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ARTICLE

Synthesis of tetrahydrobenzo[*b*]furans via a gold(I)-catalyzed rearrangement/cycloisomerization sequence of cyclic 1-aryl-2-propargyl-cyclohex-2enols

Hsiao-Feng Chen | Ming-Chang P. Yeh

Department of Chemistry, National Taiwan Normal University, Taipei, Taiwan

Correspondence
Ming-Chang P. Yeh, Department of Chemistry, National Taiwan Normal University, 88 Ding-Jou Road, Section 4, Taipei 11677, Taiwan.
Email: cheyeh@ntnu.edu.tw

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A facile synthesis of tetrahydrobenzo[*b*]furans via gold(I)-catalyzed cycloisomerization of 1-aryl-2-propargylcyclohex-2-enols is described. The transformation is suggested to proceed through a gold(I)-catalyzed tertiary allylic alcohol rearrangement to give a secondary allylic alcohol that underwent a *5-exo-dig* addition of the hydroxyl group onto the gold(I)-activated alkyne to give a vinylgold species. Protodeauration of the resulting vinylgold intermediate followed by aromatization furnished the tetrahydrobenzo[*b*]furans.

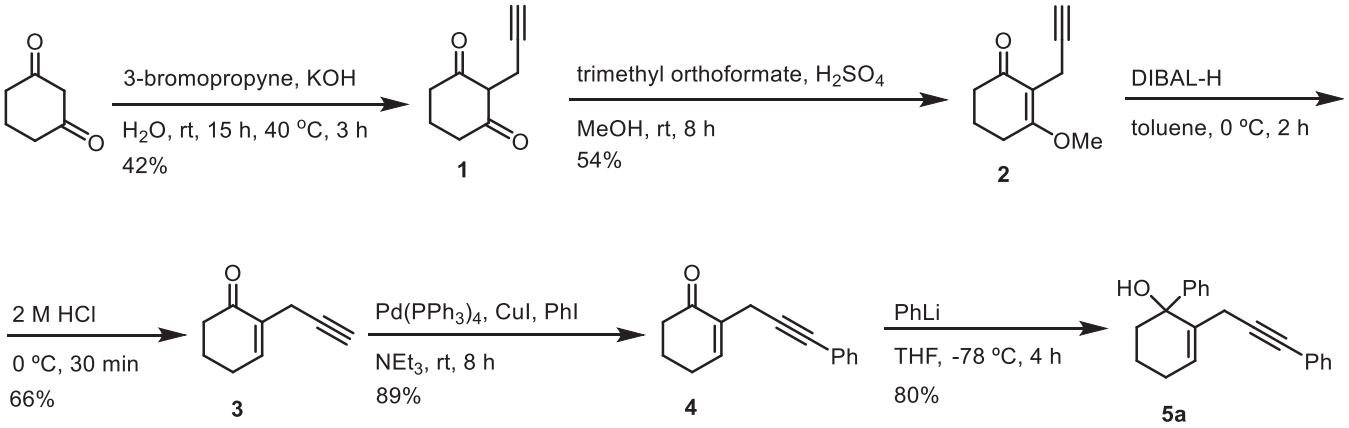
KEYWORDS
allylic alcohol, benzofuran, cycloisomerization, gold

1 | INTRODUCTION

The benzo[*b*]furan scaffold is an important core structure of many natural and/or biologically relevant compounds.[1] Therefore, the efficient synthesis of the benzo[*b*]furan framework continues to attract much interest from synthetic organic chemists. Many transition metal-assisted synthetic approaches, such as Cu,[2] Au,[3] Pd,[4] Pt,[5] Zn,[6] Ag,[7] and Ru[8], to the benzo[*b*]furans have been extensively studied and well documented.[9] Among the transition-metal catalysts, gold salts have emerged as powerful catalysts in recent decades owing to their high catalytic activity and high chemoselectivity for the electrophilic activation of alkynes toward various nucleophiles.[10] Larock et al reported the $AuCl_3$-catalyzed cyclization of 2-(arylethynyl)cyclohex-2-enones with nucleophiles that provided tetrahydrobenzo[*b*]furans.[11] An alternative approach to dihydrobenzo[*b*]furans has been achieved by using a gold(I)-catalyzed Claisen rearrangement of aryl allyl ethers followed by addition of the resulting phenol to the pendant gold-activated olefin.[12] Hashmi et al have revealed the gold(I)-catalyzed transformation of *ortho*-alkyloxy-substituted arylynamides into benzo[*b*]furans with an amino group at the 2-position.[10a] Here, we report an unexpected formation of tetrahydrobenzo[*b*]furans from a gold(I)-catalyzed rearrangement/cycloisomerization sequence of 1-aryl-2-propargylcyclohex-2-enols. In this transformation, a gold(I)-promoted rearrangement of a six-membered ring tertiary allylic alcohol led to a secondary allylic alcohol. The addition of the secondary allylic alcohol to the gold-activated alkyne in a *5-exo-dig* cyclization fashion provided a vinylgold species. Protodeauration of the resulting vinylgold intermediate followed by aromatization furnished 2,4-disubstituted tetrahydrobenzo[*b*]furans. In most cases, these transformations finished in just a few minutes at room temperature under nitrogen.

2 | RESULTS AND DISCUSSION

The parent 1-phenyl-2-(3-phenylpropargyl)cyclohex-2-enol required for the gold(I)-catalyzed rearrangement/cycloisomerization study was prepared according to the sequence depicted in Scheme 1. Alkylation of cyclohexane-1,3-dione with 3-bromopropyne in the presence of potassium hydroxide gave 2-(2-propynyl)cyclohexane-1,3-dione (1), which was then treated with trimethyl orthoformate and sulfuric acid in methanol to give 3-methoxy-2-(2-propynyl)



SCHEME 1 Synthesis of 1-Phenyl-2-(3-phenylpropargyl)cyclohex-2-enol (**5a**)

cyclohex-2-enone (**2**). Reaction of **2** with DIBAL-H at 0°C in toluene followed by an acid treatment with $HCl_{(aq)}$ afforded 2-(2-propynyl)cyclohex-2-enone (**3**). According to the Sonogashira protocol,[13] coupling of the terminal alkyne with iodobenzene using a catalytic amount of $Pd(PPh_3)_4$ and CuI in triethylamine gave 2-(3-phenylpropargyl)cyclohex-2-enone (**4**). Addition of phenyllithium to **4** in THF at − 78°C led to the desired starting substrate 1-phenyl-2-(3-phenylpropargyl)cyclohex-2-enol (**5a**) (The Supporting Information contains NMR spectra for all compounds).

In light of the previous examples employing gold(I) cations in Claisen-type rearrangements of enynols leading to various carbocycles,[14] the parent compound **5a** was tested with 5 mol% of the $Ph_3PAuCl/AgOTf$ cocatalyst system in DCM at rt for an initial survey of reaction conditions. The reaction was performed with the expectation that a *6-endo-dig* cyclization of the hydroxyl group to the gold(I)- activated alkyne in **6** (Figure 1) would give the cationic allylic vinyl ether gold intermediate **7**. Intermediate **7** then undergo a Claisen-type rearrangement and final protodeauration to afford the fused bicyclic ketone **8** (Figure 1). To our surprise, compound 5a delivered the tetrahydrobenzo[*b*]furan derivative **9a** in 1 min in 61% isolated yield upon treatment with 5 mol% of $Ph_3PAuCl/AgOTf$ in DCM at room temperature. None of the bicyclic ketone **8** was observed. It must be noted that prior to our study, benzofuran derivatives were available from aryl allyl ethers in good yields by the same catalytic $Ph_3PAuCl/AgOTf$ system, albeit required long reaction times and elevated temperatures.[12] Hashmi et al. have also reported gold(I)-catalyzed transformations of silyl-protected furan-yn-ols[15] and 1-(arylethynyl)-7-oxabicyclo [4.1.0]heptan-2-ones[16] into benzofuran ring skeletons. Our approach to the tetrahydrobenzo[*b*]furans starts from easily available substrates under mild reaction conditions, in minutes, for terminal aryl alkynes.

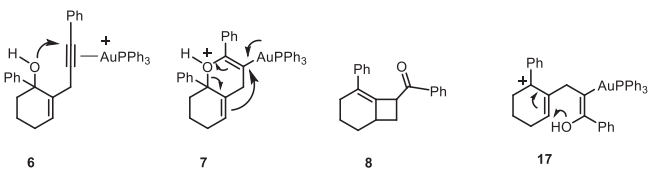
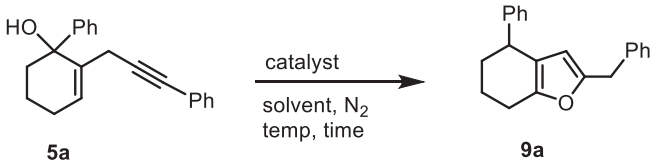


FIGURE 1 Structures of **6**, **7**, **8**, and **17**

Having the preliminary result in hand, we then examined various reaction conditions to optimize the yield of **9a**. Replacing DCM with toluene, **5a** cycloisomerized to **9a** in the presence of 5 mol% of $Ph_3PAuCl/AgOTf$ in 1 min at rt; however, the yield has diminished considerably (40%, Table 1, entry 2). Therefore, DCM was used as the reaction media for further studies. Decreasing or increasing the catalyst loading did not improve the yield and **9a** was isolated in 49 and 42% yield, respectively (Table 1, entries 3 and 4). A longer reaction time (25 min) and a low yield (18%) were observed when the reaction was conducted at 0°C (Table 1, entry 5). Running the reaction under reflux in DCM did not provide a better result as **9a** was isolated in 24% yield (Table 1, entry 6). Evaluation of various silver salts as chloride scavengers revealed that AgOTf was optimal (Table 1, entries 7 and 8). Moreover, the use of Ph_3PAuCl alone in DCM at rt failed to provide any of the desired product 9a and the starting substrate **5a** remained intact (Table 1, entry 9). Running the reaction with AgOTf (5 mol%), in the absence of Ph_3PAuCl, gave a complex crude reaction mixture (Table 1, entry 10). When Ph_3PAuCl was replaced by other gold(I) complexes, including IprAuCl, JohnPhosAuCl, $(C_6F_5)_3PAuCl$, and Cy_3PAuCl, comparable yields and reaction times were observed (47–65%, Table 1, entries 11–14). It is well known that a catalytic amount of triflic acid (TfOH) is capable of transforming the alkynylalkyl-tethered cyclic tertiary alcohols into cyclic ketones.[17] However, when the reaction was carried out with 10 mol% of TfOH in DCM, **5a** afforded an inseparable mixture of dehydrated cyclohexadienes **10a** and **10b** in 70% yield (Table 1, entry 15, Figure 2). Interestingly, when subjected to $BF_3\dot{c}OEt_2$, **5a** underwent an allylic alcohol rearrangement to give the secondary allylic alcohol **11** in 15% yield together with a trace amount of a mixture of dehydrated products **10a** and **10b** (Table 1, entry 16, Figure 2). The six-membered ring secondary allylic alcohol **11** was then subjected to 5 mol% of $Ph_3PAuCl/AgOTf$ at rt for 4 min to give **9a** in 38% isolated

TABLE 1 Optimization studies on the rearrangement/cycloisomerization of **5a**[a]



Entry	Catalyst (Mol %)	Solvent	Temp (°C)	Time	Yield (%)[b]
1	$Ph_3PAuCl/AgOTf$ (5)	DCM	31	1 min	61
2	$Ph_3PAuCl/AgOTf$ (5)	Toluene	28	1 min	40
3	$Ph_3PAuCl/AgOTf$ (2)	DCM	31	30 min	49
4	$Ph_3PAuCl/AgOTf$ (10)	DCM	32	1 min	42
5	$Ph_3PAuCl/AgOTf$ (5)	DCM	0	25 min	18[c]
6	$Ph_3PAuCl/AgOTf$ (5)	DCM	Reflux	1 min	24
7	$Ph_3PAuCl/AgBF_4$ (5)	DCM	19	13 min	30
8	$Ph_3PAuCl/AgPF_6$ (5)	DCM	19	30 min	40
9	Ph_3PAuCl (5)	DCM	29	1 d	—
10	AgOTf (5)	DCM	30	18 hr	—[d]
11	IprAuCl/AgOTf (5)	DCM	29	4 min	47
12	JohnPhosAuCl/AgOTf (5)	DCM	28	2 min	49
13	$(C_6F_5)_3PAuCl/AgOTf$ (5)	DCM	30	1 min	46
14	$Cy_3PAuCl/AgOTf$ (5)	DCM	30	5 min	65
15	TfOH (10)	DCM	30	2 min	—[d]
16	BF_3·OEt_2 (10)	DCM	28	2 min	—[e]

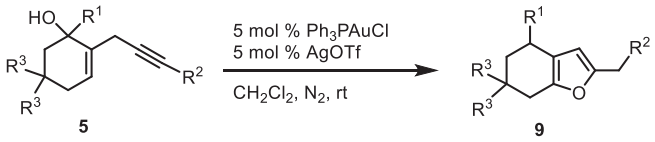
[a] All reactions were conducted on a 0.2 mmol scale with 2–10% molar of the catalyst in DCM or toluene (2.0 mL).
[b] Isolated yields obtained from column chromatography over silica gel.
[c] NMR yields.
[d] A mixture of **10a** and **10b** were obtained.
[e] The secondary allylic alcohol **11** was isolated in 15% yield.

yield. Therefore, the use of $Ph_3PAuCl/AgOTf$ as the catalyst system (5 mol%) and DCM as the solvent at rt under nitrogen were the most effective for the transformation of six-membered ring tertiary allylic alcohol **5a** into the tetrahydrobenzo[*b*]furan derivative **9a** (Table 1, entry 1).

Next, a series of six-membered ring enynols **5b–t** were subjected to the optimal reaction conditions (Table 1, entry1) to delineate the scope of the transformation and reveal the influence of the substitution pattern on the product yield. Results are compiled in Table 2.

While substrates **5b–e** bearing electron-neutral aryl group attached to the alkyne were efficient to deliver the corresponding tetrahydrobenzo[*b*]furans **9b–e** in 1 to 4 min and in yields ranging from 38 to 66% (Table 2, entries 2–5), the electron-rich *p*-methoxyphenyl-substituted derivative, **5f**, delivered the corresponding tetrahydrobenzo[*b*]furan **9f** in 27% isolated yield accompanied by a longer reaction time (20 min) (Table 2, entry 6). Terminal alkyne **5g** also successfully transformed into the desired product **9g**, albeit in low yield (26%, Table 2, entry 7). Pleasingly, substrates containing an electron-withdrawing ester (**5h** and **5i**) or nitro (**5j** and **5k**) group at the *m*-position or *p*-position of the phenyl ring were tolerated and afforded tetrahydrobenzo[*b*]furans **9h–k** in higher yields ranging from 68 to 78% (Table 2, entries **8**–**11**). Structure of **9k** was confirmed using X-ray diffraction analysis (The Supporting Information contains the supplementary crystallographic data for this compound).[18] Figure 3 shows the ORTEP structure of benzo[*b*]furan **9k**. However, substrate **5l**, bearing an *o*-nitrophenyl group at the alkyne terminus, required a longer reaction time (24 hr) and gave the desired tetrahydrobenzo[*b*]furan **9l** in only 11% yield (Table 2, entry 12). Substrate **5m**, containing a *m*-CF_3Ph group at the alkyne cyclized smoothly with the catalyst, afforded tetrahydrobenzo[*b*]furan **9m** in 73% yield (Table 2, entry 13). A bromo atom at the *para* position of the phenylalkyne, for example **5n**, did not impede the activity of the catalyst and tetrahydrobenzo[*b*]furan **9n** was isolated in 53% yield (Table 2, entry 14). When the aromatic alkynes were replaced by an *n*-butyl group, the desired product **9o** was obtained in only 29% yield (Table 2, entry 15). A geminal dimethyl group at the C-5 position of the six-membered ring, **5p**, was also effective and afforded the desired tetrahydrobenzo[*b*]furan **9p** in 62% yield (Table 2, entry 16). Next, we explored the substrate scope with respect to the R^1 at the C-1 position of the six-membered ring. When R^1 was a *p*-methoxyphenyl, the desired product **9q** was obtained in only 12% yield (Table 2, entry 17). Compound **5r**, with a methyl group attached to the carbinol carbon, required a longer time (60 min) for the transformation and produced the corresponding tetrahydrobenzo[*b*]furan **9r**

TABLE 2 Substrate scope for the formation of Benzo[*b*]furan **9**



Entry	R^1	R^2	R^3	Substrate	Time (min)	Product (%)[a]
1	Phenyl	Phenyl	H	**5a**	1	**9a** (61)
2	Phenyl	3-methylphenyl	H	**5b**	1	**9b** (51)
3	Phenyl	4-methylphenyl	H	**5c**	1	**9c** (38)
4	Phenyl	4-phenylphenyl	H	**5d**	4	**9d** (66)
5	Phenyl	1-naphthyl	H	**5e**	1	**9e** (50)
6	Phenyl	4-methoxyphenyl	H	**5f**	20	**9f** (27)
7	Phenyl	H	H	**5g**	1	**9g** (26)
8	Phenyl	3-(ethoxycarbonyl)phenyl	H	**5h**	1	**9h** (70)
9	Phenyl	4-(ethoxycarbonyl)phenyl	H	**5i**	5	**9i** (78)
10	Phenyl	3-nitrophenyl	H	**5j**	3	**9j** (68)
11	Phenyl	4-nitrophenyl	H	**5k**	1	**9k** (76)[b,c]
12	Phenyl	2-nitrophenyl	H	**5l**	1,440	**9l** (11)
13	Phenyl	3-trifluoromethylphenyl	H	**5m**	4	**9m** (73)
14	Phenyl	4-bromophenyl	H	**5n**	1	**9n** (53)
15	Phenyl	*n*-butyl	H	**5o**	5	**9o** (29)
16	Phenyl	Phenyl	CH_3	**5p**	1	**9p** (62)
17	4-methoxyphenyl	Phenyl	H	**5q**	1	**9q** (12)
18	Methyl	Phenyl	H	**5r**	60	**9r** (39)
19	*n*-butyl	Phenyl	H	**5s**	1	**9s** (15)[d]
20	Ethyl	Phenyl	H	**5t**	30	**9t** (18)[e]

[a] Isolated yields obtained from column chromatography over silica gel.
[b] The reaction was performed with 10 mol% $Ph_3PAuCl/AgOTf$.
[c] The structure has been confirmed by X-ray crystallography.
[d] Diene **12a** was obtained in 32% yield.
[e] Diene product **12b** was obtained in 59% yield.

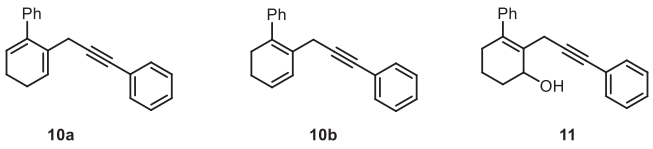


FIGURE 2 Structures of **10a**, **10b,** and **11**

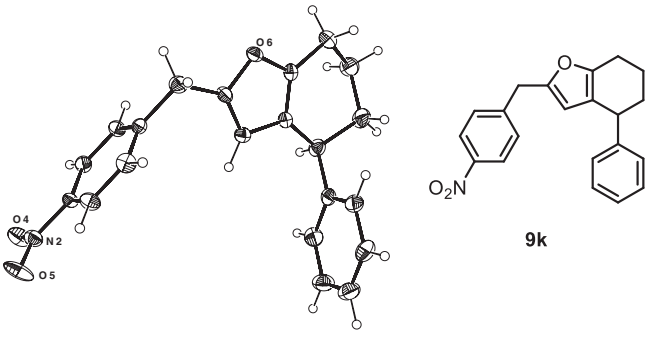


FIGURE 3 ORTEP structure of **9k**

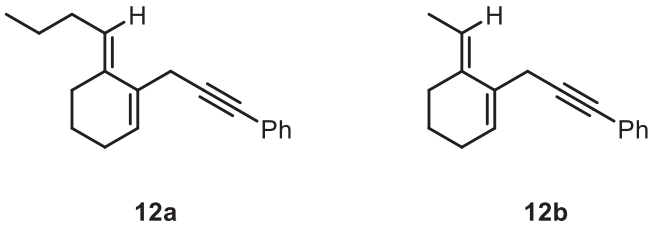
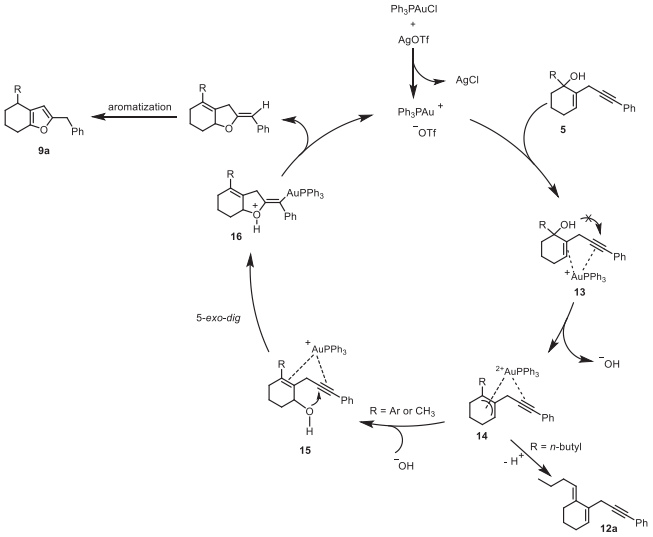


FIGURE 4 Structures of **12a** and **12b**

in 39% yield (Table 2, entry 18). When R^1 is an *n*-butyl group, the reaction completed in 1 min with the gold(I) catalyst and generated the expected product **9s** in only 15% along with the dehydration product **12a** (Figure 4) in 32% yield (Table 2, entry 19). Similarly, substrate **5t** bearing an ethyl substituent at the C-1 position of the six-membered ring led to the formation of the dehydration product **12b** (Figure 4) as the major product in 59% yield and the desired tetrahydrobenzo[*b*]furan **9t** in 18% yield (Table 2, entry 20).

Based on the obtained results, a plausible catalytic cycle is proposed in Scheme 2. Coordination of the gold(I) species to both the double and triple bond provided intermediate **13**. Due to the steric hindrance of the tertiary carbinol, the nucleophilic attack of the hydroxyl group on the gold(I)-activated alkyne was not possible. Instead, dehydroxylation of the allylic alcohol occurred, thus generating the cationic η^3-



SCHEME 2 A proposed reaction mechanism for the formation of Tetrahydrobenzo[*b*]furan **9a**

allyl-π-alkynyl-gold(I) cationic intermediate **14**. Readdition of a hydroxyl group at the less-hindered allylic carbon afforded intermediate **15**. The intermediate **15** underwent a *5-exo-dig* cyclization of the alcohol oxygen onto the gold(I)-activated alkyne to form the benzofuran skeleton **16**, which evolved into tetrahydrobenzo[*b*]furan **9** after protodeauration of the vinylgold(I) and regeneration of the gold(I) species into the catalytic cycle followed by aromatization. Alternatively, detachment of the hydroxyl group of postulated intermediate **7** would afford allyl cation **17** (Figure 1). Readdition of the hydroxyl group at the C-3 allylic carbon center also led to intermediate **16**. However, when intermediate **14** contained an *n*-butyl group at the allylic carbon, deprotonation proceeded to deliver the dehydration product **12a**.

3 | CONCLUSIONS

In summary, we have presented a gold(I)-catalyzed allylic alcohol rearrangement/cycloisomerization reaction under mild reaction conditions, which provides a simple access to 2,4-disubstituted tetrahydrobenzo[*b*]furans from readily available tertiary1 2-propargylcyclohex-2-enols. Further study will focus on employing this method to *N*-heterocyclic systems.

4 | EXPERIMENTAL

4.1 | General considerations

All reactions were performed under a positive pressure of nitrogen using flame-dried glassware with dry solvents. The addition of air-sensitive and moisture-sensitive liquid (reagents) or anhydrous solvents was performed with an oven-dried syringe or cannula through a septum. Solids were added under gentle stream of nitrogen. Solvents were predried over molecular sieves followed by passing through an activated Al_2O_3 column. All commercial reagents were purchased from commercial sources and used without further purification. Melting points were measured in open glass capillaries with an electronic apparatus and are uncorrected. All reactions were monitored using analytical thin-layer chromatography (TLC) with 0.2 mm precoated silica gel 60 F_{254} plates. The plates were visualized under UV light at 254–360 nm. Flash column chromatography was performed using silica gel P60, 40–63 μm (230–400 mesh). ^{1}H NMR spectra were recorded in $CDCl_3$ solution on 500 MHz NMR and 400 MHz NMR spectrometers. Proton chemical shifts (δ) are reported in parts per million (ppm) relative to Me_4Si (δ 0.00 ppm) or the residual protic solvent peak of $CHCl_3$ (δ 7.26 ppm). Data for ^{1}H NMR are reported as follows: chemical shift (number of protons, multiplicity [s = singlet, d = doublet, t = triplet, q = quartet, quin = quintet, sex = sextet, and m = multiplet]), coupling constant *J* (Hz), integration). ^{13}C NMR spectra were obtained in $CDCl_3$ at 125 or 100 MHz on the same NMR spectrometers. All peaks were reported using the residual protic solvent peak of $CHCl_3$ (δ 77.00 ppm) as an internal reference. Infrared (IR) spectra were recorded as a solid or a thin film on an FT-IR spectrometer and are reported in terms of frequency of absorption (cm^{-1}). Mass spectra (MS) were taken on spectrometers using electrospray ionization (ESI) with ion trap analyzers. Peaks are listed according to their mass/charge (*m/e*) value with percent relative abundance. High-resolution mass spectra (HRMS) were obtained using electron impact ionization (EI+), electrospray ionization (ESI+), fast atom bombardment (FAB+), or atmospheric pressure chemical ionization (APCI+) experiments.

4.2 | General experimental procedure for the synthesis of 1-aryl-2-(3-arylpropargyl)cyclohex-2-en-1-ols 5a–g, r–t

To a stirred solution of cyclohexane-1,3-dione (7.849 g, 70.0 mmol) in KOH (4.870 g, 86.8 mmol) and water (16 mL), 3-bromopropyne (7.8 mL, 70.0 mmol) was added via a syringe at 0°C under a nitrogen atmosphere. After 10 min, the reaction mixture was warmed to room temperature. The reaction mixture was stirred for 15 hr and then for 3 hr at 40°C. The mixture was poured into 4 M $NaOH_{(aq)}$ (7.115 g, 45.0 mL) and extracted with diethyl ether (50 mL × 1). The aqueous solution was acidified with cold HCl solution (37.0 g of 12 M HCl in 37.0 g of cracked ice). After filtration of the precipitate, the remaining solution was washed with water. The organic solvent was removed in vacuo to give a yellow powder. The solid was further crystallized from dichloromethane/hexanes to give 2-(prop-2-yn-1-yl)cyclohexane-1,3-dione (**1**) (4.415 g, 29.4 mmol, 42%) as a light yellow powder: ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.31 (d, *J* = 2.6 Hz, 2H), 2.50 (t, *J* =

6.5 Hz, 4H), 2.23 (t, J = 2.8 Hz, 1H), and 1.98 (quin, J = 6.4 Hz, 2H). To a stirred solution of compound 1 (3.421 g, 22.8 mmol) in MeOH (163.0 mL) was added trimethyl orthoformate (22.4 mL, 205.0 mmol) followed by slow addition of conc. H_2SO_4 (1.4 mL) at rt. The reaction mixture was stirred at rt for 8 hr. After which, the mixture was then neutralized with saturated aqueous $NaHCO_3$ solution (50 mL) and most of the MeOH was concentrated in vacuo. The aqueous layer was extracted with CH_2Cl_2 (100 mL × 3), and the combined organic layers were dried over anhydrous $MgSO_4$ (40 g). Concentration of the organic layer in vacuo gave a crude powder. The crude mixture was purified by flash column chromatography over silica gel (1:2 ethyl acetate/hexanes) to afford 3-methoxy-2-(prop-2-yn-1-yl)cyclohex-2-enone (**2**) (2.020 g, 12.3 mmol, 54%) as a yellow powder: mp 124–125°C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.88 (s, 3H), 3.21–3.17 (m, 2H), 2.60 (t, J = 6.2 Hz, 2H), 2.38 (t, J = 6.7 Hz, 2H), and 2.02 (quin, J = 6.5 Hz, 2H), 1.84 (t, J = 2.7 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 196.6, 173.0, 114.6, 83.2, 65.8, 55.5, 36.0, 24.8, 20.5, and 11.5. To a stirred solution of 2 (3.727 g, 22.7 mmol) in anhydrous toluene (76.0 mL), a solution of DIBAL-H in toluene (1.2 M, 28.4 mL) was added dropwise over 30 min at 0°C under nitrogen. The reaction mixture was stirred at 0°C for 2 hr. To the reaction mixture, 21 mL of water was then added dropwise followed by addition of 2 M HCl (13 mL). The mixture was stirred vigorously for 30 min, and extracted with diethyl ether (50 mL × 4). The combined organic extracts were washed with saturated aqueous $NaHCO_3$ solution (100 mL) and then dried over anhydrous $MgSO_4$ (30 g). The solvent was removed in vacuo and the resulting crude product was purified by flash column chromatography over silica gel (1:30 ethyl acetate/hexanes) to provide 2-(prop-2-yn-1-yl) cyclohex-2-enone (**3**) (2.014 g, 15.0 mmol, 66%) as a pale yellow oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.18 (tt, J = 4.0, 1.7 Hz, 1H), 3.16 (quin, J = 2.2 Hz, 2H), 2.48–2.40 (m, 4H), 2.17 (t, J = 2.7 Hz, 1H), and 2.01 (quin, J = 6.4 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.7, 146.0, 133.7, 80.6, 71.6, 37.9, 25.7, 22.7, and 18.7. To a solution of 3 (0.567 g, 4.23 mmol) in Et_3N (4.2 mL), iodobenzene (1.035 g, 5.07 mmol), $Pd(PPh_3)_4$ (9.8 mg, 0.008 mmol), and CuI (0.032 g, 0.17 mmol) were added under nitrogen. The reaction mixture was stirred at room temperature for 8 hr and the reaction was quenched with saturated aqueous NH_4Cl solution (20 mL). The resulting solution was extracted with CH_2Cl_2 (50 mL × 3). To combine organic solution was washed with water (50 mL × 3), brine (50 mL × 3), and dried over anhydrous $MgSO_4$ (20 g). The solvent was concentrated in vacuo followed by silica gel flash column chromatography purification of the resulting residue (1:30 ethyl acetate/hexanes) to give 2-(3-phenylprop-2-yn-1-yl)cyclohex-2-enone (**4**) (0.790 g, 3.76 mmol, 89%) as a tan oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.46–7.40 (m, 2H),7.34–7.26 (m, 3H), 7.24 (tt, J = 3.9, 1.7 Hz, 1H), 3.38 (q, J = 2.1 Hz, 2H), 2.51–2.41 (m, 4H), and 2.03 (quin, J = 6.4 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 198.2, 146.2, 134.5, 131.6, 128.2, 127.8, 123.5, 86.3, 84.1, 38.2, 26.0, 23.0, 19.9; IR (CH_2Cl_2) 3,330, 2,200, 1,667, and 1,599 cm^{-1}; MS (ESI) *m/e* 233.1 ([M + Na]$^+$, 100), 228.1 (4), 211.1 (2), and 158.1 (1); HRMS (ESI) *m/e* calcd for $C_{15}H_{14}ONa$ [M + Na]$^+$ 233.0942, found 233.0939. To a solution of 4 (1.051 g, 5.00 mmol) in anhydrous THF (12.5 mL), a solution of phenyllithium in dibutyl ether (2.0 M, 3.8 mL,) was added dropwise over 20 min at −78°C under nitrogen. The reaction mixture was maintained at −78°C for 4 hr. The crude mixture was diluted with EtOAc (10 mL) and quenched with saturated aqueous NH_4Cl solution (20 mL) at −78°C. The water layer was extracted with ethyl acetate (30 mL × 3) and dried over anhydrous $MgSO_4$ (10 g). The organic solution was concentrated and the residue was purified by flash column chromatography over silica gel (1:30 ethyl acetate/hexanes and 2% Et_3N) to produce 6-(3-phenylprop-2-yn-1-yl)-1,2,3,4-tetrahydro-[1,1′-biphenyl]-1-ol (**5a**) (1.152 g, 4.00 mmol, 80%) as a yellow oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.48–7.43 (m, 2H), 7.38–7.33 (m, 4H), 7.29–7.24 (m, 4H), 6.25 (br s, 1H), 3.15 (d, J = 19.5 Hz, 1H), 2.87 (d, J = 19.6 Hz, 1H), 2.34 (s, 1H), 2.28–2.17 (m, 2H), 2.02–1.90 (m, 2H), 1.80–1.70 (m, 1H), and 1.66–1.57 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 146.1, 135.8, 131.5, 128.3, 128.2, 128.1, 127.7, 126.8, 125.7, 123.6, 87.6, 83.8, 75.3, 41.6, 25.7, 22.7, and 19.0; IR (CH_2Cl_2) 3,444, 2,235, 1,723, and 1,599 cm^{-1}; MS (ESI) *m/e* 311.1 ([M + Na]$^+$, 100), 288.1 (14), 265.1 (15), 247.1 (27), 224.1 (10), 190.0 (12), and 143.1 (11); HRMS (ESI) *m/e* calcd for $C_{21}H_{20}ONa$ [M + Na]$^+$ 311.1412, found 311.1405.

4.2.1 | 6-(3-[*m*-Tolyl]prop-2-yn-1-yl)-1,2,3,4-tetrahydro-[1,1′-biphenyl]-1-ol (5b)

The crude mixture obtained from the addition of phenyllithium (2.2 mL, 2.0 M in dibutyl ether) to the 2-(3-[*m*-tolyl] prop-2-yn-1-yl)cyclohex-2-enone (0.897 g, 4.00 mmol) was purified by flash column chromatography over silica gel (1:30 ethyl acetate/hexanes, 2% Et_3N) to give **5b** (0.207 g, 0.68 mmol, 17%) as a yellow oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.46 (d, J = 8.2 Hz, 2H), 7.35 (t, J = 7.4 Hz, 2H), 7.25 (t, J = 6.9 Hz, 1H), 7.20–7.15 (m, 3H), 7.11–7.06 (m, 1H), 6.24 (br s, 1H), 3.13 (d, J = 19.7 Hz, 1H), 2.87 (d, J = 19.5 Hz, 1H), 2.37 (s, 1H), 2.31 (s, 3H), 2.28–2.17 (m, 2H), 2.02–1.90 (m, 2H), 1.81–1.70 (m, 1H), and 1.67–1.57 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 146.0, 137.8, 135.8, 132.1, 128.6, 128.5, 128.2, 128.1 (2C), 126.7, 125.7, 123.3, 87.2, 83.9, 75.2, 41.6, 25.6, 22.7, 21.1, and 19.0; IR (CH_2Cl_2) 3,453, 2,228, 1,697, and 1,598 cm^{-1}; MS (ESI) *m/e* 325.2 ([M + Na]$^+$, 60), 294.1 (8), 288.1 (28), 284.2 (25),

and 247.1 (10); HRMS (ESI) *m/e* calcd for $C_{22}H_{22}ONa$ $[M + Na]^+$ 325.1568, found 325.1560.

4.2.2 | 6-(3-[*p*-Tolyl]prop-2-yn-1-yl)-1,2,3,4-tetrahydro-[1,1′-biphenyl]-1-ol (5c)

The crude mixture obtained from the addition of phenyllithium (1.1 mL, 2.0 M in dibutyl ether) to the 2-(3-[*p*-tolyl] prop-2-yn-1-yl)cyclohex-2-enone (0.330 g, 1.47 mmol) was purified by flash column chromatography over silica gel (1:30 ethyl acetate/hexanes, 2% Et_3N) to give **5c** (0.149 g, 0.50 mmol, 33%) as a yellow oil: ^1H NMR (400 MHz, $CDCl_3$) δ 7.48–7.43 (m, 2H), 7.38–7.32 (m, 2H), 7.28–7.24 (m, 3H), 7.08 (d, J = 8.0 Hz, 2H), 6.24 (br s, 1H), 3.13 (d, J = 19.5 Hz, 1H), 2.86 (d, J = 19.5 Hz, 1H), 2.39 (s, 1H), 2.33 (s, 3H), 2.28–2.15 (m, 2H), 2.02–1.89 (m, 2H), 1.80–1.69 (m, 1H), and 1.66–1.59 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 146.1, 137.8, 135.9, 131.4, 128.9, 128.3, 128.1, 126.8, 125.8, 120.5, 86.8, 83.9, 75.3, 41.6, 25.7, 22.8, 21.4, and 19.0; IR (CH_2Cl_2) 3,452, 2,197, 1,712, and 1,606 cm^{-1}; MS (ESI) *m/e* 325.2 ($[M + Na]^+$, 31), 298.2 (4), 288.1 (10), 248.1 (4), and 247.1 (21); HRMS (ESI) *m/e* calcd for $C_{22}H_{22}ONa$ $[M + Na]^+$ 325.1568, found 325.1564.

4.2.3 | 6-(3-([1,1'-Biphenyl]-4-yl)prop-2-yn-1-yl)-1,2,3,4-tetrahydro-[1,1′-biphenyl]-1-ol (5d)

The crude mixture obtained from the addition of phenyllithium (1.7 mL, 2.0 M in dibutyl ether) to the 2-(3-([1,1′-biphenyl]-4-yl)prop-2-yn-1-yl)cyclohex-2-enone (0.859 g, 2.98 mmol) was purified by flash column chromatography over silica gel (1:30 ethyl acetate/hexanes and 2% Et_3N) to give **5d** (0.512 g, 1.40 mmol, 47%) as a pale yellow solid: mp 101–102°C; ^1H NMR (400 MHz, $CDCl_3$) δ 7.58 (d, J = 7.5 Hz, 2H), 7.52 (d, J = 8.2 Hz, 2H), 7.47 (d, J = 7.5 Hz, 2H), 7.46–7.41 (m, 4H), 7.39–7.33 (m, 3H), 7.26 (t, J = 7.3 Hz, 1H), 6.27 (t, J = 3.8 Hz, 1H), 3.17 (d, J = 19.7 Hz, 1H), 2.90 (d, J = 19.6 Hz, 1H), 2.35 (s, 1H), 2.31–2.15 (m, 2H), 2.03–1.91 (m, 2H), 1.81–1.70 (m, 1H), and 1.67–1.59 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 146.0, 140.5, 140.4, 135.8, 131.9, 128.8, 128.3, 128.1, 127.5, 127.0, 126.9, 126.8, 125.7, 122.5, 88.3, 83.6, 75.3, 41.6, 25.7, 22.8, and 19.0; IR (CH_2Cl_2) 3,446, 2,230, 1,668, and 1,601 cm^{-1}; MS (ESI) *m/e* 387.2 ($[M + Na]^+$, 100), 359.2 (22), 342.2 (12), 391.2 (13), 284.2 (7), 235.2 (15), and 118.1 (53); HRMS (ESI) *m/e* calcd for $C_{27}H_{24}ONa$ $[M + Na]^+$ 387.1725, found 387.1723.

4.2.4 | 6-(3-[Naphthalen-1-yl]prop-2-yn-1-yl)-1,2,3,4-tetrahydro-[1,1′-biphenyl]-1-ol (5e)

The crude mixture obtained from the addition of phenyllithium (8.3 mL, 2.0 M in dibutyl ether) to the 2-(3-[naphthalen-1-yl] prop-2-yn-1-yl)cyclohex-2-enone (0.781 g, 3.00 mmol) was purified by flash column chromatography over silica gel (1:30 ethyl acetate/hexanes and 2% Et_3N) to give **5e** (0.146 g, 0.43 mmol, 14%) as a tan oil: ^1H NMR (400 MHz, $CDCl_3$) δ 8.27 (d, J = 8.2 Hz, 1H), 7.83 (d, J = 8.1 Hz, 1H), 7.78 (d, J = 8.2 Hz, 1H), 7.60 (d, J = 7.3 Hz, 1H), 7.56–7.47 (m, 4H), 7.41–7.36 (m, 3H), 7.28 (tt, J = 7.3, 1.6 Hz, 1H), 6.36 (br s, 1H), 3.32 (d, J = 19.6 Hz, 1H), 3.02 (d, J = 19.6 Hz, 1H), 2.37 (br s, 1H), 2.32–2.18 (m, 2H), 2.05–1.93 (m, 2H), 1.82–1.72 (m, 1H), and 1.69–1.59 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 146.0, 136.0, 133.4, 133.2, 130.2, 128.4, 128.2 (2C), 128.1, 126.8, 126.5, 126.3, 126.2, 125.8, 125.2, 121.3, 92.6, 81.8, 75.3, 41.7, 25.7, 23.0, and 19.0; IR (CH_2Cl_2) 3,444, 2,935, 2,220, 1,712, and 1,583 cm^{-1}; MS (ESI) *m/e* 361.1 ($[M + Na]^+$, 25), 236.2 (8), 235.2 (100), 119.1 (4), and 118.1 (63); HRMS (ESI) *m/e* calcd for $C_{25}H_{22}ONa$ $[M + Na]^+$ 361.1568, found 361.1565.

4.2.5 | 6-(3-[4-Methoxyphenyl]prop-2-yn-1-yl)-1,2,3,4-tetrahydro-[1,1′-biphenyl]-1-ol (5f)

The crude mixture obtained from the addition of phenyllithium (2.3 mL, 2.0 M in di-*n*-butyl ether) to the 2-(3-[4-methoxyphenyl]prop-2-yn-1-yl)cyclohex-2-enone (0.800 g, 3.33 mmol) was purified by flash column chromatography over silica gel (1:30 ethyl acetate/hexanes and 2% Et_3N) to give **5f** (0.920 g, 2.89 mmol, 87%) as a yellow oil: ^1H NMR (400 MHz, $CDCl_3$) δ 7.46 (d, J = 8.0 Hz, 2H), 7.35 (t, J = 7.6 Hz, 2H), 7.30 (d, J = 8.6 Hz, 2H), 7.25 (t, J = 7.3 Hz, 1H), 6.80 (d, J = 8.6 Hz, 2H), 6.23 (br s, 1H), 3.80 (s, 3H), 3.12 (d, J = 19.3 Hz, 1H), 2.86 (d, J = 19.3 Hz, 1H), 2.40 (s, 1H), 2.29–2.14 (m, 2H), 2.02–1.89 (m, 2H), 1.81–1.69 (m, 1H), and 1.67–1.56 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.2, 146.2, 136.0, 132.9, 128.3, 128.1, 126.8, 125.8, 115.7, 113.8, 85.9, 83.6, 75.3, 55.3, 41.6, 25.7, 22.8, and 19.0; IR (CH_2Cl_2) 3,455, 2,360, 1,715, and 1,606 cm^{-1}; MS (ESI) *m/e* 341.2 ($[M + Na]^+$, 100), 294.1 (13), 290.2 (9), and 135.1 (15); HRMS (ESI) *m/e* calcd for $C_{22}H_{22}O_2Na$ $[M + Na]^+$ 341.1517, found 341.1515.

4.2.6 | 6-(Prop-2-yn-1-yl)-1,2,3,4-tetrahydro-[1,1′-biphenyl]-1-ol (5g)

The crude mixture obtained from the addition of phenyllithium (16.4 mL, 2.0 M in dibutyl ether) to the 3 (2.000 g, 14.90 mmol) was purified by flash column chromatography over silica gel (1:30 ethyl acetate/hexanes and 2% Et_3N) to give **5g** (2.588 g, 12.19 mmol, 82%) as a colorless oil: ^1H NMR (400 MHz, $CDCl_3$) δ 7.43–7.39 (m, 2H), 7.36–7.31 (m, 2H), 7.27–7.22 (m, 1H), 6.22 (br s, 1H), 2.93 (d, J = 19.4 Hz, 1H), 2.64 (d, J = 19.4 Hz, 1H), 2.28–2.15 (m, 3H), 2.13 (t, J = 2.7 Hz, 1H), 2.00–1.88 (m, 2H), 1.77–1.67 (m, 1H), and 1.65–1.57 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 145.8, 135.3, 128.3, 128.1, 126.8, 125.7, 82.2, 75.2, 71.4, 41.6, 25.6, 21.6, 19.0; IR (CH_2Cl_2) 3,447, 2,120, and 1,602 cm^{-1}; MS (ESI) *m/e* 211.1 ($[M - H]^-$, 98), 205.2 (13), 191.1 (8), 166.0 (9), 132.9 (10), 125.9 (12), and 113.0 (100); HRMS (ESI) *m/e* calcd for $C_{15}H_{15}O$ $[M - H]^-$ 211.1123, found 211.1117.

4.2.7 | General experimental procedure for the arylation of terminal alkynes employing the Sonogashira reaction conditions: Synthesis of 1-aryl-2-(3-arylpropargyl)cyclohex-2-en-1-ols 5h–n

Example for the synthesis of **5h:** To a solution of 5 g (0.500 g, 2.36 mmol) in Et_3N (2.4 mL), ethyl 3-iodobenzoate (0.780 g, 2.83 mmol), $Pd(PPh_3)_4$ (10.9 mg, 0.009 mmol), and CuI (0.036 g, 0.19 mmol) were sequentially added at room temperature under nitrogen. The reaction mixture was stirred for 8 hr before quenching with saturated aqueous NH_4Cl solution (10 mL). The resulting solution was extracted with CH_2Cl_2 (20 mL × 3). The combined organic layer was washed with water (20 mL × 3) and brine (20 mL × 3) and dried over anhydrous $MgSO_4$ (20 g), filtered and concentrated in vacuo to give the crude product. The crude oil was purified by flash column chromatography over silica gel (1:20 ethyl acetate/hexanes) to give ethyl 3-(3-(1-hydroxy-1,4,5,6-tetrahydro-[1,1′-biphenyl]-2-yl)prop-1-yn-1-yl)benzoate (**5h**) (0.628 g, 1.74 mmol, 74%) as a tan oil: ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.04 (t, J = 1.5 Hz, 1H), 7.94 (dt, J = 7.9, 1.4 Hz, 1H), 7.53 (dt, J = 7.7, 1.4 Hz, 1H), 7.48–7.44 (m, 2H), 7.39–7.33 (m, 3H), 7.26 (tt, J = 7.3, 1.2 Hz, 1H), 6.26 (br s, 1H), 4.38 (q, J = 7.1 Hz, 2H), 3.16 (d, J = 19.6 Hz, 1H), 2.88 (d, J = 19.6 Hz, 1H), 2.31–2.16 (m, 2H), 2.24 (s, 1H), 2.02–1.92 (m, 2H), 1.78–1.70 (m, 1H), 1.66–1.58 (m, 1H), and 1.40 (t, J = 7.1 Hz, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.0, 145.9, 135.7, 135.6, 132.6, 130.7, 128.8, 128.4, 128.3, 128.2, 126.9, 125.8, 124.0, 88.7, 82.9, 75.3, 61.1, 41.7, 25.6, 22.6, 19.0, and 14.3; IR (CH_2Cl_2) 3,501, 2,236, 1,716, and 1,601 cm^{-1}; MS (ESI) *m/e* 383.2 ([M + Na]$^+$, 100), 361.2 (18), 311.2 (13), 261.6 (17), 143.1 (28), and 122.5 (16); HRMS (ESI) *m/e* calcd for $C_{24}H_{24}O_3Na$ [M + Na]$^+$ 383.1623, found 383.1624.

Ethyl 4-(3-(1-hydroxy-1,4,5,6-tetrahydro-[1,1′-biphenyl]-2-yl)prop-1-yn-1-yl)- benzoate (**5i**): The crude mixture obtained from the coupling reaction of ethyl 4-iodobenzoate (0.745 g, 2.70 mmol) and **5g** (0.477 g, 2.25 mmol) was purified by flash column chromatography over silica gel (1:20 ethyl acetate/hexanes) to give **5i** (0.711 g, 1.97 mmol, 88%) as a pale yellow solid: mp 73–74°C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.99–7.92 (m, 2H), 7.49–7.44 (m, 2H), 7.43–7.39 (m, 2H), 7.38–7.33 (m, 2H), 7.26 (tt, J = 7.3, 1.1 Hz, 1H), 6.25 (br s, 1H), 4.37 (q, J = 7.1 Hz, 2H), 3.18 (d, J = 19.7 Hz, 1H), 2.90 (d, J = 19.7 Hz, 1H), 2.27 (s, 1H), 2.31–2.15 (m, 2H), 2.03–1.91 (m, 2H), 1.79–1.68 (m, 1H), 1.67–1.59 (m, 1H), and 1.39 (t, J = 7.1 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 166.1, 145.9, 135.6, 131.4, 129.4, 129.3, 128.4, 128.3, 128.2, 126.9, 125.7, 91.0, 83.2, 75.2, 61.0, 41.6, 25.6, 22.7, 19.0, and 14.3; IR (CH_2Cl_2) 3,502, 2,230, 1,715, and 1,606 cm^{-1}; MS (ESI) *m/e* 359.2 ([M – H]$^-$, 100), 328.1 (4), 298.0 (12), 295.0 (3), 252.0 (6), 245.0 (2), and 211.1 (5); HRMS (ESI) *m/e* calcd for $C_{24}H_{23}O_3$ [M – H]$^-$ 359.1647, found 359.1643.

6-(3-[3-Nitrophenyl]prop-2-yn-1-yl)-1,2,3,4-tetrahydro-[1,1′-biphenyl]-1-ol (**5j**): The crude mixture obtained from the coupling reaction of 1-iodo-3-nitrobenzene (0.448 g, 1.80 mmol) and **5g** (0.318 g, 1.50 mmol) was purified by flash column chromatography over silica gel (1:20 ethyl acetate/hexanes) to give **5j** (0.489 g, 1.47 mmol, 98%) as a tan oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.18 (t, J = 1.8 Hz, 1H), 8.12 (ddd, J = 8.3, 2.3, 0.9 Hz, 1H), 7.64 (dt, J = 7.7, 1.1 Hz, 1H), 7.49–7.42 (m, 3H), 7.36 (ddd, J = 7.8, 6.8, 1.2 Hz, 2H), 7.27 (tt, J = 7.1, 1.5 Hz, 1H), 6.24 (br s, 1H), 3.19 (d, J = 19.8 Hz, 1H), 2.91 (d, J = 19.7 Hz, 1H), 2.33–2.17 (m, 2H), 2.15 (s, 1H), 1.98 (dd, J = 7.1, 5.0 Hz, 2H), 1.79–1.68 (m, 1H), and 1.68–1.57 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 148.0, 145.7, 137.2, 135.4, 129.1, 128.3, 128.2, 126.9, 126.3, 125.7, 125.5, 122.4, 90.8, 81.5, 75.2, 41.6, 25.6, 22.5, and 19.0; IR (CH_2Cl_2) 3,560, 2,229, and 1,530 cm^{-1}; MS (ESI) *m/e* 332.1 ([M – H]$^-$, 100), 316.7 (8), 298.0 (2), 252.0 (1), and 224.8 (1); HRMS (ESI) *m/e* calcd for $C_{21}H_{18}NO_3$ [M – H]$^-$ 332.1287, found 332.1280.

6-(3-[4-Nitrophenyl]prop-2-yn-1-yl)-1,2,3,4-tetrahydro-[1,1′-biphenyl]-1-ol (**5k**): The crude mixture obtained from the coupling reaction of 1-iodo-4-nitrobenzene (0.598 g, 2.40 mmol) and **5g** (0.425 g, 2.00 mmol) was purified by flash column chromatography over silica gel (1:20 ethyl acetate/hexanes) to give **5k** (0.542 g, 1.63 mmol, 81%) as a yellow solid: mp 120–121°C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.19–8.10 (m, 2H), 7.50–7.44 (m, 4H), 7.36 (ddd, J = 7.8, 6.8, 1.2 Hz, 2H), 7.27 (tt, J = 7.3, 1.2 Hz, 1H), 6.24 (br s, 1H), 3.21 (d, J = 19.9 Hz, 1H), 2.92 (d, J = 19.8 Hz, 1H), 2.32–2.19 (m, 2H), 2.16 (d, J = 2.5 Hz, 1H), 1.98 (dd, J = 7.0, 5.1 Hz, 2H), 1.78–1.67 (m, 1H), and 1.67–1.56 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 146.7, 145.7, 135.4, 132.2, 130.7, 128.4, 128.2, 127.0, 125.7, 123.5, 93.9, 82.2, 75.2, 41.6, 25.6, 22.7, and 19.0; IR (CH_2Cl_2) 3,558, 2,229, and 1,593 cm^{-1}; MS (ESI) *m/e* 332.1 ([M – H]$^-$, 100), 298.0 (4), 252.0 (3), and 211.1 (2); HRMS (ESI) *m/e* calcd for $C_{21}H_{18}NO_3$ [M – H]$^-$ 332.1287, found 322.1279.

6-(3-[2-Nitrophenyl]prop-2-yn-1-yl)-1,2,3,4-tetrahydro-[1,1′-biphenyl]-1-ol (**5l**): The crude mixture obtained from the coupling reaction of 1-iodo-2-nitrobenzene (0.448 g, 1.80 mmol) and **5g** (0.318 g, 1.50 mmol) was purified by flash column chromatography over silica gel (1:20 ethyl acetate/hexanes) to give **5l** (0.289 g, 0.87 mmol, 58%) as a dark brown oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.00 (d, J = 8.2 Hz, 1H), 7.55–7.49 (m, 2H), 7.49–7.44 (m, 2H), 7.41 (td, J = 5.6, 3.0 Hz, 1H), 7.38–7.32 (m, 2H), 7.29–7.22 (m, 1H), 6.32 (br s 1H), 3.21 (d, J = 19.6 Hz, 1H), 2.95 (d, J = 19.7 Hz, 1H), 2.29 (s, 1H), 2.28–2.18 (m, 2H), 2.04–1.92 (m, 2H), 1.80–1.69 (m, 1H), and 1.67–1.58 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 149.7, 145.8, 135.3, 134.9, 132.6, 128.9, 128.2, 128.0, 126.8, 125.8, 124.5, 119.1, 96.8, 78.8, 75.2, 41.7, 25.7, 23.1, and 19.0;

IR (CH_2Cl_2) 3,556, 2,229, 1,608, 1,520 cm^{-1}; MS (ESI) *m/e* 332.1 ($[M - H]^-$, 100), 314.1 (11), 231.0 (4), 210.1 (22), 195.1 (5), and 126.9 (3); HRMS (ESI) *m/e* calcd for $C_{21}H_{18}NO_3$ $[M - H]^-$ 332.1287, found 332.1287.

6-(3-(3-[Trifluoromethyl]phenyl)prop-2-yn-1-yl)-1,2,3,4-tetrahydro-[1,1′-bi-phenyl]-1-ol (**5m**): The crude mixture obtained from the coupling reaction of 3-iodobenzotrifluoride (0.800 g, 2.94 mmol) and **5g** (0.500 g, 2.36 mmol) was purified by flash column chromatography over silica gel (1:20 ethyl acetate/hexanes) to give **5m** (0.466 g, 1.31 mmol, 56%) as a pale yellow oil: ^1H NMR (400 MHz, $CDCl_3$) δ 7.59 (s, 1H), 7.52 (d, J = 7.7 Hz, 2H), 7.49–7.43 (m, 2H), 7.43–7.33 (m, 3H), 7.30–7.23 (m, 1H), 6.25 (br s, 1H), 3.17 (d, J = 19.7 Hz, 1H), 2.90 (d, J = 19.7 Hz, 1H), 2.31–2.16 (m, 3H), 2.03–1.92 (m, 2H), 1.79–1.68 (m, 1H), and 1.67–1.57 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 145.8, 135.5, 134.5, 130.7 (q, $^2J_{C-F}$ = 32 Hz), 128.6, 128.2 (q, $^3J_{C-F}$ = 4 Hz), 128.0 (2C), 126.8, 125.8, 124.5, 124.1 (q, $^3J_{C-F}$ = 4 Hz), 123.7 (q, $^1J_{C-F}$ = 271 Hz), 89.6, 82.3, 75.2, 41.5, 25.5, 22.4, and 18.9; ^{19}F NMR (376 MHz, $CDCl_3$) δ −63.9 (s, 3F); IR (CH_2Cl_2) 3,452, 2,244, 1,602, and 1,488 cm^{-1}; MS (ESI) *m/e* 355.1 ($[M - H]^-$, 100), 298.0 (3), 275.1 (2), 229.1 (2), 190.0 (1), and 189.0 (17); HRMS (ESI) *m/e* calcd for $C_{22}H_{18}OF_3$ $[M - H]^-$ 355.1310, found 355.1309.

6-(3-[4-Bromophenyl]prop-2-yn-1-yl)-1,-2,3,4-tetrahydro-[1,1′-biphenyl]-1-ol (**5n**): The crude mixture obtained from the coupling reaction of 1-bromo-4-iodobenzene (0.800 g, 2.83 mmol) and **5g** (0.500 g, 2.36 mmol) was purified by flash column chromatography over silica gel (1:20 ethyl acetate/hexanes) to give **5n** (0.288 g, 0.78 mmol, 33%) as a pale yellow oil: ^1H NMR (400 MHz, $CDCl_3$) δ 7.47–7.42 (m, 2H), 7.42–7.38 (m, 2H), 7.35 (dd, J = 8.5, 6.8 Hz, 2H), 7.28–7.23 (m, 1H), 7.23–7.18 (m, 2H), 6.22 (br s, 1H), 3.13 (d, J = 19.7 Hz, 1H), 2.86 (d, J = 19.6 Hz, 1H), 2.31–2.15 (m, 3H), 2.02–1.90 (m, 2H), 1.79–1.68 (m, 1H), and 1.66–1.56 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 145.9, 135.6, 133.0, 131.4, 128.4, 128.2, 126.9, 125.7, 122.6, 121.9, 88.9, 82.8, 75.2, 41.6, 25.6, 22.7, and 19.0; IR (CH_2Cl_2) 3,452, 2,234, and 1,601 cm^{-1}; MS (ESI) *m/e* 367.1 ($[M + 2 - H]^-$, 100), 365.1 ($[M - H]^-$, 85), 327.3 (9), 281.3 (11), 275.1 (17), 268.9 (16), 229.1 (15), 200.9 (69), and 126.9 (6); HRMS (ESI) *m/e* calcd for $C_{21}H_{18}OBr$ $[M - H]^-$ 365.0541, found 365.0540; $[M + 2 - H]^-$ 367.0521, found 367.0511.

6-(Hept-2-yn-1-yl)-1,2,3,4-tetrahydro-[1,1′-biphenyl]-1-ol (**5o**): To a solution of **5g** (0.550 g, 2.60 mmol) in anhydrous THF (13 mL) at −78°C, *n*-BuLi (3.4 mL, 1.6 M in hexanes) was added dropwise over 20 min via a syringe under nitrogen. After being stirred for 1 hr, to the reaction mixture 1-bromobutane (0.390 g, 2.85 mmol) in HMPA (1.1 mL, 6.50 mmol) was added at −78°C. The reaction mixture was allowed to stir for 24 hr at room temperature. The crude mixture was quenched with saturated aqueous $NaHCO_3$ solution (30 mL) and extracted with diethyl ether (50 mL × 4). The combined organic layers were dried over anhydrous $MgSO_4$ (20 g) and concentrated under vacuum. The crude product was purified by flash column chromatography over silica gel (1:30 ethyl acetate/hexanes) yielding **5o** (0.301 g, 1.12 mmol, 43%) as a tan oil: ^1H NMR (400 MHz, $CDCl_3$) δ 7.45–7.39 (m, 2H), 7.32 (dd, J = 8.6. 6.8 Hz, 2H), 7.23 (t, J = 7.2 Hz, 1H), 6.12 (br s, 1H), 2.90 (br d, J = 19.2 Hz 1H), 2.62 (br d, J = 19.2 Hz 1H), 2.57 (s, 1H), 2.23–2.12 (m, 4H), 1.95 (ddd, J = 13.1, 7.2, 3.1 Hz, 1H), 1.87 (ddd, J = 13.1, 10.1, 3.2 Hz, 1H), 1.80–1.70 (m, 1H), 1.64–1.56 (m, 1H), 1.49–1.42 (m, 2H), 1.41–1.32 (m, 2H), and 0.90 (t, J = 7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 146.4, 136.2, 128.0 (2C), 126.6, 125.7, 83.8, 77.6, 75.3, 41.5, 31.0, 25.6, 22.4, 21.9, 19.0, 18.4, and 13.6; IR (CH_2Cl_2) 3,526, 2,230, 1,601 cm^{-1}; MS (ESI) *m/e* 291.2 ($[M + Na]^+$, 100), 288.2 (3), 251.2 (29), 216.1 (5), 215.6 (19), 143.1 (9), and 122.5 (4); HRMS (ESI) *m/e* calcd for $C_{19}H_{24}ONa$ $[M + Na]^+$ 291.1725, found 291.1726.

3,3-Dimethyl-6-(3-phenylprop-2-yn-1-yl)-1,2,3,4-tetrahydro-[1,1′-biphenyl]-1-ol (**5p**): To a solution of 5,5-dimethylcyclohexane-1,3-dione (9.813 g, 70.0 mmol) in KOH (4.870 g, 86.8 mmol) and water (16.0 mL), 3-bromopropyne (7.8 mL, 70.0 mmol) was added via a syringe at 0°C. After 10 min, the reaction mixture was warmed to room temperature to stir for 15 hr and then 3 hr at 40°C. The mixture was poured into 4 M $NaOH_{(aq)}$ (7.115 g, 45 mL) and extracted with diethyl ether (50 mL × 1). The aqueous solution was acidified with cold HCl solution (37.0 g of 12 M HCl in 37.0 g of cracked ice). After filtration of the precipitate, the remaining solution was washed with water and dried in vacuo and was further crystallized from dichloromethane/hexanes to give 5,5-dimethyl-2-(prop-2-yn-1-yl)cyclohexane-1,3-dione (5.500 g, 30.9 mmol, 44%) as a light yellow powder. To a solution of 5,5-dimethyl-2-(prop-2-yn-1-yl)cyclohexane-1,3-dione (5.500 g, 30.9 mmol) in MeOH (237.0 mL), trimethyl orthoformate (30.4 mL, 277.7 mmol) was added, followed by slow addition of conc. H_2SO_4 (1.9 mL). The reaction mixture was stirred at room temperature for 10 hr. After which, the mixture was then neutralized with saturated aqueous $NaHCO_3$ solution (50 mL) and most of the MeOH was concentrated in vacuo. The aqueous layer was extracted with CH_2Cl_2 (100 mL × 3), and the combined organic layers were dried over anhydrous $MgSO_4$ (40 g), and concentrated under reduced pressure to give a crude powder. The crude mixture was purified by flash column chromatography over silica gel (1:2 ethyl acetate/hexanes) to afford 3-methoxy-5,5-dimethyl-2-(prop-2-yn-1-yl) cyclohex-2-enone (1.890 g, 9.83 mmol, 32%) as a yellow solid: ^1H NMR (400 MHz, $CDCl_3$) δ 3.86 (s, 3H), 3.19 (d, J = 2.6 Hz, 2H), 2.44 (s, 2H), 2.27 (s, 2H), 1.83 (t, J = 2.7 Hz, 1H), and 1.10 (s, 6H). To a stirred solution of 3-methoxy-5,5-dimethyl-2-(prop-2-yn-1-yl)cyclohex-2-enone (1.890 g, 9.83 mmol) in anhydrous toluene (33.0 mL), DIBAL-H (12.3 mL, 1.2 M in toluene) was added dropwise

over 30 min at 0°C under nitrogen. After stirring at 0°C for 2 hr, to the reaction mixture, water (21 mL) was added dropwise followed by addition of 2 M HCl (13 mL). The mixture was stirred vigorously for 30 min, and extracted with diethyl ether (50 mL × 4). The combined organic extracts were washed with saturated aqueous $NaHCO_3$ solution (100 mL) and then dried over anhydrous $MgSO_4$ (30 g). The filtrate was concentrated under reduced pressure, and the resulting crude product was purified by flash column chromatography over silica gel (1:30 ethyl acetate/hexanes) yielding 5,5-dimethyl-2-(prop-2-yn-1-yl)cyclohex-2-enone (0.889 g, 5.48 mmol, 56%) as a colorless oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.02 (tt, J = 3.9, 1.7 Hz, 1H), 3.16–3.11 (m, 2H), 2.33–2.29 (m, 4H), 2.21 (t, J = 2.6 Hz, 1H), and 1.04 (s, 6H). To a solution of 5,5-dimethyl-2-(prop-2-yn-1-yl) cyclohex-2-enone (0.600 g, 3.70 mmol) in Et_3N (3.7 mL), iodobenzene (0.905 g, 4.44 mmol), $Pd(PPh_3)_4$ (8.6 mg, 0.007 mmol), and CuI (0.028 g, 0.15 mmol) were added under nitrogen. The reaction mixture was stirred at room temperature for 8 hr before quenching with saturated aqueous NH_4Cl solution (20 mL). The resulting solution was extracted with CH_2Cl_2 (50 mL × 3). To combine, organic solution was washed with water (50 mL × 3) and brine (50 mL × 3) and dried over anhydrous $MgSO_4$ (20 g). The filtrate was concentrated in vacuo to give a crude oil. The crude mixture was purified by flash column chromatography over silica gel (1:30 ethyl acetate/hexanes) to give 5,5-dimethyl-2-(3-phenylprop-2-yn-1-yl)cyclohex-2-enone (0.733 g, 3.08 mmol, 83%) as a tan oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.44 (dd, J = 6.7, 3.0 Hz, 2H), 7.34–7.27 (m, 3H), 7.08 (tt, J = 4.0, 2.1 Hz, 1H), 3.38 (q, J = 2.0 Hz, 2H), 2.35–2.30 (m, 4H), and 1.05 (s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 198.4, 144.0, 133.5, 131.6, 128.2, 127.9, 123.5, 86.3, 84.1, 51.8, 40.1, 34.2, 28.3 (2C), and 19.6; IR (CH_2Cl_2) 2,958, 2,230, 1,676, and 1,599 cm^{-1}; MS (APCI) *m/e* 239.1 ([M + H]$^+$, 100), 229.2 (1), 202.1 (1), and 165.1 (3); HRMS (APCI) *m/e* calcd for $C_{17}H_{19}O$ [M + H]$^+$ 239.1436, found 239.1430. To a solution of 5,5-dimethyl-2-(3-phenylprop-2-yn-1-yl) cyclohex-2-enone (0.713 g, 3.00 mmol) in anhydrous THF (7.5 mL), phenyllithium (2.2 mL, 2.0 M in dibutyl ether) was added dropwise over 20 min at −78°C under nitrogen. The reaction mixture was maintained at −78°C for 5 hr. The crude mixture was diluted with EtOAc (10 mL) and quenched with saturated aqueous NH_4Cl solution (20 mL) at −78°C. The water layer was extracted with ethyl acetate (30 mL × 3) and dried over anhydrous $MgSO_4$ (10 g). The mixture was concentrated, and the residue was purified by flash column chromatography over silica gel (1:30 ethyl acetate/hexanes, 2% Et_3N) to produce (**5p**) (0.714 g, 2.25 mmol, 75%) as a yellow oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.39 (tt, J = 6.9, 2.6 Hz, 4H), 7.32 (t, J = 7.7 Hz, 2H), 7.29–7.24 (m, 3H), 7.22 (t, J = 7.2 Hz, 1H), 6.18 (br s, 1H), 3.11 (dd, J = 19.4, 2.0 Hz, 1H), 2.83 (d, J = 19.4 Hz, 1H), 2.49 (s, 1H), 2.13–2.00 (m, 2H), 1.85 (s, 2H), 1.19 (s, 3H), and 0.95 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 147.5, 134.8, 131.5, 128.2 (2C), 127.7, 126.7, 126.5, 125.3, 123.5, 87.7, 83.7, 75.8, 54.5, 39.8, 31.8, 29.7, 26.6, and 22.3; IR (CH_2Cl_2) 3,537, 2,237, 1,599, and 1,490 cm^{-1}; MS (EI, 70 eV) *m/e* 316.3 ([M]$^+$, 59), 260.2 (100), 239.2 (78), 183.2 (93), and 105.2 (68); HRMS (EI) *m/e* calcd for $C_{23}H_{24}O$ [M]$^+$ 316.1827, found 316.1835.

4′-Methoxy-6-(3-phenylprop-2-yn-1-yl)-1,-2,3,4-tetrahydro-[1,1′-biphenyl]-1-ol (**5q**): To a solution of 4-bromoanisole (0.6 mL, 5.00 mmol) in anhydrous THF (25 mL) at −78°C, *n*-BuLi (3.1 mL, 1.6 M in hexanes) was added dropwise over 20 min via a syringe. The reaction mixture was stirred for 10 min at −78°C under nitrogen. Then, the resultant (4-methoxyphenyl)lithium solution was cannulated dropwise into a stirred solution of **4** (0.700 g, 3.33 mmol) in anhydrous THF (16.6 mL) at −78°C under nitrogen. The reaction was maintained at this temperature and stirred for 4 hr. The crude mixture was poured into saturated aqueous NH_4Cl solution (40 mL) and extracted with EtOAc (60 mL × 4). The combined organic layers were dried over anhydrous $MgSO_4$ (20 g) and removed of solvent under reduced pressure to give a crude product, which was purified by flash column chromatography over silica gel (1:30 ethyl acetate/hexanes) to afford **5q** (0.603 g, 1.89 mmol, 57%) as a yellow oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.37 (d, J = 6.6 Hz, 4H), 7.30–7.26 (m, 3H), 6.88 (d, J = 8.6 Hz, 2H), 6.22 (br s, 1H), 3.81 (s, 3H), 3.16 (d, J = 19.5 Hz, 1H), 2.88 (d, J = 19.6 Hz, 1H), 2.27 (s, 1H), 2.25–2.12 (m, 2H), 2.00–1.88 (m, 2H), 1.79–1.68 (m, 1H), and 1.64–1.55 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 158.4, 138.1, 135.9, 131.4, 128.1, 127.8, 127.6, 126.9, 123.6, 113.4, 87.7, 83.7, 74.9, 55.1, 41.6, 25.6, 22.5, and 19.0; IR (CH_2Cl_2) 3,446, 2,360, 1,724, 1,609 cm^{-1}; MS (ESI) *m/e* 341.2 ([M + Na]$^+$, 100), 324.1 (8), 322.2 (4), 301.2 (11), 259.2 (3), and 230.2 (2); HRMS (ESI) *m/e* calcd for $C_{22}H_{22}O_2Na$ [M + Na]$^+$ 341.1517, found 341.1511.

1-Methyl-2-(3-phenylprop-2-yn-1-yl)cyclohex-2-enol (**5r**): The crude mixture obtained from the addition of methyllithium (1.2 mL, 1.6 M in diethyl ether) to the **4** (0.376 g, 1.8 mmol) was purified by flash column chromatography over silica gel (1:30 ethyl acetate/hexanes, 2% Et_3N) to give **5r** (0.255 g, 1.13 mmol, 63%) as a yellow liquid: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.42 (dd, J = 6.6, 3.1 Hz, 2H), 7.31–7.27 (m, 3H), 5.95 (br s, 1H), 3.40 (d, J = 19.5 Hz, 1H), 3.22 (d, J = 19.3 Hz, 1H), 2.18–2.08 (m, 1H), 2.08–1.99 (m, 1H), 1.82–1.64 (m, 5H), and 1.38 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 137.0, 131.5, 128.2, 127.7, 126.0, 123.7, 87.9, 83.6, 70.2, 39.7, 27.1, 25.7, 21.7, and 19.5; IR (CH_2Cl_2) 3,392, 2,238, 1,715, and 1,598 cm^{-1}; MS (ESI) *m/e* 249.1 ([M + Na]$^+$, 100), 232.1 (50), 228.2 (12), 226.2 (8), 191.1 (4), and 118.1 (7); HRMS (ESI) *m/e*

calcd for $C_{16}H_{18}ONa$ $[M + Na]^+$ 249.1255, found 249.1255.

Butyl-2-(3-phenylprop-2-yn-1-yl)cyclohex-2-enol (**5s**): The crude mixture obtained from the addition of *n*-butyllithium (1.6 mL, 1.6 M in hexanes) to the **4** (0.500 g, 2.38 mmol) was purified by flash column chromatography over silica gel (1:30 ethyl acetate/hexanes, 2% Et_3N) to give **5s** (0.203 g, 0.76 mmol, 32%) as a yellow oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.45–7.39 (m, 2H), 7.31–7.26 (m, 3H), 6.03 (br s, 1H), 3.37 (d, J = 19.4 Hz, 1H), 3.15 (d, J = 19.4 Hz, 1H), 2.18–2.08 (m, 1H), 2.05–1.95 (m, 1H), 1.87–1.73 (m, 2H), 1.71–1.62 (m, 5H), 1.38–1.29 (m, 3H), 1.24–1.14 (m, 1H), and 0.92 (t, J = 7.1 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 136.5, 131.5, 128.2, 127.7, 127.4, 123.7, 87.9, 83.7, 72.2, 38.9, 35.6, 26.2, 25.7, 23.3, 21.7, 18.9, and 14.1; IR (CH_2Cl_2) 3,419, 2,360, 1,715, and 1,598 cm^{-1}; MS (EI, 70 eV) *m/e* 268.2 ($[M]^+$, 2), 267.2 (3), 211.1 (100), 183.1 (4), 153.1 (10), and 105.0 (14); HRMS (EI) *m/e* calcd for $C_{19}H_{24}O$ $[M]^+$ 268.1827, found 268.1831.

1-Ethyl-2-(3-phenylprop-2-yn-1-yl)cyclohex-2-enol (**5t**): To the solution of **4** (0.500 g, 2.38 mmol) in THF (24.0 mL) at 0°C, ethylmagnesium bromide (9.2 mL, 0.9 M in THF) was added via a syringe under nitrogen. The mixture was stirred for 3 hr and quenched with water (30 mL) at 0°C. The organic layer was separated, and the aqueous layer was extracted with ethyl acetate (50 mL × 3). The combined organic layers were dried over anhydrous $MgSO_4$ (20 g) and concentrated under reduced pressure to give the crude product. The crude mixture was purified by flash column chromatography over silica gel (1:30 ethyl acetate/hexanes, 2% Et_3N) to give **5t** (0.210 g, 0.87 mmol, 37%) as a yellow liquid: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.46–7.39 (m, 2H), 7.31–7.26 (m, 3H), 6.05 (br s, 1H), 3.36 (d, J = 19.3 Hz, 1H), 3.15 (d, J = 19.4 Hz, 1H), 2.18–2.08 (m, 1H), 2.05–1.95 (m, 1H), 1.81 (s, 1H), 1.81–1.73 (m, 1H), 1.73–1.68 (m, 2H), 1.68–1.62 (m, 3H), and 0.89 (t, J = 7.5 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 136.2, 131.5, 128.2, 127.7, 127.5, 123.6, 87.9, 83.6, 72.4, 34.8, 31.5, 25.7, 21.6, 18.8, and 8.3; IR (CH_2Cl_2) 3,419, 2,230, 1,705, and 1,598 cm^{-1}; MS (EI, 70 eV) *m/e* 240.1 ($[M]^+$, 16), 239.1 (23), 223.1 (22), 211.1 (100), 165.1 (6), 155.1 (11), and 105.0 (20); HRMS (EI) *m/e* calcd for $C_{17}H_{20}O$ $[M]^+$ 240.1514, found 240.1518.

4.3 | General experimental procedure for the cycloisomerization of 1-ary-2-(3-arylpropargyl)cyclohex-2-en-1-ols: Synthesis of aryl-substituted tetrahydrobenzo[*b*]furan 9a–f, h–n, and p–q

4.3.1 | Example for the synthesis of 9a

A solution of AgOTf (2.5 mg, 0.010 mmol) in CH_2Cl_2 (1.0 mL) was in an oven-dried two-neck-flask equipped with a stirrer bar and capped with a rubber septum at room temperature under nitrogen. The apparatus was evacuated (oil pump) and filled with nitrogen three times. To the solution at 31°C, Ph_3PAuCl (4.9 mg, 0.010 mmol) and six-membered ring enynol substrates **5a** (57.7 mg, 0.200 mmol) in CH_2Cl_2 (1.0 mL) were then added sequentially under N_2 flow. After reactant **5a** consumed (monitored by TLC, 1 min), the resulting dark brown solution was filtered through a bed of celite/silica gel and concentrated under reduced pressure. The crude mixture was purified by flash column chromatography over silica gel (hexanes) to give 2-benzyl-4-phenyl-4,5,6,7-tetrahydrobenzofuran (**9a**) (34.9 mg, 0.121 mmol, 61%) as a yellow brown oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.31–7.26 (m, 4H), 7.25–7.20 (m, 3H), 7.20–7.17 (m, 1H), 7.17–7.14 (m, 2H), 5.63 (s, 1H), 3.90 (s, 2H), 3.81 (dd, J = 7.6, 5.6 Hz, 1H), 2.70–2.55 (m, 2H), 2.07 (dddd, J = 12.9, 7.4, 5.3, 2.3 Hz, 1H), 1.96–1.87 (m, 1H), 1.82–1.71 (m, 1H), and 1.64 (dddd, J = 17.9, 10.2, 7.7, 2.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 152.4, 150.5, 145.7, 138.5, 128.7, 128.4, 128.2, 128.0, 126.3, 126.1, 120.1, 106.9, 40.2, 34.7, 33.7, 23.1, and 21.4; IR (CH_2Cl_2) 1,708, 1,599, 1,493, and 1,451 cm^{-1}; MS (EI, 70 eV) *m/e* 288.1 ($[M]^+$, 23), 284.1 (32), 283.1 (16), 214.1 (12), 181.1 (14), 157.1 (15), and 122.0 (31); HRMS (EI) *m/e* calcd for $C_{21}H_{20}O$ $[M]^+$ 288.1514, found 288.1507.

4.3.2 | 2-(3-Methylbenzyl)-4-phenyl-4,5,6,7-tetrahydrobenzofuran (9b)

The crude mixture obtained from the cycloisomerization of **5b** (90.7 mg, 0.300 mmol) was purified by flash column chromatography over silica gel (hexanes) to give **9b** (46.3 mg, 0.153 mmol, 51%) as a yellow oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.31–7.26 (m, 2H), 7.22–7.14 (m, 4H), 7.07–0.6.99 (m, 3H), 5.62 (s, 1H), 3.85 (s, 2H), 3.81 (ddd, J = 7.4, 5.7, 2.3 Hz, 1H), 2.69–2.56 (m, 2H), 2.32 (s, 3H), 2.07 (dddd, J = 12.9, 7.5, 5.3, 2.3 Hz, 1H), 1.95–1.87 (m, 1H), 1.81–1.70 (m, 1H), and 1.64 (dddd, J = 12.9, 10.2, 7.7, 2.5 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 152.5, 150.5, 145.8, 138.4, 138.0, 129.5, 128.3, 128.2, 128.0, 127.1, 126.1, 125.8, 120.0, 106.8, 40.2, 34.7, 33.7, 23.1, and 21.4 (2C); IR (CH_2Cl_2) 1,601, 1,564, and 1,487 cm^{-1}; MS (EI, 70 eV) *m/e* 302.1 ($[M]^+$, 11), 298.1 (9), 202.1 (8), 182.1 (63), 181.1 (14), and 119.0 (18); HRMS (EI) *m/e* calcd for $C_{22}H_{22}O$ $[M]^+$ 302.1671, found 302.1668.

4.3.3 | 2-(4-Methylbenzyl)-4-phenyl-4,5,6,7-tetrahydrobenzofuran (9c)

The crude mixture obtained from the cycloisomerization of **5c** (105.8 mg, 0.350 mmol) was purified by flash column chromatography over silica gel (hexanes) to give **9c** (40.2 mg, 0.133 mmol, 38%) as a yellow oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.30–7.25 (m, 2H), 7.21–7.14 (m, 3H), 7.14–7.03 (m, 4H), 5.60 (s, 1H), 3.85 (s, 2H), 3.80 (dd, J = 7.5, 5.6 Hz, 1H), 2.69–2.55 (m, 2H), 2.31 (s, 3H), 2.07 (dddd, J = 12.9, 7.4, 5.3, 2.2 Hz, 1H), 1.96–1.86 (m, 1H), 1.81–1.70 (m, 1H), and 1.63 (dddd, J = 12.9, 10.2, 7.8, 2.5 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 152.7, 150.4, 145.8, 135.8, 135.4, 129.1, 128.6, 128.2, 128.0, 126.1,

120.0, 106.7, 40.2, 34.3, 33.7, 23.1, 21.5, and 21.0; IR (CH_2Cl_2) 1,602, 1,572, and 1,515 cm^{-1}; MS (ESI) *m/e* 325.2 ($[M + Na]^+$, 28), 288.1 (49), 265.1 (12), 247.1 (100), 233.1 (18), 190.0 (10), and 143.1 (11); HRMS (ESI) *m/e* calcd for $C_{22}H_{22}ONa$ $[M + Na]^+$ 325.1568, found 325.1561.

4.3.4 | 2-([1,1'-Biphenyl]-4-ylmethyl)-4-phenyl-4,5,6,7-tetrahydrobenzofuran (9d)

The crude mixture obtained from the cycloisomerization of **5d** (109.3 mg, 0.300 mmol) was purified by flash column chromatography over silica gel (hexanes) to give **9d** (72.2 mg, 0.198 mmol, 66%) as a pale yellow solid: mp 105–106°C; ^{1}H NMR (400 MHz, CDCl3) δ 7.57 (d, J = 7.2 Hz, 2H), 7.52 (d, J = 8.2 Hz, 2H), 7.42 (dd, J = 8.5, 6.9 Hz, 2H), 7.35–7.26 (m, 5H), 7.22–7.15 (m, 3H), 5.68 (s, 1H), 3.94 (s, 2H), 3.83 (dd, J = 7.4, 5.7 Hz, 1H), 2.71–2.58 (m, 2H), 2.08 (dddd, J = 12.8, 7.4, 5.3, 2.3 Hz, 1H), 1.97–1.88 (m, 1H), 1.83–1.72 (m, 1H), and 1.65 (dddd, J = 12.8, 10.2, 7.7, 2.5 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 152.2, 150.6, 145.7, 141.0, 139.4, 137.6, 129.1, 128.7, 128.2, 128.0, 127.2, 127.1, 127.0, 126.1, 120.1, 107.0, 40.2, 34.4, 33.7, 23.1, and 21.5; IR (CH_2Cl_2) 1,602, 1,573, 1,488 cm^{-1}; MS (EI, 70 eV) *m/e* 364.2 ($[M]^+$, 100), 336.1 (13), 335.1 (6), 214.1 (5), 197.1 (18), 167.1 (29), 152.1 (11), and 141.1 (8); HRMS (EI) *m/e* calcd for $C_{27}H_{24}O$ $[M]^+$ 364.1827, found 364.1820.

4.3.5 | 2-(Naphthalen-1-ylmethyl)-4-phenyl-4,5,6,7-tetrahydrobenzofuran (9e)

The crude mixture obtained from the cycloisomerization of **5e** (101.5 mg, 0.300 mmol) was purified by flash column chromatography over silica gel (hexanes) to give **9e** (50.8 mg, 0.150 mmol, 50%) as a yellow oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.09–8.03 (m, 1H), 7.86–7.81 (m, 1H), 7.74 (d, J = 8.0 Hz, 1H), 7.51–7.43 (m, 2H), 7.43–7.38 (m, 1H), 7.35 (d, J = 6.7 Hz, 1H), 7.26–7.21 (m, 2H), 7.16 (tt, J = 7.3, 2.2 Hz, 1H), 7.14–7.09 (m, 2H), 5.57 (s, 1H), 4.35 (d, J = 2.0 Hz, 2H), 3.78 (dd, J = 7.4, 5.7 Hz, 1H), 2.70–2.56 (m, 2H), 2.06 (dddd, J = 12.9, 7.6, 5.3, 2.3 Hz, 1H), 1.94–1.85 (m, 1H), 1.80–1.70 (m, 1H), and 1.67–1.57 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 151.9, 150.4, 145.7, 134.4, 133.9, 132.0, 128.6, 128.2, 128.0, 127.3, 126.9, 126.0, 125.9, 125.6, 125.5, 124.1, 120.1, 107.3, 40.2, 33.8, 32.2, 23.1, and 21.4; IR (CH_2Cl_2) 1,599, 1,568, 1,493, 1,224, 778, 698 cm^{-1}; MS (EI, 70 eV) *m/e* 338.1 ($[M]^+$, 100), 310.1 (14), 309.1 (5), 197.1 (18), 141.1 (24), and 115.0 (8); HRMS (EI) *m/e* calcd for $C_{25}H_{22}O$ $[M]^+$ 338.1671, found 338.1669.

4.3.6 | 2-(4-Methoxybenzyl)-4-phenyl-4,5,6,7-tetrahydrobenzofuran (9f)

The crude mixture obtained from the cycloisomerization of **5f** (95.5 mg, 0.300 mmol) was purified by flash column chromatography over silica gel (1:50 ethyl acetate/hexanes) to give **9f** (25.8 mg, 0.081 mmol, 27%) as a yellow brown oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.30–7.26 (m, 2H), 7.22–7.17 (m, 1H), 7.17–7.13 (m, 4H), 6.85–6.80 (m, 2H), 5.59 (s, 1H), 3.85–3.78 (m, 3H), 3.78 (s, 3H), 2.69–2.56 (m, 2H), 2.07 (dddd, J = 12.8, 7.5, 5.3, 2.3 Hz, 1H), 1.96–1.87 (m, 1H), 1.81–1.70 (m, 1H), and 1.64 (dddd, J = 12.9, 10.3, 7.7, 2.5 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 158.2, 152.9, 150.4, 145.8, 130.6, 129.7, 128.2, 128.0, 126.1, 120.0, 113.9, 106.7, 55.3, 40.2, 33.9, 33.7, 23.1, and 21.5; IR (CH_2Cl_2) 1,612, 1,512, and 1,455 cm^{-1}; MS (EI, 70 eV) *m/e* 318.1 ($[M]^+$, 100), 290.1 (13), 287.1 (7), 197.1 (22), 169.1 (9), and 121.1 (17); HRMS (EI) *m/e* calcd for $C_{22}H_{22}O_2$ $[M]^+$ 318.1620, found 318.1625.

4.3.7 | Ethyl 3-([4-phenyl-4,5,6,7-tetrahydrobenzofuran-2-yl]methyl)benzoate (9h)

The crude mixture obtained from the cycloisomerization of **5h** (126.2 mg, 0.350 mmol) was purified by flash column chromatography over silica gel (1:50 ethyl acetate/hexanes) to give **9h** (88.3 mg, 0.245 mmol, 70%) as a pale yellow solid: mp 66–67°C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.94–7.87 (m, 2H), 7.42 (d, J = 7.6 Hz, 1H), 7.35 (t, J = 7.6 Hz, 1H), 7.30–7.25(m, 2H), 7.23–7.18 (m, 1H), 7.17–7.14 (m, 2H), 5.63 (s, 1H), 4.36 (q, J = 7.1 Hz, 2H), 3.94 (s, 2H), 3.81 (dd, J = 7.4, 5.7 Hz, 1H), 2.69–2.55 (m, 2H), 2.07 (dddd, J = 13.1, 7.4, 5.3, 2.2 Hz, 1H), 1.97–1.87 (m, 1H), 1.82–1.70 (m, 1H), 1.64 (ddt, J = 12.8, 10.2, 5.1 Hz, 1H), and 1.38 (t, J = 7.1 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 166.6, 151.7, 150.7, 145.6, 138.8, 133.2, 130.7, 129.9, 128.4, 128.2, 128.0, 127.7, 126.1, 120.1, 107.2, 60.9, 40.2, 34.5, 33.6, 23.1, 21.4, and 14.3; IR (CH_2Cl_2) 1,718, 1,605, 1,589 cm^{-1}; MS (ESI) *m/e* 383.2 ($[M + Na]^+$, 100), 359.2 (22), 262.1 (2), 261.6 (9), 143.1 (8), and 102.1 (6); HRMS (ESI) *m/e* calcd for $C_{24}H_{24}O_3Na$ $[M + Na]^+$ 383.1623, found 383.1619.

4.3.8 | Ethyl 4-([4-phenyl-4,5,6,7-tetrahydrobenzofuran-2-yl]methyl)benzoate (9i)

The crude mixture obtained from the cycloisomerization of **5i** (126.2 mg, 0.350 mmol) was purified by flash column chromatography over silica gel (1:50 ethyl acetate/hexanes) to give **9i** (98.4 mg, 0.273 mmol, 78%) as a pale yellow oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.99–7.94 (m, 2H), 7.32–7.26 (m, 4H), 7.22–7.18 (m, 1H), 7.17–7.13 (m, 2H), 5.64 (s, 1H), 4.36 (q, J = 7.1 Hz, 2H), 3.94 (s, 2H), 3.81 (dd, J = 7.4, 5.7 Hz, 1H), 2.69–2.55 (m, 2H), 2.07 (dddd, J = 13.1, 7.4, 5.3, 2.2 Hz, 1H), 1.97–1.87 (m, 1H), 1.82–1.70 (m, 1H), 1.64 (dddd, J = 12.8, 10.2, 7.8, 2.5 Hz, 1H), and 1.38 (t, J = 7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 166.5, 151.3, 150.8, 145.6, 143.7, 129.8, 128.7 (2C), 128.2, 127.9, 126.1, 120.2, 107.3, 60.8, 40.2, 34.7, 33.6, 23.1, 21.4, and 14.3; IR (CH_2Cl_2) 1,716, 1,611, and 1,576 cm^{-1}; MS (ESI) *m/e* 383.2 ($[M + Na]^+$, 100), 361.2 (21), 359.2 (36), 302.6 (15), 294.1 (19), 282.1 (16), 255.1

(10), and 130.2 (11); HRMS (ESI) *m/e* calcd for $C_{24}H_{24}O_3Na$ $[M + Na]^+$ 383.1623, found 383.1625.

4.3.9 | 2-(3-Nitrobenzyl)-4-phenyl-4,5,6,7-tetrahydrobenzofuran (9j)

The crude mixture obtained from the cycloisomerization of **5j** (116.7 mg, 0.350 mmol) was purified by flash column chromatography over silica gel (1:50 ethyl acetate/hexanes) to give **9j** (79.3 mg, 0.238 mmol, 68%) as a yellow oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.12–8.06 (m, 2H), 7.60–7.54 (m, 1H), 7.46 (t, J = 7.9 Hz, 1H), 7.32–7.27 (m, 2H), 7.20 (tt, J = 7.3, 1.3 Hz, 1H), 7.18–7.13 (m, 2H), 5.70 (s, 1H), 4.00 (s, 2H), 3.83 (dd, J = 7.5, 5.6 Hz, 1H), 2.71–2.55 (m, 2H), 2.09 (dddd, J = 12.9, 7.5, 5.3, 2.3 Hz, 1H), 1.98–1.88 (m, 1H), 1.83–1.72 (m, 1H), and 1.65 (dddd, J = 12.9, 10.3, 7.8, 2.5 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 151.2, 150.4, 148.4, 145.5, 140.6, 134.9, 129.3, 128.3, 127.9, 126.2, 123.6, 121.6, 120.3, 107.8, 40.1, 34.3, 33.6, 23.1, and 21.4; IR (CH_2Cl_2) 1,531, 1,350 cm^{-1}; MS (ESI) *m/e* 334.1 ($[M + H]^+$, 18), 332.1 (16), 289.1 (29), 268.6 (42), 161.1 (84), 143.1 (100), 122.5 (28), and 102.1 (91); HRMS (ESI) *m/e* calcd for $C_{21}H_{20}NO_3$ $[M + H]^+$ 334.1443, found 334.1439.

4.3.10 | 2-(4-Nitrobenzyl)-4-phenyl-4,5,6,7-tetrahydrobenzofuran (9k)

The crude mixture obtained from the cycloisomerization of **5k** (116.7 mg, 0.350 mmol) was purified by flash column chromatography over silica gel (1:50 ethyl acetate/hexanes) to give **9k** (88.7 mg, 0.266 mmol, 76%) as a yellow solid: mp 120–121°C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.18–8.12 (m, 2H), 7.41–7.36 (m, 2H), 7.31–7.26 (m, 2H), 7.20 (tt, J = 7.3, 1.6 Hz, 1H), 7.18–7.12 (m, 2H), 5.70 (s, 1H), 3.99 (s, 2H), 3.82 (dd, J = 7.6, 5.6 Hz, 1H), 2.69–2.55 (m, 2H), 2.08 (dddd, J = 12.9, 7.4, 5.3, 2.2 Hz, 1H), 1.98–1.88 (m, 1H), 1.83–1.72 (m, 1H), and 1.65 (dddd, J = 13.0, 10.3, 7.8, 2.5 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 151.2, 150.2, 146.8, 146.2, 145.5, 129.5, 128.3, 127.9, 126.2, 123.7, 120.3, 107.8, 40.1, 34.5, 33.6, 23.1, and 21.4; IR (CH_2Cl_2) 1,601, 1,571, and 1,519 cm^{-1}; MS (ESI) *m/e* 332.1 ($[M - H]^-$, 27), 327.3 (100), 325.2 (28), 283.3 (22), 281.2 (97), 279.2 (38), 255.2 (32), 221.1 (28), and 109.0 (11); HRMS (ESI) *m/e* calcd for $C_{21}H_{18}O_3N$ $[M - H]^-$ 332.1287, found 332.1293. Crystals suitable for X-ray diffraction analysis were grown from hexanes and pentanes.

4.3.11 | 2-(2-Nitrobenzyl)-4-phenyl-4,5,6,7-tetrahydrobenzofuran (9l)

The crude mixture obtained from the cycloisomerization of **5l** (116.7 mg, 0.350 mmol) was purified by flash column chromatography over silica gel (1:50 ethyl acetate/hexanes) to give **9l** (12.8 mg, 0.039 mmol, 11%) as a yellow brown oil: ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.92 (dd, J = 8.1, 1.2 Hz, 1H), 7.53 (td, J = 7.6, 1.3 Hz, 1H), 7.39–7.34 (m, 2H), 7.30–7.26 (m, 2H), 7.19 (tt, J = 7.4, 1.2 Hz, 1H), 7.15–7.12 (m, 2H), 5.68 (s, 1H), 4.27 (s, 2H), 3.80 (dd, J = 7.6, 5.7 Hz, 1H), 2.67–2.55 (m, 2H), 2.07 (dddd, J = 13.0, 7.5, 5.4, 2.3 Hz, 1H), 1.95–1.87 (m, 1H), 1.80–1.72 (m, 1H), and 1.63 (dddd, J = 13.0, 10.4, 7.8, 2.6 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 151.0, 149.6, 149.1, 145.5, 133.5, 133.0, 132.0, 128.2, 127.9, 127.6, 126.2, 124.8, 120.2, 108.0, 40.1, 33.7, 31.7, 23.1, and 21.4; IR (CH_2Cl_2) 1,610, 1,528, 1,455 cm^{-1}; MS (EI, 70 eV) *m/e* 333.2 ($[M]^+$, 18), 316.2 (81), 293.2 (50), 260.2 (56), 213.2 (31), 185.2 (26), 149.1 (59), and 115.1 (24); HRMS (EI) *m/e* calcd for $C_{21}H_{19}O_3N$ $[M]^+$ 333.1365, found 333.1362.

4.3.12 | 4-Phenyl-2-(3-[trifluoromethyl]benzyl)-4,5,6,7-tetrahydrobenzofuran (9m)

The crude mixture obtained from the cycloisomerization of **5m** (124.7 mg, 0.350 mmol) was purified by flash column chromatography over silica gel (hexanes) to give **9m** (91.1 mg, 0.256 mmol, 73%) as a yellow oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.50–7.45 (m, 2H), 7.44–7.39 (m, 2H), 7.29 (t, J = 7.4 Hz, 2H), 7.20 (t, J = 7.3 Hz, 1H), 7.15 (d, J = 7.1 Hz, 2H), 5.66 (s, 1H), 3.95 (s, 2H), 3.82 (dd, J = 7.5, 5.4 Hz, 1H), 2.69–2.56 (m, 2H), 2.08 (dddd, J = 12.9, 7.3, 5.5, 2.1 Hz, 1H), 1.97–1.88 (m, 1H), 1.82–1.72 (m, 1H), and 1.65 (ddt, J = 12.9, 10.3, 5.0 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 151.1, 151.0, 145.6, 139.5, 132.1, 130.8 (q, $^2J_{C-F}$ = 32 Hz), 128.8, 128.2, 128.0, 126.2, 125.5 (q, $^3J_{C-F}$ = 4 Hz), 124.3 (q, $^1J_{C-F}$ = 293 Hz), 123.3 (q, $^3J_{C-F}$ = 4 Hz), 120.2, 107.4, 40.2, 34.5, 33.6, 23.1, and 21.4; ^{19}F NMR (376 MHz, $CDCl_3$) δ −63.5; IR (CH_2Cl_2) 1,599, 1,573, and 1,493 cm^{-1}; MS (EI, 70 eV) *m/e* 356.2 ($[M]^+$, 100), 328.2 (46), 337.2 (24), 197.2 (80), 169.2 (99), 141.1 (51), and 115.1 (17); HRMS (EI) *m/e* calcd for $C_{22}H_{19}OF_3$ $[M]^+$ 356.1388, found 356.1384.

4.3.13 | 2-(4-Bromobenzyl)-4-phenyl-4,5,6,7-tetrahydrobenzofuran (9n)

The crude mixture obtained from the cycloisomerization of **5n** (128.5 mg, 0.350 mmol) was purified by flash column chromatography over silica gel (hexanes) to give **9n** (68.1 mg, 0.186 mmol, 53%) as a yellow oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.43–7.37 (m, 2H), 7.30–7.26 (m, 2H), 7.20 (tt, J = 7.3, 1.7 Hz, 1H), 7.17–7.13 (m, 2H), 7.13–7.08 (m, 2H), 5.62 (s, 1H), 3.84 (s, 2H), 3.81 (dd, J = 7.5, 5.7 Hz, 1H), 2.68–2.55 (m, 2H), 2.07 (dddd, J = 12.8, 7.4, 5.4, 2.2 Hz, 1H), 1.96–1.87 (m, 1H), 1.82–1.71 (m,1H), and 1.64 (dddd, J = 12.9, 10.3, 7.8, 2.5 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 151.6, 150.7, 145.6, 137.5, 131.5, 130.5, 128.2, 127.9, 126.1, 120.2, 120.1, 107.1, 40.2, 34.1, 33.6, 23.1, 21.4; IR (CH_2Cl_2) 1,600, 1,571, and 1,488 cm^{-1}; MS (EI, 70 eV) *m/e* 368.2 ($[M + 2]^+$, 100), 366.2 ($[M]^+$, 98), 338.1 (26), 287.2 (7), 197.2 (39), 169.2 (27), 141.2 (11), and 115.1 (6); HRMS (EI) *m/e* calcd for $C_{21}H_{19}OBr$ $[M]^+$ 366.0619, found 366.0622; $[M + 2]^+$ 368.0599, found 368.0612.

4.3.14 | 2-Benzyl-6,6-dimethyl-4-phenyl-4,5,6,7-tetrahydrobenzofuran (9p)

The crude mixture obtained from the cycloisomerization of **5p** (110.8 mg, 0.350 mmol) was purified by flash column chromatography over silica gel (hexanes) to give **9p** (68.7 mg, 0.217 mmol, 62%) as a yellow oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.31–7.26 (m, 4H), 7.24–7.16 (m, 6H), 5.59 (s, 1H), 3.89 (s, 2H), 3.75–3.68 (m, 1H), 2.49 (dd, J = 16.1, 2.8 Hz, 1H), 2.36 (d, J = 16.1 Hz, 1H), 1.70 (ddd, J = 13.2, 5.3, 1.4 Hz, 1H), 1.50–1.42 (m, 1H), 1.07 (s, 3H), and 1.04 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 152.6, 150.2, 145.6, 138.5, 128.8, 128.4, 128.3, 127.9, 126.3, 126.1, 118.9, 106.6, 48.1, 38.6, 36.9, 34.8, 32.2, 31.5, and 25.4; IR (CH_2Cl_2) 1,601, 1,572, and 1,493 cm^{-1}; MS (APCI) *m/e* 317.2 ([M + H]$^+$, 100), 299.2 (11), 227.1 (2), and 143.1 (7); HRMS (APCI) *m/e* calcd for $C_{23}H_{25}O$ [M + H]$^+$ 317.1905, found 317.1905.

4.3.15 | 2-Benzyl-4-(4-methoxyphenyl)-4,5,6,7-tetrahydrobenzofuran (9q)

The crude mixture obtained from the cycloisomerization of **5q** (95.5 mg, 0.300 mmol) was purified by flash column chromatography over silica gel (1:50 ethyl acetate/hexanes) to give **9q** (11.5 mg, 0.036 mmol, 12%) as a pale yellow oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.31–7.19 (m, 5H), 7.10–7.05 (m, 2H), 6.85–6.80 (m, 2H), 5.62 (s, 1H), 3.89 (s, 2H), 3.79–3.74 (m, 4H), 2.68–2.55 (m, 2H), 2.04 (dddd, J = 12.9, 7.6, 5.3, 2.4 Hz, 1H), 1.94–1.85 (m, 1H), 1.80–1.69 (m, 1H), and 1.60 (dddd, J = 12.8, 10.2, 7.8, 2.5 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 158.0, 152.3, 150.4, 138.5, 137.9, 128.8, 128.7, 128.4, 126.3, 120.4, 113.6, 106.9, 55.2, 39.3, 34.8, 33.8, 23.1, 21.4; IR (CH_2Cl_2) 1,611, 1,573, 1,511, and 1,454 cm^{-1}; MS (EI, 70 eV) *m/e* 318.1 ([M]$^+$, 100), 290.1 (45), 289.1 (9), 227.1 (24), 199.1 (27), 171.1 (11), 128.0 (6), and 115.0 (7); HRMS (EI) *m/e* calcd for $C_{22}H_{22}O_2$ [M]$^+$ 318.1620, found 318.1625.

4.4 | General experimental procedure for the cycloisomerization of 1-ary-2-(3-arylpropargyl)cyclohex-2-en-1-ols: Synthesis of alkyl-substituted tetrahydrobenzo[*b*]furan 9g, o, and r–t

4.4.1 | Example for the synthesis of 9g

A solution of AgOTf (4.5 mg, 0.018 mmol) in CH_2Cl_2 (1.8 mL) was in an oven-dried two-neck-flask equipped with a stirrer bar and capped with a rubber septum at room temperature under nitrogen. The apparatus was evacuated (oil pump) and filled with nitrogen three times. To the solution at room temperature, Ph_3PAuCl (8.7 mg, 0.018 mmol) and six-membered ring enynol substrates **5g** (74.3 mg, 0.350 mmol) in CH_2Cl_2 (1.7 mL) were then added sequentially under N_2 flow. After reactant **5a** consumed (monitored by TLC, 1 min), the resulting dark brown solution was filtered through a bed of Celite/silica gel and concentrated under reduced pressure. The crude mixture was purified by flash column chromatography over silica gel (hexanes) to give 2-methyl-4-phenyl-4,5,6,7-tetrahydrobenzofuran (**9g**) (19.3 mg, 0.091 mmol, 26%) as a pale yellow liquid: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.31–7.26 (m, 2H), 7.22–7.15 (m, 3H), 5.59 (s, 1H), 3.82 (dd, J = 7.6, 5.6 Hz, 1H), 2.70–2.57 (m, 2H), 2.23 (s, 3H), 2.08 (dddd, J = 12.8, 7.4, 5.3, 2.3 Hz, 1H), 1.97–1.88 (m, 1H), 1.82–1.72 (m, 1H), and 1.65 (dddd, J = 12.8, 10.2, 7.8, 2.5 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 149.8, 149.7, 145.8, 128.2, 128.0, 126.1, 120.1, 106.1, 40.2, 33.7, 23.1, 21.5, 13.6; IR (CH_2Cl_2) 1,602, 1,580, and 1,493 cm^{-1}; MS (FAB) *m/e* 212.2 ([M]$^+$, 92), 191.2 (34), 147.1 (61), 135.2 (69), and 109.1 (100); HRMS (FAB) *m/e* calcd for $C_{15}H_{16}O$ [M]$^+$ 212.1201, found 212.1205.

4.4.2 | 2-Pentyl-4-phenyl-4,5,6,7-tetrahydrobenzofuran (9o)

The crude mixture obtained from the cycloisomerization of **5o** (107.4 mg, 0.400 mmol) was purified by flash column chromatography over silica gel (hexanes) to give **9o** (31.1 mg, 0.116 mmol, 29%) as a brown oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.29 (dd, J = 8.1, 6.6 Hz, 2H), 7.22–7.15 (m, 3H), 5.59 (s, 1H), 3.82 (dd, J = 7.4, 5.6 Hz, 1H), 2.71–2.58 (m, 2H), 2.54 (t, J = 7.7 Hz, 2H), 2.08 (dddd, J = 12.8, 7.4, 5.3, 2.9 Hz, 1H), 1.98–1.87 (m, 1H), 1.83–1.72 (m, 1H), 1.70–1.62 (m, 1H), 1.62–1.57 (m, 2H), 1.35–1.29 (m, 4H), and 0.91–0.86 (m, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 154.4, 149.5, 145.9, 128.2, 128.0, 126.1, 119.8, 105.2, 40.2, 33.7, 31.5, 28.2, 27.8, 23.1, 22.4, 21.5, 14.0; IR (CH_2Cl_2) 1,601, 1,575, and 1,454 cm^{-1}; MS (APCI) *m/e* 269.2 ([M + H]$^+$, 100), 267.2 (12), 239.1 (6), 213.1 (5), 207.1 (2), and 143.1 (2); HRMS (APCI) *m/e* calcd for $C_{19}H_{25}O$ [M + H]$^+$ 269.1905, found 269.1907.

4.4.3 | 2-Benzyl-4-methyl-4,5,6,7-tetrahydrobenzofuran (9r)

The crude mixture obtained from the cycloisomerization of **5r** (67.9 mg, 0.300 mmol) was purified by flash column chromatography over silica gel (hexanes) to give **9r** (26.5 mg, 0.117 mmol, 39%) as a pale yellow oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.33–7.26 (m, 3H), 7.26–7.20 (m, 2H), 5.83 (s, 1H), 3.91 (s, 2H), 2.64–2.55 (m, 1H), 2.54–2.49 (m, 2H), 1.96–1.81 (m, 2H), 1.74–1.63 (m, 1H), 1.29–1.21 (m, 1H), and 1.10 (d, J = 6.9 Hz, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 152.3, 149.1, 138.6, 128.8, 128.4, 126.3, 123.0, 105.8, 34.8, 32.1, 28.0, 23.1, 21.8, and 21.0; IR (CH_2Cl_2) 1,573, 1,453 cm^{-1}; MS (FAB) *m/e* 226.2 ([M]$^+$, 45), 225.2 (48), 191.2 (39), 145.1 (54), and 135.1 (79); HRMS (EI) *m/e* calcd for $C_{16}H_{18}O$ [M]$^+$ 226.1358, found 226.1353.

4.4.4 | 2-Benzyl-4-butyl-4,5,6,7-tetrahydrobenzofuran (9s)

The crude mixture obtained from the cycloisomerization of **5s** (80.5 mg, 0.300 mmol) was purified by flash column chromatography over silica gel (hexanes) to give **9s** (12.1 mg, 0.045 mmol, 15%) and **12a** (24.0 mg,

0.096 mmol, 32%). **9s**: a pale yellow oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.33–7.28 (m, 2H), 7.27–7.20 (m, 3H), 5.84 (s, 1H), 3.91 (s, 2H), 2.51 (t, J = 6.0 Hz, 2H), 2.49–2.43 (m, 1H), 1.95–1.81 (m, 2H), 1.74–1.64 (m, 1H), 1.64–1.57 (m, 1H), 1.41–1.25 (m, 6H), and 0.93–0.87 (m, 3H); ^{13}C NMR (125 MHz, $CDCl_3$,) δ 152.1, 149.3, 138.6, 128.8, 128.4, 126.3, 122.1, 106.2, 35.4, 34.8, 33.0, 29.5, 29.1, 23.2, 23.0, 21.5, and 14.1; IR (CH_2Cl_2) 1,638, 1,454 cm^{-1}; MS (EI, 70 eV) *m/e* 268.2 ([M]$^+$, 39), 211.1 (100), 184.1 (2), 155.1 (4), 141.0 (4), and 115.0 (3); HRMS (EI) *m/e* calcd for $C_{19}H_{24}O$ [M]$^+$ 268.1827, found 268.1829.

4.4.5 | *(E)*-(3-[6-Butylidenecyclohex-1-en-1-yl]prop-1-yn-1-yl) benzene (12a)

A pale yellow oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.44–7.39 (m, 2H), 7.31–7.26 (m, 3H), 6.05 (t, J = 4.1 Hz, 1H), 5.47 (t, J = 7.1 Hz, 1H), 3.31 (q, J = 1.9 Hz, 2H), 2.35 (t, J = 5.7 Hz, 2H), 2.22–2.15 (m, 2H), 2.11 (q, J = 7.3 Hz, 2H), 1.69 (quin, J = 6.2 Hz, 2H), 1.43 (sex, J = 7.3 Hz, 2H), and 0.93 (t, J = 7.4 Hz, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 134.2, 132.1, 131.6, 128.1, 127.5, 126.6, 124.1, 123.5, 88.1, 83.0, 29.7, 26.0 (2C), 23.9, 22.9, 22.8, 13.9; IR (CH_2Cl_2) 2,918, 2,359, and 1,598 cm^{-1}; MS (EI, 70 eV) *m/e* 250.2 ([M]$^+$, 15), 231.1 (74), 208.1 (83), 191.1 (70), 149.0 (100), 135.1 (68), and 115.1 (38); HRMS (EI) *m/e* calcd for $C_{19}H_{22}$ [M]$^+$ 250.1722, found 250.1719.

4.4.6 | 2-Benzyl-4-ethyl-4,5,6,7-tetrahydrobenzofuran (9t)

The crude mixture obtained from the cycloisomerization of **5t** (72.1 mg, 0.300 mmol) was purified by flash column chromatography over silica gel (hexanes) to give **9t** (13.0 mg, 0.054 mmol, 18%) and **12b** (39.4 mg, 0.177 mmol, 59%). **9t**: a yellow oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.33–7.27 (m, 2H), 7.26–7.21 (m, 3H), 5.84 (s, 1H), 3.91 (s, 2H), 2.51 (t, J = 6.0 Hz, 2H), 2.44–2.36 (m, 1H), 1.96–1.81 (m, 2H), 1.73–1.59 (m, 2H), 1.37–1.25 (m, 2H), and 0.93 (t, J = 7.4 Hz, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 152.1, 149.4, 138.6, 128.8, 128.4, 126.3, 121.9, 106.2, 34.8, 34.6, 28.5, 28.2, 23.2, 21.5, and 11.7; IR (CH_2Cl_2) 1745, 1,660 cm^{-1}; MS (EI, 70 eV) *m/e* 240.1 ([M]$^+$, 46), 211.1 (100), 165.1 (19), 137.1 (28), and 105.0 (21); HRMS (EI) *m/e* calcd for $C_{17}H_{20}O$ [M]$^+$ 240.1514, found 240.1516.

4.4.7 | *(E)*-(3-[6-Ethylidenecyclohex-1-en-1-yl]prop-1-yn-1-yl) benzene (12b)

A yellow oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.46–7.39 (m, 2H), 7.31–7.26 (m, 3H), 6.05 (s, 1H), 5.55 (q, J = 6.7 Hz, 1H), 3.30 (s, 2H), 2.35 (t, J = 6.2 Hz, 2H), 2.22–2.16 (m, 2H), and 1.74–1.66 (m, 5H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 135.1, 132.0, 131.6, 128.2, 127.6, 126.4, 124.1, 117.2, 88.1, 83.1, 26.0, 25.7, 23.7, 22.6, and 13.2; IR (CH_2Cl_2) 2,936, 2,196, and 1,599, cm^{-1}; MS (EI, 70 eV) *m/e* 222.3 ([M]$^+$, 100), 207.3 (74), 194.3 (35), 179.3 (55), and 165.2 (39); HRMS (EI) *m/e* calcd for $C_{17}H_{18}$ [M]$^+$ 222.1409, found 222.1409.

4.4.8 | 6-(3-Phenylprop-2-yn-1-yl)-3,4-dihydro-1,1′-biphenyl (10a) and 6-(3-phenylprop-2-yn-1-yl)-2,3-dihydro-1,1′-biphenyl (10b)

To a solution of 5a (57.7 mg, 0.200 mmol) in CH_2Cl_2 (2.0 mL) at room temperature under N_2 flow, TfOH (1.8 μL, 0.020 mmol) was added. After 2 min, **5a** had been consumed. The reaction was quenched with saturated aqueous $NaHCO_3$ solution (5 mL) and the mixture was extracted with CH_2Cl_2 (15 mL × 3). The combined organic layers were dried over anhydrous $MgSO_4$ (5 g) and concentrated in vacuo to give a crude mixture. Then, the crude mixture was purified by flash column chromatography over silica gel (hexanes) to give the two compounds **10a** and **10b** (37.9 mg, 0.140 mmol, 70%) as a yellow oil: **10a** and **10b** were diastereomers, ratio1:1.1: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.43–7.40 (m, 2H), 7.39–7.36 (m, 3H), 7.36–7.33 (m, 2H), 7.33–7.29 (m, 5H), 7.29–7.26 (m, 6H), 7.22–7.19 (m, 2H), 6.25 (dt, J = 9.6, 1.9 Hz, 1H, **10b**), 6.23–6.19 (m, 1H, 10a), 5.96 (dt, J = 9.6, 4.6 Hz, 1H, 10b), 5.87–5.83 (m, 1H, **10a**), 3.23 (s, 2H, **10b**), 3.08 (d, J = 1.2 Hz, 2H, **10a**), 2.55–2.49 (m, J = 9.2 Hz, 2H, **10b**), 2.35–2.27 (m, 2H, **10b**), and 2.26–2.23 (m, 4H, **10a**); ^{13}C NMR (100 MHz, $CDCl_3$) δ 142.0, 140.8, 139.6, 133.4, 131.7, 131.7, 131.5, 128.4, 128.2 (2C), 128.1 (2C), 128.0, 127.6 (2C), 127.6, 126.8, 126.7, 126.5, 126.5, 126.4, 124.0, 123.9, 123.9, 88.4, 87.5, 83.3, 81.0, 29.6, 24.5, 23.2, 22.9, 22.9, and 22.5; IR (CH_2Cl_2) 3,033, 2,235, and 1,599 cm^{-1}; MS (EI, 70 eV) *m/e* 270.0 ([M]$^+$, 100), 255.0 (12), 193.0 (11), 179.1 (50), 178.1 (14), and 155.0 (12); HRMS (EI) *m/e* calcd for $C_{21}H_{18}$ [M]$^+$ 270.1409, found 270.1407.

4.4.9 | 2-(3-Phenylprop-2-yn-1-yl)-1,4,5,6-tetrahydro-[1,1′-biphenyl]-3-ol (11)

To a solution of **5a** (57.7 mg, 0.200 mmol) in CH_2Cl_2 (2.0 mL) at room temperature under nitrogen, BF_3ċOEt_2 (2.5 μL, 0.020 mmol) was added. After 2 min, **5a** had been consumed, and the reaction mixture was neutralized with saturated aqueous $NaHCO_3$ solution (5 mL) and extracted with CH_2Cl_2 (15 mL × 3). The combined organic layers were dried over anhydrous $MgSO_4$ (5 g), and the solvent was evaporated under reduced pressure to give a crude mixture. Then, the crude mixture was purified by flash column chromatography over silica gel (1:15 ethyl acetate/hexanes) to give **11** (8.7 mg, 0.030 mmol, 15%) as a yellow oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.41–7.38 (m, 2H), 7.38–7.34 (m, 2H), 7.30–7.26 (m, 4H), 7.25–7.22 (m, 2H), 4.59 (s, 1H), 3.28 (dt. J = 17.5, 1.7 Hz, 1H), 3.10 (d, J = 17.4 Hz, 1H), 2.41–2.32 (m, 1H), 2.31–2.22 (m, 1H), 2.19–2.09 (br s, 1H), 1.97–1.86 (m, 3H), and 1.79–1.72 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 142.3, 138.9, 131.6, 129.9, 128.3, 128.2, 127.9, 127.7, 126.9, 123.7, 88.5, 81.3, 66.8, 32.6, 31.6, 21.9, and 18.4; IR (CH_2Cl_2) 3,394, 2,234, 1,671, and

1,068 cm^{-1}; MS (EI, 70 eV) *m/e* 288.2 ($[M]^+$, 57), 270.1 (66), 260.1 (26), 217.1 (22), 211.1 (20), and 173.1 (100); HRMS (EI) *m/e* calcd for $C_{21}H_{20}O$ $[M]^+$ 288.1514, found 288.1515.

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ORCID

Ming-Chang P. Yeh https://orcid.org/0000-0003-2963-5707

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[18] The SI contains the crystallographic data for **9k**. CCDC 1007450 (**9k**) contains the supplementary crystallographic data for this paper. These data can be obtained free of charge from the Cambridge crystallographic data Centre via www.ccdc.cam.ac.uk/data_request/cif.

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