40 min (major); α = −202.1° (c = 0.50, $CHCl_3$). **2b**: white solid, m.p. = 66−69 °C, TLC, R_f = 0.53 (PE/EA, 5:1); ^{1}H NMR (400 MHz, CD_2Cl_2) δ 7.38−7.28 (m, 6H), 7.27−7.22 (m, 1H), 7.20 (d, J = 8.0 Hz, 2H), 7.15−7.10 (m, 2H), 7.06 (d, J = 8.0 Hz, 2H), 6.69 (d, J = 10.6 Hz, 1H), 5.28 (d, J = 10.6 Hz, 1H), 4.44 (dd, J = 12.1, 1.6 Hz, 1H), 3.20 (d, J = 12.1 Hz, 1H), 3.10 (ddd, J = 16.0, 9.4, 9.4 Hz, 1H), 2.50 (ddd, J = 16.0, 7.8, 4.1 Hz, 1H), 2.41 (s, 3H), 2.35 (s, 3H), 2.32−2.23 (m, 2H); $^{13}C\{^1H\}$ NMR (101 MHz, CD_2Cl_2) δ 146.1, 144.1, 140.3, 140.0, 136.7, 136.3, 130.0, 129.9, 129.3, 128.5, 127.9, 127.4, 127.23, 127.17, 126.9, 106.8, 59.4, 55.5, 31.6, 29.2, 21.7, 21.3; IR (neat) 3051, 3025, 2923, 2854, 1654, 1612, 1599, 1513, 1495, 1445, 1424, 1401, 1347, 1321, 1290, 1241, 1224, 1184, 1163, 1116, 1091, 1031, 1020, 983, 918 cm^{-1}; HRMS (ESI) calcd for $C_{28}H_{28}NO_2S$ ([M + H]$^+$) 442.1835, found 442.1835.

*(R)-1-(4-Methoxyphenyl)-6-phenyl-3-tosyl-3-azabicyclo[5.2.0]nona-4,6-diene (**2c**).* Following general procedure B, 91.8 mg of **1c** was used, and the reaction time was 12 h. After flash column chromatography on silica gel (eluted with PE/EA, 20:1), 89.1 mg of **2c** was obtained in 97% yield and 97% e.e., as determined by HPLC analysis (chiral OD-H, hexane/*i*-PrOH = 90/10, 1.0 mL/min, 220 nm, 25 °C), t_r, 10.37 min (minor), 12.67 min (major); α = −211.1° (c = 0.50, $CHCl_3$). **2c**: white solid, m.p. = 65−68 °C, TLC, R_f = 0.39 (PE/EA, 5:1); ^{1}H NMR (400 MHz, CD_2Cl_2) δ 7.39−7.28 (m, 6H), 7.27−7.22 (m, 1H), 7.19 (d, J = 8.0 Hz, 2H), 7.17−7.11 (m, 2H), 6.80−6.74 (m, 2H), 6.71 (d, J = 10.6 Hz, 1H), 5.29 (d, J = 10.6 Hz, 1H), 4.41 (dd, J = 12.2, 1.6 Hz, 1H), 3.80 (s, 3H), 3.20 (d, J = 12.2 Hz, 1H), 3.10 (ddd, J = 16.0, 9.4, 9.4 Hz, 1H), 2.50 (ddd, J = 16.0, 8.1, 3.7 Hz, 1H), 2.41 (s, 3H), 2.33−2.22 (m, 2H); $^{13}C\{^1H\}$ NMR (101 MHz, CD_2Cl_2) δ 158.9, 146.2, 144.1, 140.3, 136.4, 134.9, 130.0, 129.9, 128.6, 128.5, 127.9, 127.18, 127.17, 127.0, 113.9, 106.7, 59.1, 55.6, 55.5, 31.5, 29.2, 21.6; IR (neat) 3043, 2925, 2844, 1609, 1505, 1452, 1349, 1245, 1168, 1085, 1031, 985, 917 cm^{-1}; HRMS (ESI) calcd for $C_{28}H_{28}NO_3S$ ([M + H]$^+$) 458.1784, found 458.1786.

Following general procedure B, 99.1 mg of **1d** was used, and the reaction time was 12 h. Only a complex mixture was obtained, which was determined by crude ^{1}H NMR.

*(R)-1-Phenyl-6-(p-tolyl)-3-tosyl-3-azabicyclo[5.2.0]nona-4,6-diene (**2e**).* Following general procedure B, 88.1 mg of **1e** was used, and the reaction time was 12 h. After flash column chromatography on silica gel (eluted with PE/EA, 35:1), 85.0 mg of **2e** was obtained in

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96% yield and 98% e.e., as determined by HPLC analysis (chiral AD-H, hexane/*i*-PrOH = 90/10, 1.0 mL/min, 220 nm, 25 °C), t_r, 7.79 min (minor), 8.88 min (major); α = −184.2° (*c* = 0.50, $CHCl_3$). **2e**: white solid, m.p. = 71−73 °C, TLC, R_f = 0.49 (PE/EA, 5:1); ^{1}H NMR (400 MHz, CD_2Cl_2) δ 7.37 (d, *J* = 8.3 Hz, 2H), 7.30−7.23 (m, 5H), 7.23−7.18 (m, 4H), 7.15 (d, *J* = 8.3 Hz, 2H), 6.65 (d, *J* = 10.7 Hz, 1H), 5.27 (d, *J* = 10.7 Hz, 1H), 4.46 (dd, *J* = 12.1, 1.5 Hz, 1H), 3.19 (d, *J* = 12.1 Hz, 1H), 3.11 (ddd, *J* = 16.0, 9.4, 9.4 Hz, 1H), 2.50 (ddd, *J* = 16.0, 8.3, 3.6 Hz, 1H), 2.40 (s, 3H), 2.36−2.27 (m, 2H), 2.34 (s, 3H); $^{13}C\{^1H\}$ NMR (101 MHz, CD_2Cl_2) δ 145.1, 144.2, 143.2, 137.3, 137.0, 136.3, 130.1, 130.0, 129.2, 128.7, 127.8, 127.6, 127.2, 127.0, 126.9, 107.0, 59.7, 55.5, 31.6, 29.2, 21.7, 21.2; IR (neat) 2955, 2923, 2869, 2852, 1658, 1632, 1612, 1512, 1493, 1457, 1424, 1377, 1347, 1320, 1184, 1163, 1091, 1070, 984, 918 cm^{-1}; HRMS (ESI) calcd for $C_{28}H_{28}NO_2S$ ($[M + H]^+$) 442.1835, found 442.1837.

*(R)-6-(4-Methoxyphenyl)-1-phenyl-3-tosyl-3-azabicyclo[5.2.0]-nona-4,6-diene (**2f**).* Following general procedure B, 90.9 mg of **1f** was used, and the reaction time was 12 h. After flash column chromatography on silica gel (eluted with PE/EA, 20:1), 87.6 mg of **2f** was obtained in 96% yield and 99% e.e., as determined by HPLC analysis (chiral AD-H, hexane/*i*-PrOH = 90/10, 1.0 mL/min, 220 nm, 25 °C), t_r, 12.01 min (minor), 14.73 min (major); α = −175.8° (*c* = 0.50, $CHCl_3$). **2f**: white solid, m.p. = 67−70 °C, TLC, R_f = 0.37 (PE/EA, 5:1); ^{1}H NMR (400 MHz, CD_2Cl_2) δ 7.37 (d, *J* = 8.1 Hz, 2H), 7.34−7.14 (m, 9H), 6.88 (d, *J* = 8.6 Hz, 2H), 6.65 (d, *J* = 10.7 Hz, 1H), 5.27 (d, *J* = 10.7 Hz, 1H), 4.46 (d, *J* = 12.1 Hz, 1H), 3.80 (s, 3H), 3.19 (d, *J* = 12.1 Hz, 1H), 3.10 (ddd, *J* = 15.7, 9.4, 9.4 Hz, 1H), 2.51 (ddd, *J* = 15.7, 8.2, 3.7 Hz, 1H), 2.40 (s, 3H), 2.37−2.24 (m, 2H); $^{13}C\{^1H\}$ NMR (101 MHz, CD_2Cl_2) δ 159.0, 144.3, 144.2, 143.2, 136.2, 132.7, 130.1, 129.6, 129.0, 128.7, 127.6, 127.2, 127.0, 126.9, 113.8, 107.1, 59.6, 55.61, 55.60, 31.6, 29.2, 21.6; IR (neat) 2954, 2919, 1606, 1506, 1455, 1349, 1305, 1245, 1166, 1087, 1030, 981, 920 cm^{-1}; HRMS (ESI) calcd for $C_{28}H_{28}NO_3S$ ($[M + H]^+$) 458.1784, found 458.1784.

*(R)-1-Phenyl-3-tosyl-6-(4-(trifluoromethyl)phenyl)-3-azabicyclo-[5.2.0]nona-4,6-diene (**2g**).* Following general procedure B, 99.5 mg of **1g** was used, and the reaction time was 12 h. After flash column chromatography on silica gel (eluted with PE/EA, 35:1), 92.4 mg of **2g** was obtained in 93% yield and 99% e.e., as determined by HPLC analysis (chiral OD-H, hexane/*i*-PrOH = 90/10, 1.0 mL/min, 220 nm, 25 °C), t_r, 8.71 min (major), 10.83 min (minor); α = −179.8° (*c* = 0.47, $CHCl_3$). **2g**: white solid, m.p. = 69−71 °C, TLC, R_f = 0.45 (PE/EA, 5:1); ^{1}H NMR (400 MHz, CD_2Cl_2) δ 7.63 (d, *J* = 8.3 Hz, 2H), 7.45 (d, *J* = 8.2 Hz, 2H), 7.39 (d, *J* = 8.3 Hz, 2H), 7.33−7.25 (m, 5H), 7.22 (d, *J* = 8.2 Hz, 2H), 6.75 (d, *J* = 10.6 Hz, 1H), 5.28 (d, *J* = 10.6 Hz, 1H), 4.51 (dd, *J* = 12.2, 1.4 Hz, 1H), 3.22 (d, *J* = 12.2 Hz, 1H), 3.16 (ddd, *J* = 15.9, 9.2, 9.2 Hz, 1H), 2.53 (ddd, *J* = 15.9, 8.6, 3.2 Hz, 1H), 2.42 (s, 3H), 2.40−2.29 (m, 2H); $^{13}C\{^1H\}$ NMR (101 MHz, $CDCl_3$) δ 147.3, 143.7, 143.6 (q, *J* = 1.0 Hz), 142.2, 135.9, 129.8, 129.1, 128.9 (q, *J* = 32.4 Hz), 128.6, 128.0, 127.4, 127.2, 127.1, 126.9, 125.2 (q, *J* = 3.6 Hz), 124.4 (q, *J* = 272.0 Hz), 105.4, 59.7, 55.1, 31.3, 29.0, 21.6; IR (neat) 3057, 3030, 2923, 2866, 1610, 1494, 1449, 1410, 1327, 1232, 1165, 1121, 1079, 1019, 984, 921 cm^{-1}; HRMS (ESI) calcd for $C_{28}H_{25}F_3NO_2S$ ($[M + H]^+$) 496.1553, found 496.1549.

*(R)-6-(4-Bromophenyl)-1-phenyl-3-tosyl-3-azabicyclo[5.2.0]-nona-4,6-diene (**2h**).* Following general procedure B, 101.5 mg of **1h** was used, and the reaction time was 12 h. After flash column chromatography on silica gel (eluted with PE/EA, 35:1), 96.2 mg of **2h** was obtained in 95% yield and 99% e.e., as determined by HPLC analysis (chiral AD-H, hexane/*i*-PrOH = 90/10, 1.0 mL/min, 220 nm, 25 °C), t_r, 10.72 min (minor), 12.18 min (major); α = −147.4° (*c* = 0.50, $CHCl_3$). **2h**: white solid, m.p. = 72−75 °C, TLC, R_f = 0.64 (PE/EA, 5:1); ^{1}H NMR (400 MHz, CD_2Cl_2) δ 7.52−7.44 (m, 2H), 7.36 (d, *J* = 8.3 Hz, 2H), 7.30−7.23 (m, 5H), 7.23−7.17 (m, 4H), 6.68 (d, *J* = 10.6 Hz, 1H), 5.23 (d, *J* = 10.6 Hz, 1H), 4.46 (dd, *J* = 12.1, 1.6 Hz, 1H), 3.18 (d, *J* = 12.1 Hz, 1H), 3.10 (ddd, *J* = 16.0, 9.4, 9.4 Hz, 1H), 2.49 (ddd, *J* = 16.0, 8.5, 3.4 Hz, 1H), 2.40 (s, 3H), 2.38−2.26 (m, 2H); $^{13}C\{^1H\}$ NMR (101 MHz, CD_2Cl_2) δ 146.5, 144.3, 142.8, 139.3, 136.2, 131.6, 130.2, 129.7, 129.3, 128.7, 127.6, 127.4, 127.2, 127.1, 120.9, 106.1, 59.9, 55.4, 31.6, 29.2, 21.7; IR (neat) 2954, 2918, 1653, 1609, 1487, 1455, 1350, 1233, 1165, 1086, 981 cm^{-1}; HRMS (ESI) calcd for $C_{27}H_{25}BrNO_2S$ ($[M + H]^+$) 506.0784, found 506.0779.

*(R)-1-Phenyl-3-tosyl-6-vinyl-3-azabicyclo[5.2.0]nona-4,6-diene (**2i**).* Following general procedure B, 75.8 mg of **1i** was used, and the reaction time was 1 h. After flash column chromatography on silica gel (eluted with PE/EA, 20:1), 62.0 mg of **2i** was obtained in 82% yield and 90% e.e., as determined by HPLC analysis (chiral OD-H, hexane/*i*-PrOH = 90/10, 0.5 mL/min, 220 nm, 25 °C), t_r, 15.17 min (major), 16.32 min (minor); α = −241.9° (*c* = 0.51, $CHCl_3$). **2i**: white solid, m.p. = 44−47 °C, TLC, R_f = 0.55 (PE/EA, 5:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.30 (d, *J* = 8.3 Hz, 2H), 7.25−7.18 (m, 3H), 7.17−7.09 (m, 4H), 6.63 (d, *J* = 10.6 Hz, 1H), 6.35 (dd, *J* = 17.5, 10.9 Hz, 1H), 5.37−5.27 (m, 2H), 5.10 (d, *J* = 10.6 Hz, 1H), 4.47 (dd, *J* = 12.1, 1.5 Hz, 1H), 3.17 (d, *J* = 12.1 Hz, 1H), 2.86 (ddd, *J* = 15.7, 9.4, 9.4 Hz, 1H), 2.71 (ddd, *J* = 15.7, 8.4, 3.5 Hz, 1H), 2.38 (s, 3H), 2.35−2.24 (m, 2H); $^{13}C\{^1H\}$ NMR (101 MHz, $CDCl_3$) δ 147.9, 143.6, 142.4, 136.0, 133.6, 129.8, 128.5, 127.3, 127.1, 126.8, 126.5, 126.4, 112.1, 101.7, 59.1, 55.1, 30.5, 26.3, 21.6; IR (neat) 3056, 2921, 2860, 1614, 1492, 1448, 1349, 1268, 1165, 1092, 1027, 985, 930 cm^{-1}; HRMS (ESI) calcd for $C_{23}H_{24}NO_2S$ ($[M + H]^+$) 378.1522, found 378.1521.

*(R)-1-Phenyl-6-(prop-1-en-2-yl)-3-tosyl-3-azabicyclo[5.2.0]nona-4,6-diene (**2j**).* Following general procedure B, 78.2 mg of **1j** was used, and the reaction time was 12 h. After flash column chromatography on silica gel (eluted with PE/EA, 20:1), 52.8 mg of **2j** was obtained in 68% yield and 97% e.e., as determined by HPLC analysis (chiral OD-H, hexane/*i*-PrOH = 90/10, 0.5 mL/min, 220 nm, 25 °C), t_r, 12.79 min (major), 14.07 min (minor); α = −223.1° (*c* = 0.50, $CHCl_3$). **2j**: colorless oil, TLC, R_f = 0.52 (PE/EA, 5:1); ^{1}H NMR (400 MHz, CD_2Cl_2) δ 7.41−7.32 (m, 2H), 7.30−7.10 (m, 7H), 6.51 (d, *J* = 10.7 Hz, 1H), 5.09 (dd, *J* = 10.7, 0.8 Hz, 1H), 5.01−4.95 (m, 1H), 4.89 (d, *J* = 0.8 Hz, 1H), 4.43 (dd, *J* = 12.0, 1.7 Hz, 1H), 3.14 (d, *J* = 12.0 Hz, 1H), 2.94 (ddd, *J* = 16.0, 9.4, 9.4 Hz, 1H), 2.66 (ddd, *J* = 16.0, 6.9, 5.4 Hz, 1H), 2.40 (s, 3H), 2.29−2.20 (m, 2H), 1.90 (dd, *J* = 1.3, 0.8 Hz, 3H); $^{13}C\{^1H\}$ NMR (101 MHz, CD_2Cl_2) δ 145.3, 144.2, 144.1, 143.1, 136.3, 131.7, 130.1, 128.7, 127.5, 127.2, 126.9, 126.1, 113.7, 106.2, 59.0, 55.5, 31.3, 29.0, 22.6, 21.6; IR (neat) 2956, 2919, 2870, 2850, 1613, 1493, 1448, 1377, 1348, 1163, 1095, 948 cm^{-1}; HRMS (ESI) calcd for $C_{24}H_{26}NO_2S$ ($[M + H]^+$) 392.1679, found 392.1680.

*(R)-6-(2-Methylprop-1-en-1-yl)-1-phenyl-3-tosyl-3-azabicyclo-[5.2.0]nona-4,6-diene (**2k**).* Following general procedure B, 81.4 mg of **1k** was used, and the reaction time was 3 h. After flash column chromatography on silica gel (eluted with PE/EA, 20:1), 69.3 mg of **2k** was obtained in 85% yield and 97% e.e., as determined by HPLC analysis (chiral OD-H, hexane/*i*-PrOH = 90/10, 1.0 mL/min, 220 nm, 25 °C), t_r, 5.88 min (major), 6.63 min (minor); α = −127.9° (*c* = 0.52, $CHCl_3$). **2k**: colorless oil, TLC, R_f = 0.67 (PE/EA, 5:1); ^{1}H NMR (400 MHz, CD_2Cl_2) δ 7.35−7.30 (m, 2H), 7.28−7.16 (m, 7H), 6.48 (d, *J* = 10.5 Hz, 1H), 5.67 (s, 1H), 5.00 (d, *J* = 10.5 Hz, 1H), 4.43 (dd, *J* = 12.0, 1.6 Hz, 1H), 3.07 (d, *J* = 12.0 Hz, 1H), 2.73−2.63 (m, 1H), 2.39 (s, 3H), 2.37−2.31 (m, 1H), 2.30−2.22 (m, 2H), 1.79 (d, *J* = 1.2 Hz, 3H), 1.66 (d, *J* = 1.1 Hz, 3H); $^{13}C\{^1H\}$ NMR (101 MHz, CD_2Cl_2) δ 145.1, 144.1, 143.6, 136.3, 135.8, 130.1, 128.6, 127.7, 127.20, 127.18, 126.9, 125.4, 123.5, 108.0, 60.1, 55.5, 30.7, 28.2, 26.0, 21.6, 20.1; IR (neat) 2954, 2924, 2869, 2854, 1611, 1494, 1447, 1378, 1346, 1321, 1236, 1165, 1091, 1070, 948, 928 cm^{-1}; HRMS (ESI) calcd for $C_{25}H_{28}NO_2S$ ($[M + H]^+$) 406.1835, found 406.1836.

Reaction of **1l**: following general procedure B, 81.3 mg of **1l** was used, and the reaction time was 12 h. Only 66.2 mg of **1l** was recollected in 81% yield.

*(R)-6-Methyl-1-phenyl-3-tosyl-3-azabicyclo[5.2.0]nona-4,6-diene (**2m**) and (1S,6R)-6-Methyl-1-phenyl-3-tosyl-3-azaspiro-[bicyclo[4.1.0]heptane-7,1′-cyclopropan]-4-ene (**3m**).* Following a similar procedure (the reaction scale was 0.6 mmol) of the general procedure B, 219.3 mg of **1m** was used, and the reaction time was 3 h. After flash column chromatography on silica gel (eluted with PE/EA, 50:1), 187.7 mg of **2m** + **3m** was obtained in 86% yield with **2m**/**3m** = 1.3/1, which was determined by crude ^{1}H NMR. **2m**: 27% e.e., as

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determined by HPLC analysis (chiral OD-H, hexane/*i*-PrOH = 90/10, 1.0 mL/min, 220 nm, 25 °C), t_r, 6.45 min (major), 7.59 min (minor); α = −28.6° (*c* = 0.25, $CHCl_3$); colorless oil, TLC, R_f = 0.52 (PE/EA, 5/1); ^{1}H NMR (400 MHz, CD_2Cl_2) δ 7.32 (d, *J* = 8.1 Hz, 2H), 7.27−7.13 (m, 7H), 6.44 (d, *J* = 10.5 Hz, 1H), 4.95 (d, *J* = 10.5 Hz, 1H), 4.42 (d, *J* = 11.9 Hz, 1H), 3.02 (d, *J* = 11.9 Hz, 1H), 2.75−2.64 (m, 1H), 2.56−2.48 (m, 1H), 2.39 (s, 3H), 2.26−2.19 (m, 2H), 1.71 (s, 3H); ^{13}C{^{1}H} NMR (101 MHz, CD_2Cl_2) δ 144.1, 143.7, 142.6, 136.3, 130.1, 128.5, 127.7, 127.2, 126.8, 125.1, 124.0, 109.0, 59.0, 55.4, 30.5, 26.3, 21.6, 18.4; IR (neat) 3030, 2920, 2856, 1730, 1610, 1493, 1451, 1348, 1242, 1163, 1094, 1058, 938 cm^{-1}; HRMS (ESI) calcd for $C_{22}H_{24}NO_2S$ ([M + H]$^+$) 366.1522, found 366.1517.

3m: 64% e.e., as determined by HPLC analysis (chiral OD-H, hexane/*i*-PrOH = 90/10, 0.5 mL/min, 220 nm, 25 °C), t_r, 13.23 min (major), 14.71 min (minor); α = +15.3° (*c* = 0.42, $CHCl_3$); colorless oil, TLC, R_f = 0.57 (PE/EA, 5:1); ^{1}H NMR (400 MHz, CD_2Cl_2) δ 7.63 (d, *J* = 8.2 Hz, 2H), 7.37−7.27 (m, 4H), 7.27−7.22 (m, 1H), 7.19−7.14 (m, 2H), 6.50 (d, *J* = 8.1 Hz, 1H), 5.15 (d, *J* = 8.1 Hz, 1H), 3.82 (d, *J* = 11.2 Hz, 1H), 2.94 (d, *J* = 11.2 Hz, 1H), 2.42 (s, 3H), 1.07−1.01 (m, 1H), 0.89 (s, 3H), 0.76−0.68 (m, 2H), 0.67−0.61 (m, 1H); ^{13}C{^{1}H} NMR (101 MHz, CD_2Cl_2) δ 144.3, 139.3, 135.6, 130.2, 130.0, 128.8, 127.4, 127.3, 121.9, 115.2, 48.1, 39.8, 29.7, 22.4, 21.7, 18.9, 4.7, 4.5; IR (neat) 2920, 2855, 1733, 1643, 1603, 1457, 1349, 1278, 1166, 1108, 1021, 975 cm^{-1}; HRMS (ESI) calcd for $C_{22}H_{24}NO_2S$ ([M + H]$^+$) 366.1522, found 366.1521.

*(R)-3-((4-Nitrophenyl)sulfonyl)-1-phenyl-6-vinyl-3-azabicyclo-[5.2.0]nona-4,6-diene (**2n**).* Following general procedure B, 81.9 mg of **1n** was used, and the reaction time was 12 h. After flash column chromatography on silica gel (eluted with PE/EA, 35:1), 68.4 mg of **2n** was obtained in 84% yield and 82% e.e., as determined by HPLC analysis (chiral OD-H, hexane/*i*-PrOH = 90/10, 1.0 mL/min, 220 nm, 25 °C), t_r, 16.80 min (major), 21.11 min (minor); α = −137.7° (*c* = 0.48, $CHCl_3$). **2n**: yellow solid, m.p. = 57−59 °C, TLC, R_f = 0.57 (PE/EA, 5:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.13−8.01 (m, 2H), 7.50−7.40 (m, 2H), 7.16−7.07 (m, 3H), 7.07−7.01 (m, 2H), 6.69 (d, *J* = 10.6 Hz, 1H), 6.34 (dd, *J* = 17.6, 10.9 Hz, 1H), 5.44 (d, *J* = 10.6 Hz, 1H), 5.33 (d, *J* = 17.6 Hz, 1H), 5.14 (d, *J* = 10.9 Hz, 1H), 4.52 (dd, *J* = 12.6, 1.6 Hz, 1H), 3.35 (d, *J* = 12.6 Hz, 1H), 2.88−2.77 (m, 1H), 2.76−2.67 (m, 1H), 2.34−2.25 (m, 2H); ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$) δ 149.8, 148.2, 144.6, 142.2, 133.4, 128.6, 128.0, 127.3, 127.1, 126.3, 125.3, 124.3, 112.6, 103.5, 59.1, 55.6, 30.6, 26.4; IR (neat) 2954, 2919, 2859, 1616, 1530, 1457, 1354, 1315, 1169, 1095, 930 cm^{-1}; HRMS (ESI) calcd for $C_{22}H_{24}N_3O_4S$ ([M + NH_4]$^+$) 426.1482, found 426.1482.

*(R)-1-(4-Methoxyphenyl)-6-phenyl-3-oxabicyclo[5.2.0]nona-4,6-diene (**2o**).* Following general procedure B, 60.1 mg of **1o** was used, and the reaction time was 12 h. After flash column chromatography on silica gel (eluted with PE/EA, 50:1), 28.0 mg of **2o** was obtained in 47% yield and 43% e.e., as determined by HPLC analysis (chiral AD-H, hexane/*i*-PrOH = 90/10, 1.0 mL/min, 220 nm, 25 °C), t_r, 5.05 min (minor), 5.79 min (major); α = −33.5° (*c* = 0.30, $CHCl_3$). **2o**: yellow oil, TLC, R_f = 0.66 (PE/EA, 5:1); ^{1}H NMR (400 MHz, CD_2Cl_2) δ 7.39−7.34 (m, 4H), 7.30−7.24 (m, 3H), 6.93−6.87 (m, 2H), 6.31 (d, *J* = 8.0 Hz, 1H), 5.14 (d, *J* = 8.0 Hz, 1H), 4.34 (d, *J* = 10.2 Hz, 1H), 3.99 (d, *J* = 10.2 Hz, 1H), 3.81 (s, 3H), 3.19 (ddd, *J* = 15.8, 9.3, 9.3 Hz, 1H), 2.62−2.54 (m, 1H), 2.27−2.21 (m, 2H); ^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$) δ 158.5, 146.7, 145.4, 139.9, 134.8, 130.0, 128.3, 128.2, 127.6, 126.9, 114.0, 104.0, 76.7, 60.4, 55.4, 29.8, 29.0; IR (neat) 2955, 2919, 2870, 2849, 1652, 1610, 1511, 1461, 1377, 1311, 1248, 1179, 1144, 970 cm^{-1}; HRMS (ESI) calcd for $C_{21}H_{21}O_2$ ([M + H]$^+$) 305.1536, found 305.1536.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.joc.9b01071.

Synthesis of substrates, copies of NMR spectra and high-performance liquid chromatography (HPLC) data, and additional computational results (PDF)

Crystallographic data for (±)-**2a** (CIF)

Crystallographic data for **2h** (CIF)

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Notes

The authors declare no competing financial interest.

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