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Note

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Enantioselective Formal [4 +1] Cycloaddition of Diazoarylacetates and the Danishefsky's Diene: Stereoselective Synthesis of (–)-1,13-Herbertenediol

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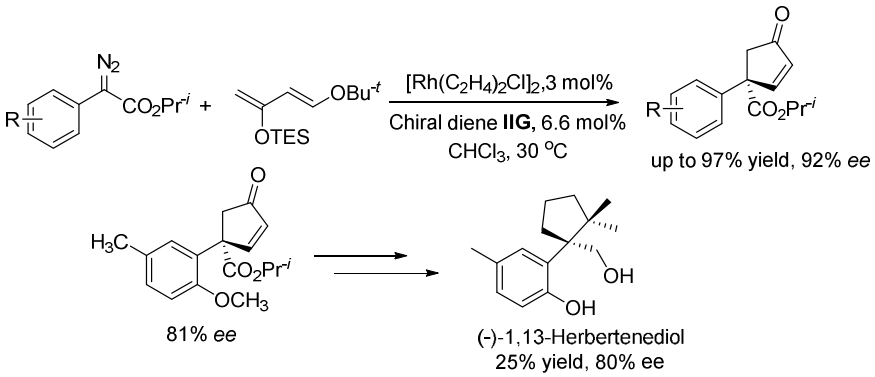
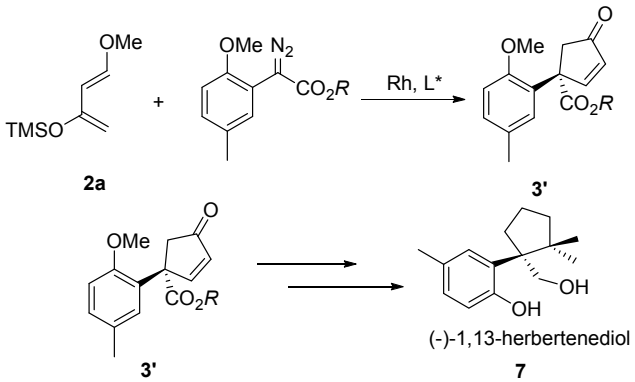
Supporting Information Placeholder



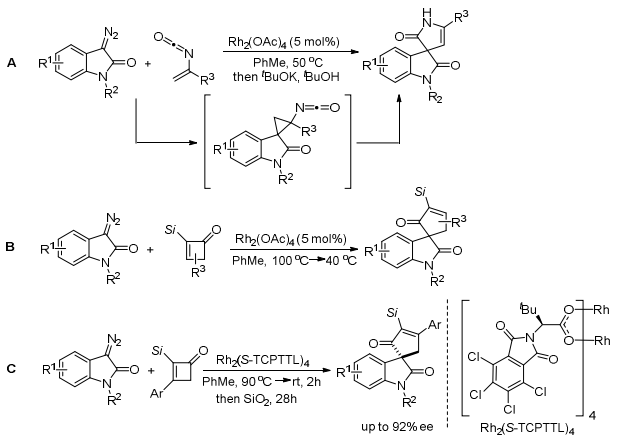
ABSTRACT: Rodium-chiral diene complexes catalyzed enantioselective cycloaddition of aryl α-diazoarylacetates and electron enriched Danishefsky type diene afforded highly functionalized and optically enriched cyclopentenones in excellent yields (up to 97% yield) and with good to excellent enantioselectivities (60-92% *ee*). (–)-1,13-Herbertenediol was successfully synthesized in overall 25% yield employing the optically enriched cyclopentenone with an all-carbon quaternary centres as the key intermediate.

Cyclopentenone scaffold is abound in many natural products as well as pharmaceutical molecules.[1] The functionally enriched cyclopentenone is also important organic intermediate in the synthesis of complicated molecules as well as pharmaceuticals.[2] One of such examples is herbertanes,[3] which are considered as chemical markers for the liverworts belonging to the genus *Herbertus*. Their synthesis draws much attentions from chemical community for their interesting structure for the presence of a sterically hindered 1-aryl-1,2,2-trimethylcyclopentane moiety, and the difficulty associated with the construction of vicinal quaternary carbon atoms on a cyclopentane ring. The significant biological properties of the phenolic herbertanes make them important synthetic targets of current interest.[4] For example, (–)-1,13-Herbertenediol **7** (Scheme 1) was isolated as early in 2000,[3] however, the total synthesis includes only five reports so far. In 2001, Fukuyama reported the first synthesis employing an intramolecular Heck reaction.[5] Later in 2003, Srikrishna described the synthesis of 1,13-herbertenediol employing orthoester Claisen rearrangement for the construction of the two vicinal quaternary carbon atoms.[4f] After that, racemic 1,13-herbertenediol was successfully achieved using a ring-closing metathesis as the key step.[3,6a] In 2004, Grainger synthesized this compound via a Paternò–Büchi photocyclisation–oxetane fragmentation strategy.[6b] All the reported synthetic methodology requires tediously long route to key intermediate cyclopentene derivatives. More importantly, up to now, the enantioselective total synthesis of (–)-1,13-herbertenediol is not known yet.



Scheme 1 Proposed synthetic route to (–)-1,13-Herbertenediol

For the versatility of cyclopentenone in organic synthesis, much efforts have been devoted to the rapid and efficient assembly of synthetically important compound.[7] Although [3+2]-cycloaddition is well-developed, [4+1]-cycloannulations are less explored in target-directed 5-membered ring construction.[8] Cycloaddition of metalcarbene and 1,3-diene equivalents is straightforward and efficient approach for achieving cyclopentene derivatives. For example, Ashfeld developed a rhodium catalyzed formal [4+1] cycloadditon of the vinyl isocyanate with diazooxindole yielding spirooxindole pyrrolones in high yields (Scheme 1A).[9] The reaction mechanism features an initial vinyl isocyanate cyclopropanation followed by a ring expansion of the formed vinyl cyclopropanes (VCPs) facilitated by the polarized nature of the intermediate cyclopropyl isocyanate. α-Silyl vinyl ketenes derived from cyclobutenones as 1,4-dipoles had also been utilized by the group of Ashfeld to assemble spirooxindole cyclopentenones in a similar manner (Scheme 1B).[10a] Very recently, Ashfeld and co-workers realized a catalytic asymmetric version of this reaction by employing tetrachloropthalimide-derived carboxylate $Rh_2(S\text{-TCPTTL})_4$ as the catalyst (Scheme 1C).[10b] However, employing phenyl diazoester resulted in a 1:2.3 ratio of cyclopentenone and the intermediate cyclopropyl ketene with moderate enantioselectivity.



Scheme 2 Rhodium catalyzed formal [4+1] cycloaddition of metalcarbene and 1,3-diene equivalents

Very recently, we successfully developed a rhodium catalyzed enantioselective formal [4+1] cycloaddition of diazooxindoles and the (*trans*)-1-Methoxy-3-trimethxoysilyl 1,3-diene (Danishefsky's diene).[11] The optically and highly structurally enriched indoline spirocyclopentenone bearing an all-carbon quaternary stereocenter was formed in one pot, two steps in up to excellent yields and with up to excellent enantioselectivities. Encouraged by the results, we surmised that the methodology could be employed in the enantioselective synthesis of 1-aryl-4-oxocyclopent-2-ene-1-carboxylate **3'**. Racemic **3'** is the key synthetic intermediate in total synthesis of racemic 1,13-herbertenediol (scheme 1).[6] To establish the efficient method for optically enriched 4-aryl-cyclopent-2-en-1-one, we initiated the enantioselective cycloaddition of the aryl α-diazoacetic ethyl ester **1** and (*trans*)-1-methoxy-3-trimethxoysilyl 1,3-diene **2a** using our reported procedure. [11] However, chiral dirhodium tetrakis carboxylate which was proved to be the most effective in our previous investigation afforded almost no selectivity (<10% *ee*, see Table S1, SI). Altering the catalyst or optimization of reaction didn't give any further positive results.

The chiral dienes as ligands in rhodium catalyzed asymmetric transformations has been well explored such as asymmetric hydroarylation,[12] but less studied in rhodium carbene chemistry. In our initial investigation, the commercially available chiral **IA** afforded 68% *ee* and 50 % yield (entry 1, Table 1). The promising result encouraged us to explore the enantioselective cycloaddition using the other chiral dienes (Figure 1). As Listed in **Figure 1**, the chiral dienes are commercially available or are readily accessed by reported procedure, and most importantly, the steric environment

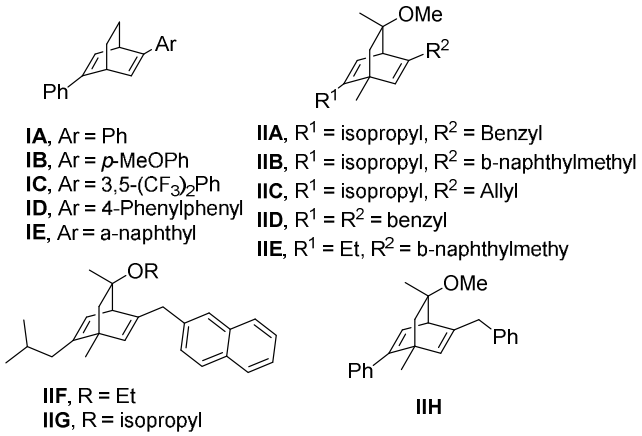
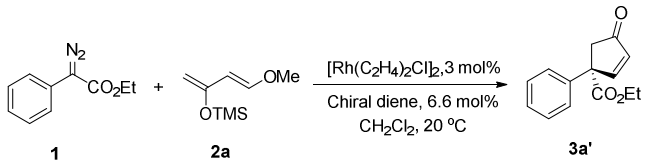


Figure 1 The chiral diene ligands investigated in the work.

of dienes **II** can be easily modified just by adjusting the substituents. Among the dienes listed, **IB-IE** were synthesized from phenyl acetaldehyde and cyclohexenone as the starting material using a reported procedure,[13] **IIA-IIH** were prepared from commercially available L-(–)-carvone according to the reported procedure.[14]

Table 1. Screening of the chiral dienes. [a]



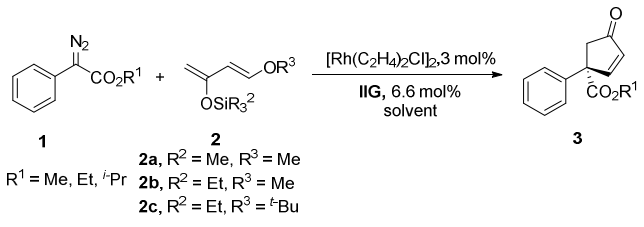
entry	diene	Time (h)	Yield (%)[b]	ee (%)[c]
1	**IA**	3	50	68
2	**IB**	3	31	64
3	**IC**	3	54	68

4	**ID**	2	44	62
5	**IE**	4	54	63
6	**IIA**	3	56	74
7	**IIB**	2	55	75
8	**IIC**	2	41	74
9	**IID**	>12	--	--
10	**IIE**	3	51	75
11	**IIF**	2	68	76
12	**IIG**	2	74	77
13	**IIH**	2	49	68

[a] Unless otherwise stated, the reaction was carried out using **1** (0.1 mmol) and **2a** (0.25 mmol) in the presence of 3 mol% rhodium and 6.6 mol% of chiral diene at 20 °C with dichloromethane as the solvent. [b] Isolated yields. [c] Determined by HPLC.

The chiral dienes **I** which derived from enantioselective conjugate/aldol condensations of cyclohexenone and phenylacetaldehyde afforded moderate enantioselectivities and yield (entries 1-5). For chiral diene **IA**-**IE**, the electronic nature and steric hindrance show little effect on the reaction. The scaffold for diene **II** draws our attention for the following considerations: 1) the more steric demanding compared to **I**, 2) the steric hindrance or electronic nature can be further adjusted by changing the R^1, R^2 or the ether moiety during the preparation. In fact, the steric more demanding structure afforded better enantioselectivities than chiral diene **I** did. The ether moiety of dienes **II** had a significant effect on the reaction. For example, **IIA**-**IIC**, **IIE** and **IIH** provided the similar selectivities (entries 6-8, 10 and 13) affording the corresponding product in around 50% yield and with 68-75% *ee*, ethyl and isopropyl ether of the diene **IIF**-**IIG** were much efficient delivering better yields (entries 11-12), and isopropyl ether **IIG** yielded the highest yield and enantioselectivities among the dienes investigated (74% yield, 77% *ee*, entry 12). Other bulky ether moiety such as tertiary butyl is not accessible. It should be noted that the chiral diene **IID** didn't provide the corresponding product **3a'** at all. Based on the investigation, we chose the chiral diene **IIG** for further optimization of the reaction.

Table 2. Optimization of the reaction. [a]

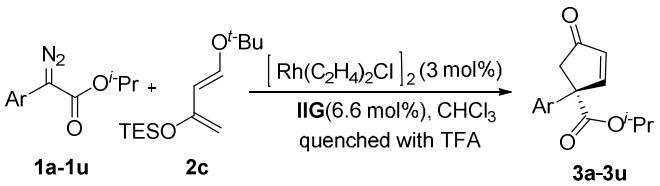


entry	R^1	2	Solvent	Yield (%)[b]	ee (%)[c]
1	Me	2a	CH_2Cl_2	62	70
2	Et	2a	CH_2Cl_2	64	77
3	$^{i}C_3H_7$	2a	CH_2Cl_2	54	80
4	$^{i}C_3H_7$	2b	CH_2Cl_2	60	83
5	$^{i}C_3H_7$	2c	CH_2Cl_2	50	88
6	$^{i}C_3H_7$	2c	$CHCl_3$	80	91
7	$^{i}C_3H_7$	2c	CCl_4	48	76
8	$^{i}C_3H_7$	2c	toluene	43	84
9	$^{i}C_3H_7$	2c	hexane	51	79
10[d]	$^{i}C_3H_7$	2c	$CHCl_3$	85	92
11[e]	$^{i}C_3H_7$	2c	$CHCl_3$	81	89
12[f]	$^{i}C_3H_7$	2c	$CHCl_3$	40	81

[a] Unless otherwise stated, the reaction was carried out using **1** (0.1 mmol) and **2** (0.25 mmol) in the presence of 3 mol% rhodium and 6.6 mol% of chiral diene at 20 °C [b] Isolated yields. [c] Determined by HPLC. [d] the reaction was carried out at 30 °C. [e] the reaction was carried out at 10 °C. [f] the reaction was carried out at 0 °C.

The steric environment of substrate may have much effects on the reaction. To further improve the selectivity of the reaction, we investigated the effect of steric hindrance of substrates on the reaction. As shown in Table 2, the reaction is sharply dependent on the steric hindrance of the substrate. Bulkier ester group of α-diazoacetate gave better selectivity, for example, methyl, ethyl and isopropyl esters afforded 70, 77 and 80% *ee* respectively although yield decreased for the bulkier substituent (entries 1-3). We also investigated the effect of diene structure on the reaction. The dienes **2b**-**2c** were prepared from commercially available (*E*)-4-methoxybut-3-en-2-one using the literature method.[15] The steric hindrance of diene substrates had a significant effect on the reaction. The bulky groups on silicon or oxygen are beneficial for achieving better selectivity. For example, **2b** afforded 83% *ee*, while the steric more demanding **2c** gave the highest 88% *ee* albeit lower yield was observed (entries 4-5). Switch of the solvent from DCM to chloroform resulted in a further improvement in both yield and selectivity (80% yield, 91% *ee*, entry 6). Other investigation in screening of solvent such as CCl_4, toluene and hexane provided less desired results in terms of both yield and selectivity (entries 7-9). The lower temperature (0 °C) did not render a higher ee but resulted in the decrease of yield (entries 10-12).

Table 3. Substrate scope. [a]

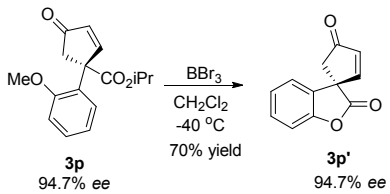


en-	Ar	3	Yield (%)[b]	ee (%)[c]

try				
1	Ph	3a	90	92
2	*o*-FPh	3b	85	76
3	*m*-FPh	3c	95	90
4	*p*-FPh	3d	91	90
5	*o*-ClPh	3e	66	60
6	*m*-ClPh	3f	93	90
7	*p*-ClPh	3g	95	86
8	*m*-BrPh	3h	97	88
9	*p*-BrPh	3i	85	82
10	*m*-CF_3Ph	3j	95	90
11	*p*-CF_3Ph	3k	92	90
12	*o*-MePh	3l	41	78
13	*m*-MePh	3m	94	91
14	*p*-MePh	3n	91	90
15	*p*-^{t}BuPh	3o	85	91
16	*o*- MeOPh	3p	95	80(95)[d]
17	*m*-MeOPh	3q	91	92
18	*p*-MeOPh	3r	91	81
19	1-naphthy	3s	71	73
20	2-naphthy	3t	93	91
21	*p*-PhenylPh	3u	97	90

[a] Unless otherwise stated, the reaction was carried out using **1** (0.1 mmol) and **2** (0.25 mmol) in the presence of 3 mol% rhodium and 6.6 mol% of chiral diene **IIG** in chloroform for 1-3h. [b]Isolated yields. [c] Determined by HPLC. [d] After a simple recrystallization from a mixed solvent of *n*-hexane and ethyl acetate, the *ee* values are listed in the parenthesis.

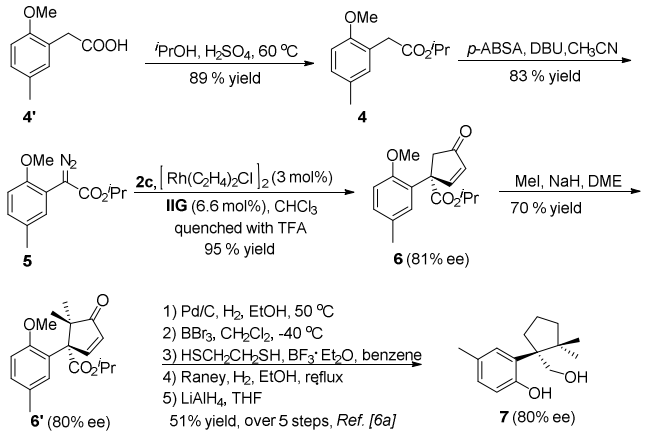
With the optimal conditions established, the substrate scope was investigated. As listed in Table 3, the yield and enantioselectivities are highly dependent on the steric hindrance and electronic nature of the substrates. Monosubstituted phenyl diazoacetic isopropyl ester, the *ortho* substituted substrates afforded the poorest selectivity compared to ones which is *meta*- or *para*- substituted. For example, *ortho* fluoro derived phenyl α-diazo acetic tertiary butyl ester gave only 76% *ee*, while the *meta*- or *para*- substrate yielded 90% *ee* (entries 2-4). The same trend was also observed in the chloro-, methyl as well as methoxy substituted diazo acetates (entries 5-7, 12-14 and 16-18). Other substituents such as bromo, trifluoromethyl or tertiary butyl at *meta*- and *para*- position all resulted good to excellent *ee*s and yields (entries 8-9, 10-11, 15). 1-naphthyl diazo substrate yielded the less desired selectivities compared to the 2-naphthyl substituted substrate, this maybe resulted from the steric hindrance (entry 19-20). Para-phenyl phenyl substituted diazo compound also gave good selectivity and excellent yield (entry 21).



Scheme 3 Transformation of cycloadduct

The cycloadduct **3** can be easily transformed to other versatile molecules. For example, deprotection of the compound **3p** upon treatment with boron tribromide readily yielded spiro[benzofuran-3,1'-cyclopentan]-2'-ene-2,4'-dione without erosion of optical purity (Scheme 3), a structure motif in natural products such as dendrochrysanene. [16]

After the development of enantioselective cycloaddition of diazoarylacetates and the Danishefsky type diene, we further initiated the enantioselective synthesis of (–)-1,13-Herbertenediol (Scheme 4). First, the ester **4** which furnished by esterification of the acid **4'** with isopropanol was submitted to diazotization with 4-acetamidobenzenesulfonyl azide (*p*-ABSA) in the presence of DBU yielded the diazo compound **5** in 83% yield. Rhodium catalyzed enantioselective [4+1] cycloaddition of diazo compound **5** and electron enriched diene **2c** under our developed condition gave the corresponding cylopentenone **6** in 88% yield and with 81% *ee*. One-step dialkylation of **6** with sodium hydride and methyl iodide in dimethoxyethane (DME) generated the second quaternary carbon



Scheme 4 Enantioselective total synthesis of (–)-1,13-Herbertenediol

atom to furnish enone **6'** (80% ee) in 70% yield. A series of transformation of the key intermediate enone **6'** according to the reported procedure[6a] afforded (–)-1,13-Herbertenediol **7** in overall 25% yield over 9 steps without erosion of optical purity. The NMR spectral is identical to that reported in literature.[3] The comparison of specific optical rotation of the compound **7** ($[\alpha]_D^{20}$ = -20.1, c = 0.18, $CHCl_3$) with that reported in literature[3] ($[\alpha]_D^{20}$ = -26, c = 0.18, $CHCl_3$) verifies the absolute configuration of 1,13-Herbertenediol to be *R*. The configuration of other cy-

cloaddition products was tentatively assigned by analogy. To our knowledge, this is the first enantioselective synthesis of (–)-1,13-Herbertenediol.

CONCLUSIONS

In summary, we have developed an enantioselective formal [4+1] cycloaddition forming the optically enriched cyclopentenone derivative with an all carbon chiral center in up to 92% *ee* and 97% yield. The methodology was successfully applied in the enantioselective total synthesis of (–)-1,13-Herbertenediol in overall 25% yield and with 80% *ee* over 9 steps.

EXPERIMENTAL SECTION

All reactions were carried out under an atmosphere of argon using standard Schlenk techniques. All the reagents were obtained from commercial supplier and used as received, without further purification unless otherwise noted. Solvents used in the reactions were distilled from appropriate drying agents prior to use. ^{1}H NMR and ^{13}C NMR spectra were recorded respectively at 400 MHz and 100 MHz. Chemical shifts were reported in parts per million (ppm) down field from TMS with the solvent resonance as the internal standard. Coupling constants (*J*) are reported in Hz and refer to apparent peak multiplications. Optical rotations were measured in the indicated solvents on Perkin Elmer polarimeter (Polartronic MH8) with a 10 cm cell (c given in g/100 mL). Flash column chromatography was performed using 200-300 mesh silica gel. Enantiomeric excess (ee) were determined by HPLC analysis on a Shimadzu LC-20A, using Daicel Chiralcel IC or C2 columns. High resolution mass spectra were obtained on Bruker Daltonics micrOTOF-Q II spectrometer in ESI mode. The diazo substrates were prepared according to literature procedure.[17]

***General experimental procedure for the synthesis of Danishefsky Dienes*:** The Danishefsky Diene **2** was prepared following a literature procedur.[15a,18] To a solution of (*E*)-4-methoxybut-3-en-2-one (10 g, 86 mmol) and *tert*-butyl alcohol (100 mL) in benzene (40 mL) was added PPTS (217 mg, 1.72 mmol), and the solution was refluxed for 28 h with continuous removal of methanol by using a trap containing 4Å molecular sieves. After the (*E*)-4-methoxybut-3-en-2-one was disappeared as followed by TLC, the reaction was concentrated under reduced pressure and to give a dark oil. The crude product was purified by column chromatography (silica gel, petroleum ether/ethyl acetate = 10:1) to give (*E*)-4-(tert-butoxy)but-3-en-2-one as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$, ppm): δ 7.65 (d, *J* = 12.0 Hz, 1H), 5.70 (d, *J* =12.0Hz, 1H), 2.14 (s, 3H), 1.35 (s, 9H). ^{13}C NMR (100 MHz, $CDCl_3$, ppm): δ 197.6, 157.9, 108.9, 80.2, 28.5, 28.1.

To a solution of (*E*)-4-(tert-butoxy) but-3-en-2-one (142.12 mg, 1 mmol) and Et_3N (0.4 mL, 2.8 mmol) in anhydrous Et_2O (4 mL) was added dropwise TESOTf (0.28 mL, 1.2 mmol) at -20 ºC. The mixture was then warmed to 0 ºC and stirred for 3 h at the same temperature. The mixture was then diluted with *n*-hexane (6 mL) and washed with saturated aqueous $NaHCO_3$, (3 × 5 mL) and brine (3 × 5 mL) sequentially. The organic layer was dried over Na_2SO_4, filtered, and the filtrate was concentrated under reduced pressure to give the **2c** as a yellow oil. The compound **2c**, which were stable for several days at -2 °C, were used without further purification. The other Danishefsky dienes mentioned in the article can be obtained in the same way.

***General experimental procedure for the synthesis of cyclopentenone derivative*:** To a flame-dried and Ar-purged Schlenk tube (25 mL), $[RhCl(C_2H_4)_2]_2$ (0.003 mmol), Chiral diene ligand **IIG** (0.0066 mmol), 3 Å MS (50 mg) were added. The schlenk tube was then evacuated and filled with argon. This cycle was repeated three times and followed by addition of $CHCl_3$ (1.0 mL). The mixture was stirred at 30 °C for 30 minutes, and then diene **2c** (0.25 mmol) and the solution of diazo **1** (0.10 mmol) in $CHCl_3$ (1.0 mL) was added sequencing. The reaction mixture was stirred under an atmosphere of argon at 30 °C until the reaction was complete (monitored by TLC). Upon completion of the reaction, the reaction mixture was cooled to 0 °C and then TFA (1.0 mL) was added at the same temperaure, the mixture was stirred at 0 °C for 6 h. The resultant solution was added water (5 mL) and the aqueous layer was extracted with CH_2Cl_2 (3 × 5 mL), washed with brine (2 × 5 mL). The combined organic layers were dried over anhydrous Na_2SO_4. After evaporation under the reduced pressure, the residue was purified through flash column chromatography on silica gel (eluent: petroleum ether/ethyl acetate 12:1- 7:1) to yield pure products **3**.

*(R)-isopropyl-4-oxo-1-phenylcyclopent-2-ene-1 carboxylate (**3a**)*. Colorless oil, 22.0 mg, yield: 90%. R_f = 0.3 (petroleum ether/ethyl acetate 7:1), $[\alpha]_D^{25}$ = –14.9 (*c* = 0.18, $CHCl_3$), 92% *ee,* determined by HPLC analysis (chiralpak IC column, 15% IPA in hexane, rate: 1.0 mL/min, 254 nm). Retention time: t (minor) = 10.8 min, t (major) = 14.4 min. **IR** (KBr): ν_{max} 2925, 2855, 1730, 1460, 1379, 1245, 1148, 1101, 1030, 916, 835, 698 cm $^{-1}$. **^{1}H NMR** (400 MHz, $CDCl_3$, ppm): δ 7.96 (d, *J* = 5.6 Hz, 1H), 7.40-7.30 (m, 3H), 7.24-7.22 (m, 2H), 6.34 (d, *J* = 5.6 Hz, 1H), 5.12-5.06 (m, 1H), 3.50 (d, *J* = 18.8 Hz, 1H), 2.60 (d, *J* = 18.8 Hz, 1H), 1.25 (d, *J* = 6.2 Hz, 3H), 1.20 (d, *J* = 6.2 Hz, 3H). **^{13}C NMR** (100 MHz, $CDCl_3$, ppm): δ 207.3, 171.3, 163.4, 141.1, 133.9, 129.0, 127.7, 125.9, 69.8, 60.1, 46.7, 21.6, 21.4. **HRMS** (ESI): calcd for $C_{30}H_{32}O_6Na$ $[M+Na]^+$ 267.0992, found 267.0992.

*(R)-isopropyl-1-(2-fluorophenyl)-4-oxocyclopent-2-ene-1-carboxylate (**3b**)*. Colorless oil, 22.3 mg, yield: 85%. R_f = 0.5 (petroleum ether/ethyl acetate 5:1), $[\alpha]_D^{25}$ = –87.5 (c = 0.23, $CHCl_3$), 76% *ee,* determined by HPLC analysis (chiralpak IC column, 10% IPA in hexane, rate: 1.0 mL/min, 254 nm). Retention time: t (minor) = 17.0 min, t (major) = 19.7 min. **IR** (KBr): ν_{max} 2963, 2924, 1726, 1635, 1453, 1383, 1260, 1099, 1022, 869, 800, 753 cm $^{-1}$. **^{1}H NMR** (400 MHz, $CDCl_3$, ppm): δ 7.85 (d, *J* = 5.6 Hz, 1H), 7.36-7.30 (m, 1H), 7.17-7.08 (m, 3H), 6.42 (d, *J* = 5.6 Hz, 1H), 5.11-5.03 (m, 1H), 3.62 (d, *J*

= 18.8 Hz, 1H), 2.46 (d, *J* = 18.8 Hz, 1H), 1.22 (d, *J* = 6.2 Hz, 3H), 1.18 (d, *J* = 6.2 Hz, 3H). **^{13}C NMR** (100 MHz, $CDCl_3$, ppm): δ 207.1, 170.7, 161.6, 160.2, 135.3, 129.6, 129.2, 127.3, 124.3, 116.0, 70.1, 57.2, 45.8, 21.5, 21.3. **HRMS** (ESI): calcd for $C_{30}H_{31}F_2O_6$ $[2M+H]^+$ 525.2083, found 525.2074.

*(R)-isopropyl-1-(3-fluorophenyl)-4-oxocyclopent-2-ene-1-carboxylate (**3c**)*. Colorless oil, 24.9 mg, yield: 95%. R_f = 0.5 (petroleum ether/ethyl acetate 5:1), $[\alpha]_D^{25}$ = −45.5 (c = 0.35, $CHCl_3$), 90% *ee,* determined by HPLC analysis (chiralpak IC column, 10% IPA in hexane, rate: 1.0 mL/min, 254 nm). Retention time: t (minor) = 12.3 min, t (major) = 17.5 min. **IR** (KBr): ν_{max} 2923, 1724, 1617, 1441, 1383, 1256, 1101.29, 1033, 891, 786, 691 cm $^{-1}$. **^{1}H NMR** (400 MHz, $CDCl_3$, ppm): δ 7.92 (d, *J* = 5.6 Hz, 1H), 7.36-7.32 (m, 1H), 7.02-6.94 (m, 3H), 6.37 (d, *J* = 5.6 Hz, 1H), 5.11-5.05 (m, 1H), 3.51 (d, *J* = 18.8 Hz, 1H), 2.56 (d, *J* = 18.8 Hz, 1H), 1.25 (d, *J* = 6.2 Hz, 3H), 1.21 (d, *J* = 6.2 Hz, 3H). **^{13}C NMR** (100 MHz, $CDCl_3$, ppm): δ 206.8, 170.8, 162.9, 162.5, 143.4, 134.4, 130.6, 121.6, 114.8, 113.3, 70.1, 59.8, 46.6, 21.6, 21.4. **HRMS** (ESI): calcd for $C_{30}H_{31}F_2O_6$ $[2M+H]^+$ 525.2083, found 525.2087.

*(R)-isopropyl-1-(4-fluorophenyl)-4-oxocyclopent-2-ene-1-carboxylate (**3d**)*. Colorless oil, 24.1 mg, yield: 92%. R_f = 0.5 (petroleum ether/ethyl acetate 5:1), $[\alpha]_D^{25}$ = −43.4 (c = 0.40, $CHCl_3$), 90% *ee,* determined by HPLC analysis (chiralpak IC column, 10% IPA in hexane, rate: 1.0 mL/min, 254 nm). Retention time: t (minor) = 13.7 min, t (major) = 20.4 min. **IR** (KBr): ν_{max} 2924, 1724, 1635, 1506, 1460, 1383, 1258, 1101, 1032, 914, 838, 794, 667 cm $^{-1}$. **^{1}H NMR** (400 MHz, $CDCl_3$, ppm): δ 7.94 (d, *J* = 5.6 Hz, 1H), 7.23-7.19 (m, 2H), 7.08-7.04 (m, 2H), 6.35 (d, *J* = 5.6 Hz, 1H), 5.10-5.04 (m, 1H), 3.51 (d, *J* = 18.8 Hz, 1H), 2.55 (d, *J* = 18.8 Hz, 1H), 1.25 (d, *J* = 6.2 Hz, 3H), 1.19 (d, *J* = 6.2 Hz, 3H). **^{13}C NMR** (100 MHz, $CDCl_3$, ppm): δ 207.0, 171.1, 163.0, 162.0, 136.9, 134.1, 127.7, 115.9, 70.0, 59.4, 46.8, 21.6, 21.4. **HRMS** (ESI): calcd for $C_{15}H_{15}FO_3Na$ $[M+Na]^+$ 285.0897, found 285.0899.

*(R)-isopropyl-1-(2-chlorophenyl)-4-oxocyclopent-2-ene-1-carboxylate (**3e**)*. Colorless oil, 18.4 mg, yield: 66%. R_f = 0.5 (petroleum ether/ethyl acetate 5:1), $[\alpha]_D^{25}$ = −71.8 (c = 0.25, $CHCl_3$), 60% *ee,* determined by HPLC analysis (chiralpak IC column, 10% IPA in hexane, rate: 1.0 mL/min, 254 nm). Retention time: t (minor) = 22.0 min, t (major) = 23.9 min. **IR** (KBr): ν_{max} 2965, 3928, 1725, 1633, 1466, 1383, 1257, 1103, 1023, 914, 871, 799, 748, 669 cm $^{-1}$. **^{1}H NMR** (400 MHz, $CDCl_3$, ppm): δ 7.85 (d, *J* = 5.6 Hz, 1H), 7.45-7.42 (m, 1H), 7.31-7.26 (m, 2H), 7.16-7.14 (m, 1H), 6.46 (d, *J* = 5.6 Hz, 1H), 5.10-5.04 (m, 1H), 3.80 (d, *J* = 18.8 Hz, 1H), 2.39 (d, *J* = 18.8 Hz, 1H), 1.22 (d, *J* = 6.2 Hz, 3H), 1.18 (d, *J* = 6.2 Hz, 3H). **^{13}C NMR** (100 MHz, $CDCl_3$, ppm): δ 207.1, 170.7, 161.7, 139.9, 135.8, 133.5, 130.6, 128.9, 128.0, 126.9, 70.1, 60.3, 45.8, 21.5, 21.3. **HRMS** (ESI): calcd for $C_{15}H_{15}ClO_3Na$ $[M+Na]^+$ 301.0602, found 301.0588.

*(R)-isopropyl-1-(3-chlorophenyl)-4-oxocyclopent-2-ene-1-carboxylate (**3f**)*. Colorless oil, 26.0 mg, yield: 93%. R_f = 0.5 (petroleum ether/ethyl acetate 5:1), $[\alpha]_D^{25}$ = −29.0 (c = 0.41, $CHCl_3$), 90% *ee,* determined by HPLC analysis (chiralpak IC column, 10% IPA in hexane, rate: 1.0 mL/min, 254 nm). Retention time: t (minor) = 11.8 min, t (major) = 16.8 min. **IR** (KBr): ν_{max} 2926, 1725, 1634, 1459, 1383.19, 1258, 1100, 1028, 875, 799, 673 cm $^{-1}$. **^{1}H NMR** (400 MHz, $CDCl_3$, ppm): δ 7.92 (d, *J* = 5.6 Hz, 1H), 7.34-7.30 (m, 2H), 7.21 (d, *J* =1.7 Hz, 1H), 7.13-7.11 (m, 1H), 6.37 (d, *J* = 5.6 Hz, 1H), 5.12-5.06 (m, 1H), 3.51 (d, *J* = 18.8 Hz, 1H), 2.55 (d, *J* = 18.8 Hz, 1H), 1.26 (d, *J* = 6.3 Hz, 3H), 1.21 (d, *J* = 6.3 Hz, 3H). **^{13}C NMR** (100 MHz, $CDCl_3$, ppm): δ 206.7, 170.7, 162.5, 134.9, 134.5, 130.3, 128.0, 126.3, 124.2, 70.2, 59.8, 46.5, 21.6, 21.4. **HRMS** (ESI): calcd for $C_{15}H_{15}ClO_3Na$ $[M+Na]^+$ 301.0602, found 301.0621.

*(R)-isopropyl-1-(4-chlorophenyl)-4-oxocyclopent-2-ene-1-carboxylate (**3g**)*. Colorless oil, 26.5 mg, yield: 95%. R_f = 0.5 (petroleum ether/ethyl acetate 5:1), $[\alpha]_D^{25}$ = −25.8 (c = 0.38, $CHCl_3$), 86% *ee,* determined by HPLC analysis (chiralpak IC column, 10% IPA in hexane, rate: 1.0 mL/min, 254 nm). Retention time: t (minor) = 19.4 min, t (major) = 32.3 min. **IR** (KBr): ν_{max} 2924, 1724, 1635, 1493, 1460, 1384, 1244, 1099, 1034, 913, 838, 794 cm $^{-1}$. **^{1}H NMR** (400 MHz, $CDCl_3$, ppm): δ 7.92 (d, *J* = 5.6 Hz, 1H), 7.35 (d, *J* = 8.6 Hz, 2H), 7.17 (d, *J* = 8.6 Hz, 2H), 6.36 (d, *J* = 5.6 Hz, 1H), 5.10-5.04 (m, 1H), 3.51 (d, *J* = 18.8 Hz, 1H), 2.54 (d, *J* = 18.8 Hz, 1H), 1.25 (d, *J* = 6.3 Hz, 3H), 1.20 (d, *J* = 6.3 Hz, 3H). **^{13}C NMR** (100 MHz, $CDCl_3$, ppm): δ 206.8, 170.9, 162.7, 139.6, 134.3, 133.7, 129.2, 127.3, 70.1, 59.6, 46.6, 21.6, 21.4. **HRMS** (ESI): calcd for $C_{15}H_{15}ClO_3Na$ $[M+Na]^+$ 301.0602, found 301.0625.

*3-(R)-isopropyl-1-(3-bromophenyl)-4-oxocyclopent-2 ene-1-carboxylate (**3h**)*. Colorless oil, 31.3 mg, yield: 97%. R_f = 0.4 (petroleum ether/ethyl acetate 5:1), $[\alpha]_D^{25}$ = -21.8 (c = 0.65, $CHCl_3$), 88% *ee,* determined by HPLC analysis (chiralpak IC column, 5% IPA in hexane, rate: 1.0 mL/min, 254 nm). Retention time: t (minor) = 10.8 min, t (major) = 14.2 min. **IR** (KBr): ν_{max} 2922, 2072, 1720, 1635, 1466, 1384, 1244, 1099.74, 874, 669 cm $^{-1}$. **^{1}H NMR** (400 MHz, $CDCl_3$, ppm): δ 7.91 (d, *J* = 5.8 Hz, 1H), 7.46-7.44 (m, 1H), 7.37-7.36 (m, 1H), 7.28-7.26 (m, 1H), 7.16 (d, *J* = 7.9 Hz, 1H), 6.37 (d, *J* = 5.8 Hz, 1H), 5.12-5.06 (m, 1H), 3.50 (d, *J* = 18.8 Hz, 1H), 2.54 (d, *J* = 18.8Hz, 1H), 1.25 (d, *J* =6.2 Hz, 3H), 1.21 (d, *J* = 6.2 Hz, 3H). **^{13}C NMR** (100 MHz, $CDCl_3$, ppm): δ 206.7, 170.7, 162.4, 143.3, 134.5, 130.9, 130.5, 129.2, 124.6, 123.1, 70.2, 59.7, 46.6, 21.6, 21.4. **HRMS** (ESI): calcd for $C_{15}H_{15}BrO_3Na$ $[M+Na]^+$ 345.0097, found 345.0100.

*(R)-isopropyl-1-(4-bromophenyl)-4-oxocyclopent-2 ene-1-carboxylate (**3i**)*. Colorless oil, 27.5 mg, yield: 85%. R_f = 0.4 (petroleum ether/ethyl acetate 5:1), $[\alpha]_D^{25}$ = −7.1 (c = 0.67, $CHCl_3$), 82% *ee,* determined by HPLC analysis (chiralpak IC column, 10% IPA in hexane, rate: 1.0 mL/min, 254 nm). Retention time: t (minor) = 15.0 min, t (major) = 25.1 min. **IR** (KBr): ν_{max} 3083, 2928, 2070, 1720, 1636, 1488, 1383, 1259, 1101, 1031, 984, 915, 873, 796, 748, 712 cm^{-1}. **^{1}H NMR** (400 MHz, $CDCl_3$, ppm): δ 7.92 (d, *J* = 5.6 Hz, 1H), 7.50 (d, *J* = 8.5 Hz, 2H), 7.10 (d, *J* = 8.6 Hz, 2H), 6.36 (d, *J* = 5.6 Hz, 1H), 5.10-5.04 (m, 1H), 3.50 (d, *J* = 18.8 Hz, 1H), 2.53 (d, *J* = 18.8 Hz, 1H), 1.24 (d, *J* = 6.2 Hz, 3H), 1.20 (d, *J* = 6.2 Hz, 3H). **^{13}C NMR** (100 MHz, $CDCl_3$, ppm): δ 206.8, 170.8, 162.6, 140.1, 134.3, 132.1, 127.7, 121.8, 70.1, 59.6, 46.6, 21.6, 21.4. **HRMS**

(ESI): calcd for $C_{15}H_{15}BrO_3Na$ $[M+Na]^+$ 345.0097, found 345.0097.

*(R)-isopropyl-4-oxo-1(3(trifluoromethyl)phenyl) cyclopent-2-ene-1-carboxylate (**3j**)*. Colorless oil, 29.6 mg, yield: 95%. R_f = 0.5 (petroleum ether/ethyl acetate 5:1), $[\alpha]_D^{25}$ = –11.1 (c = 0.63, $CHCl_3$), 90% *ee,* determined by HPLC analysis (chiralpak IC column, 10% IPA in hexane, rate: 1.0 mL/min, 254 nm). Retention time: t (minor) = 12.8 min, t (major) = 19.0 min. **IR** (KBr): ν_{max} 3075, 2979, 2931, 1725, 1635, 1592, 1469, 1410, 1382, 1337, 1246, 1102, 1032, 997, 915, 876, 836, 793, 762, 695 cm^{-1}. **^{1}H NMR** (400 MHz, $CDCl_3$, ppm): δ 7.91 (d, *J* = 5.6 Hz, 1H), 7.46-7.44 (m, 1H), 7.37-7.36 (m, 1H), 7.28-7.23 (m, 1H), 7.16 (d, *J* = 7.8 Hz, 1H), 6.37 (d, *J* = 5.6 Hz, 1H), 5.12-5.05 (m, 1H), 3.50 (d, *J* = 18.9 Hz, 1H), 2.54 (d, *J* = 18.9 Hz, 1H), 1.25 (d, *J* =6.3 Hz, 3H), 1.21 (d, *J* = 6.3 Hz, 3H). **^{13}C NMR** (100 MHz, $CDCl_3$, ppm): δ 206.7, 170.7, 162.4, 143.2, 134.5, 130.9, 130.6, 129.1, 124.6, 123.1, 70.2, 59.7, 46.6, 21.6, 21.4. **HRMS** (ESI): calcd for $C_{16}H_{15}F_3O_3Na$ $[M+Na]^+$ 335.0866, found 335.0895.

*(R)-isopropyl-4-oxo-1-(4-(trifluoromethyl) phenyl) cyclopent-2-ene-1-carboxylate (**3k**)*. Colorless oil, 28.7 mg, yield: 92%. R_f = 0.5 (petroleum ether/ethyl acetate 5:1), $[\alpha]_D^{25}$ = –38.5 (c = 0.50, $CHCl_3$), 90% *ee,* determined by HPLC analysis (chiralpak IC column, 10% IPA in hexane, rate: 1.0 mL/min, 254 nm). Retention time: t (minor) = 10.8 min, t (major) = 16.4 min. **IR** (KBr): ν_{max} 3078, 2984, 2935, 1726, 1619, 1593, 1463, 1410, 1382, 1327, 1257, 1108, 1071, 1021, 986, 915, 874, 840, 799, 730, 675 cm^{-1}. **^{1}H NMR** (400 MHz, $CDCl_3$, ppm): δ 7.95 (d, *J* = 5.6 Hz, 1H), 7.64 (d, *J* = 8.3 Hz, 2H), 7.36 (d, *J* = 8.2 Hz, 2H), 6.40 (d, *J* = 5.6 Hz, 1H), 5.14-5.04 (m, 1H), 3.54 (d, *J* = 18.8 Hz, 1H), 2.54 (d, *J* = 18.8 Hz, 1H), 1.25 (d, *J* = 6.3 Hz, 3H), 1.20 (d, *J* = 6.3 Hz, 3H). **^{13}C NMR** (100 MHz, $CDCl_3$, ppm): δ 206.4, 170.9, 162.2, 145.0, 134.7, 130.0 (q, *J* = 32.9 Hz), 126.4, 126.0 (q, *J* = 3.6 Hz), 123.8 (q, *J* = 270.3 Hz), 70.3, 60.0, 46.5, 21.6, 21.4. **HRMS** (ESI): calcd for $C_{16}H_{15}F_3O_3Na$ $[M+Na]^+$ 335.0866, found 335.0863.

*(R)-isopropyl-4-oxo-1-(o-tolyl) cyclopent-2-ene-1 carboxylate (**3l**)*. Colorless oil, 10.6 mg, yield: 41%. R_f = 0.6 (petroleum ether/ethyl acetate 5:1), $[\alpha]_D^{25}$ = –87.3 (c = 0.25, $CHCl_3$), 78% *ee,* determined by HPLC analysis (chiralpak IC column, 10% IPA in hexane, rate: 1.0 mL/min, 254 nm). Retention time: t (minor) = 16.5 min, t (major) = 27.2 min. **IR** (KBr): ν_{max} 2964, 2924, 2854, 1725, 1641, 1456, 1409, 1382, 1261, 1010, 1022, 868, 800, 744, 701 cm^{-1}. **^{1}H NMR** (400 MHz, $CDCl_3$, ppm): δ 7.94 (d, *J* = 5.6 Hz, 1H), 7.25-7.16 (m, 3H), 7.07 (d, *J* = 7.5 Hz, 1H), 6.42 (d, *J* = 5.6 Hz, 1H), 5.09-5.03 (m, 1H), 3.75 (d, *J* = 18.4 Hz, 1H), 2.34 (d, *J* = 18.4 Hz, 1H), 2.25 (s, 3H), 1.23 (d, *J* =6.2 Hz, 3H), 1.16 (d, *J* = 6.2 Hz, 3H). **^{13}C NMR** (100 MHz, $CDCl_3$, ppm): δ. 207.4, 171.6, 163.6, 140.5, 135.6, 134.8, 131.8, 127.6, 126.5, 126.0, 69.9, 60.4, 45.7, 22.6, 21.5, 21.3. **HRMS** (ESI): calcd for $C_{16}H_{18}O_3Na$ $[M+Na]^+$ 281.1148, found 281.1140.

*(R)-isopropyl-4-oxo-1-(m-tolyl) cyclopent-2-ene-1 carboxylate (**3m**)*. Colorless oil, 24.3 mg, yield: 94%. R_f = 0.6 (petroleum ether/ethyl acetate 5:1), $[\alpha]_D^{25}$ = –33.0 (c = 0.43, $CHCl_3$), 91% *ee,* determined by HPLC analysis (chiralpak IC column, 10% IPA in hexane, rate: 1.0 mL/min, 254 nm). Retention time: t (minor) = 13.4 min, t (major) = 20.1 min. **IR** (KBr): ν_{max} 2963, 2927, 1725, 1635, 1458, 1410, 1383, 1259, 1185, 1101, 1033, 916, 881, 797, 700 cm^{-1}. **^{1}H NMR** (400 MHz, $CDCl_3$, ppm): δ 7.95 (d, *J* = 5.7 Hz, 1H), 7.28-7.26 (m, 1H), 7.12 (d, *J* = 7.5 Hz, 1H), 7.02-7.01 (m, 2H), 6.33 (d, *J* = 5.7 Hz, 1H), 5.12-5.06 (m, 1H), 3.49 (d, *J* = 18.9 Hz, 1H), 2.59 (d, *J* = 18.9 Hz, 1H), 2.36 (s, 3H), 1.25 (d, *J* = 6.3 Hz, 3H), 1.20 (d, *J* = 6.3 Hz, 3H). **^{13}C NMR** (100 MHz, $CDCl_3$, ppm): δ 207.6, 171.3, 163.7, 141.0, 138.8, 133.8, 129.8, 128.4, 126.5, 122.9, 69.8, 60.0, 46.8, 21.6, 21.5, 21.4. **HRMS** (ESI): calcd for $C_{16}H_{18}O_3Na$ $[M+Na]^+$ 281.1148, found 281.1169.

*(R)-isopropyl-4-oxo-1-(p-tolyl) cyclopent-2-ene-1 carboxylate (**3n**)*. Colorless oil, 23.5 mg, yield: 91%. R_f = 0.6 (petroleum ether/ethyl acetate 5:1), $[\alpha]_D^{25}$ = –8.5 (c = 0.22, $CHCl_3$), 90% *ee,* determined by HPLC analysis (chiralpak IC column, 10% IPA in hexane, rate: 1.0 mL/min, 254 nm). Retention time: t (minor) = 14.5 min, t (major) = 21.7 min. **IR** (KBr): ν_{max} 2963, 2923, 1725, 1635, 1512, 1458, 1409, 1382, 1260, 1101, 1026, 915, 871, 801 cm^{-1}. **^{1}H NMR** (400 MHz, $CDCl_3$, ppm): δ 7.95 (d, *J* = 5.6 Hz, 1H), 7.19-7.12 (m, 4H), 6.32 (d, *J* = 5.6 Hz, 1H), 5.11-5.05 (m, 1H), 3.48 (d, *J* = 18.9 Hz, 1H), 2.58 (d, *J* = 18.9 Hz, 1H), 2.35 (s, 3H), 1.25 (d, *J* = 6.3 Hz, 3H), 1.21 (d, *J* = 6.3 Hz, 3H). **^{13}C NMR** (100 MHz, $CDCl_3$, ppm): δ 207.6, 171.4, 163.7, 138.1, 137.5, 133.7, 129.7, 125.7, 69.7, 59.7, 46.8, 21.6, 21.4, 21.0. **HRMS** (ESI): calcd for $C_{32}H_{36}O_6Na$ $[2M+Na]^+$ 539.2404, found 539.2403.

*(R)-isopropyl-1-(4-(tert-butyl) phenyl)-4-oxocyclopent-2-ene-1-carboxylate (**3o**)*. Colorless oil, 25.5 mg, yield: 85%. R_f = 0.6 (petroleum ether/ethyl acetate 6:1), $[\alpha]_D^{25}$ = –8.4 (c = 0.43, $CHCl_3$), 91% *ee,* determined by HPLC analysis (chiralpak IC column, 10% IPA in hexane, rate: 1.0 mL/min, 254 nm). Retention time: t (minor) = 11.7 min, t (major) = 17.0 min. **IR** (KBr): ν_{max} 3081, 2963, 2870, 2069, 1726, 1593, 1510, 1463, 1407, 1383, 1261, 1186, 1103, 1027, 916, 872, 797, 697 cm^{-1}. **^{1}H NMR** (400 MHz, $CDCl_3$, ppm): δ 7.95 (d, *J* = 5.6 Hz, 1H), 7.38 (d, *J* = 8.6 Hz, 2H), 7.15 (d, *J* = 8.6 Hz, 2H), 6.32 (d, *J* = 5.6 Hz, 1H), 5.14-5.05 (m, 1H), 3.47 (d, *J* = 18.9 Hz, 1H), 2.62 (d, *J* = 18.9 Hz, 1H), 1.32 (s, 9H), 1.26 (d, *J* = 6.3 Hz, 3H), 1.23 (d, *J* = 6.3 Hz, 3H). **^{13}C NMR** (100 MHz, $CDCl_3$, ppm): δ 207.7, 171.4, 163.9, 150.6, 137.9, 133.5, 125.9, 125.5, 69.8, 59.7, 46.8, 34.5, 31.3, 21.6, 21.5. **HRMS** (ESI): calcd for $C_{19}H_{24}O_3Na$ $[M+Na]^+$ 323.1618, found 323.1622.

*(R)-isoproyl-1-(2-methoxyphenyl)-4-oxocyclopent-2 ene-1-carboxylate (**3p**)*. Colorless oil, 26.0 mg, yield: 95%. R_f = 0.5 (petroleum ether/ethyl acetate 5:1), $[\alpha]_D^{25}$ = –62.7 (c = 0.20, $CHCl_3$), 80% *ee,* determined by HPLC analysis (chiralpak IC column, 10% IPA in hexane, rate: 1.0 mL/min, 254 nm). Retention time: t (minor) = 34.5 min, t (major) = 36.5 min. **IR** (KBr): ν_{max} 2923, 2854, 1725, 1634, 1500, 1460, 1383, 1240, 1104, 1031, 804, 674 cm^{-1}. **^{1}H NMR** (400 MHz, $CDCl_3$, ppm): δ 7.83 (d, *J* = 5.6 Hz, 1H), 7.31-7.29 (m, 1H), 7.06-7.03 (m, 1H), 6.96-6.38 (m, 2H), 6.38 (d, *J* = 5.6 Hz, 1H), 5.06-5.00 (m, 1H), 3.81 (s, 3H), 3.64 (d, *J* = 18.9 Hz, 1H), 2.33 (d, *J* = 18.9 Hz, 1H), 1.20 (d, *J* =6.3 Hz, 3H), 1.14 (d, *J* = 6.3 Hz, 3H). **^{13}C NMR** (100 MHz, $CDCl_3$, ppm): δ 208.3, 171.7, 162.8, 156.3, 135.1, 130.8, 128.9, 126.5, 120.5, 110.6, 69.2,

58.0, 55.1, 46.0, 21.6, 21.3. **HRMS** (ESI): calcd for $C_{16}H_{18}O_4Na$ $[M+Na]^+$ 297.1097, found 297.1092.

Recrystallization of **3p** (ee 80%) in *n*-hexane and ethyl acetate. Compound **3p** (13 mg) was dissolved in *n*-hexane and ethyl acetate (2 mL), and slowly heat with a hair dryer until it is completely dissolved. After this solution cools naturally, crystals will precipitate. This crystal was washed with hexane (3 × 4 mL) and to afford **3p** as a colorless crystal. Chiral HPLC: ee 94.7%.

To a solution of **3p** (7 mg, 0.026 mmol, ee 94.7%) in CH_2Cl_2 (1 mL) was added dropwise a solution of BBr_3 (1 M in CH_2Cl_2, 0.2 mL, 0.2 mmol) at -40 °C and the reaction mixture was stirred for 3 h at room temperature. It was then quenched with saturated aqueous $NaHCO_3$ solution and extracted with CH_2Cl_2 (3 × 2 mL). The combined organic layer was washed with brine and dried (Na_2SO_4). Evaporation of the solvent and purification of the residue over a silica-gel column using ethyl petroleum ether/ethyl acetate (9:1) as eluent furnished the lactone **3p'** (3.6 mg, 70%) as an oil.

*(R)-2H-spiro[benzofuran-3-1'-cyclopentan]-2'-ene-2,4'-dione (**3p'**).* Colorless oil, 3.6 mg, yield: 70%. R_f = 0.4 (petroleum ether/ethyl acetate 5:1), $[\alpha]_D^{25}$ = –76.2 (c = 0.10, $CHCl_3$), 94.5% *ee,* determined by HPLC analysis (chiralpak IC column, 30% IPA in hexane, rate: 1.0 mL/min, 254 nm). Retention time: t (minor) = 19.9 min, t (major) = 15.9 min. **IR** (KBr): ν_{max} 2924, 2855, 1734, 1635, 1455, 1383, 1247, 1158, 1113, 1070, 878, 847, 751 cm^{-1}. **^{1}H NMR** (400 MHz, $CDCl_3$, ppm): δ 7.44-7.40 (m, 1H), 7.36 (d, *J*= 5.5 Hz, 1H), 7.25-7.21 (m, 2H), 7.15-7.12 (m, 1H), 6.53 (d, *J* = 5.5 Hz, 1H), 3.05 (d, *J* = 18.5 Hz, 1H), 2.67 (d, *J* = 18.5 Hz, 1H). **^{13}C NMR** (100 MHz, $CDCl_3$, ppm): δ 205.5, 175.8, 159.5, 153.0, 135.7, 130.3, 127.9, 125.2, 123.5, 111.4, 54.7, 45.6. **HRMS** (ESI): calcd for $C_{12}H_8O_3Na$ $[M+Na]^+$ 223.0366, found 223.0396.

*(R)-isopropyl-1-(3-methoxyphenyl)-4-oxocyclopent-2-ene-1-carboxylate (**3q**).* Colorless oil, 24.9 mg, yield: 91%. R_f = 0.5 (petroleum ether/ethyl acetate 5:1), $[\alpha]_D^{25}$ = –23.4 (c = 0.40, $CHCl_3$), 92% *ee,* determined by HPLC analysis (chiralpak IC column, 10% IPA in hexane, rate: 1.0 mL/min, 254 nm). Retention time: t (minor) = 13.5 min, t (major) = 19.9 min. **IR** (KBr): ν_{max} 2963, 2923, 1724, 1635, 1411, 1384, 1261, 1097, 1023, 799, 674 cm^{-1}. **^{1}H NMR** (400 MHz, $CDCl_3$, ppm): δ 7.94 (d, *J* = 5.6 Hz, 1H), 7.31-7.27 (m, 1H), 6.86-6.79 (m, 2H), 6.76-7.75 (m, 1H), 6.34 (d, *J* = 5.6 Hz, 1H), 5.12-5.06 (m, 1H), 3.81 (s, 3H), 3.50 (d, *J* = 18.9 Hz, 1H), 2.58 (d, *J* = 18.9 Hz, 1H), 1.25 (d, *J* =6.3 Hz, 3H), 1.21 (d, *J* = 6.3 Hz, 3H). **^{13}C NMR** (100 MHz, $CDCl_3$, ppm): δ 207.3, 171.2, 163.3, 160.0, 142.6, 134.0, 130.0, 118.1, 112.7, 112.1, 69.9, 60.0, 55.3, 46.7, 21.6, 21.4. **HRMS** (ESI): calcd for $C_{16}H_{18}O_4Na$ $[M+Na]^+$ 297.1097, found 297.1116.

*(R)-isopropyl-1-(4-methoxyphenyl)-4 oxocyclopent-2-ene-1-carboxylate (**3r**).* Colorless oil, 24.9 mg, yield: 91%. R_f = 0.5 (petroleum ether/ethyl acetate 5:1), $[\alpha]_D^{25}$ = –8.9 (c = 0.31, $CHCl_3$), 81% *ee,* determined by HPLC analysis (chiralpak IC column, 10% IPA in hexane, rate: 1.0 mL/min, 254 nm). Retention time: t (minor) = 21.4 min, t (major) = 32.1 min. **IR** (KBr): ν_{max} 2922, 1724, 1635, 1462, 1384, 1259, 1096, 1022, 799, 673 cm^{-1}. **^{1}H NMR** (400 MHz, $CDCl_3$, ppm): δ 7.95 (d, *J* = 5.7 Hz, 1H), 7.15 (d, *J* = 8.8 Hz, 2H), 6.89 (d, *J* = 8.8 Hz, 2H), 6.31 (d, *J* = 5.7 Hz, 1H), 5.10-5.04 (m, 1H), 3.82 (s, 3H), 3.48 (d, *J* = 18.9 Hz, 1H), 2.58 (d, *J* = 18.9 Hz, 1H), 1.24 (d, *J* = 6.3Hz, 3H), 1.20 (d, *J* = 6.3 Hz, 3H). **^{13}C NMR** (100 MHz, $CDCl_3$, ppm): δ 207.6, 171.5, 163.7, 158.9, 133.6, 133.1, 127.1, 114.3, 69.7, 59.3, 55.3, 46.8, 21.6, 21.4. **HRMS** (ESI): calcd for $C_{16}H_{18}O_4Na$ $[M+Na]^+$ 297.1097, found 297.1116.

*(R)-isopropyl-1-(naphthalene-1-yl)-4-oxocyclopent-2-ene-1-carboxylate (**3s**).* Colorless oil, 20.9 mg, yield: 71%. R_f = 0.5 (petroleum ether/ethyl acetate 5:1), $[\alpha]_D^{25}$ = -79.4 (c = 0.25, $CHCl_3$), 73% *ee,* determined by HPLC analysis (chiralpak IC column, 10% IPA in hexane, rate: 1.0 mL/min, 254 nm). Retention time: t (minor) = 17.1 min, t (major) = 29.2 min. **IR** (KBr): ν_{max} 3054, 2925, 2855, 1724, 1635, 1511, 1461, 1383, 1334, 1240, 1188, 1141, 1103, 1024, 951, 914, 872, 800, 777, 674. **^{1}H NMR** (400 MHz, $CDCl_3$, ppm): δ 8.08 (d, *J* = 5.6 Hz, 1H), 7.92-7.82 (m, 3H), 7.54-7.52 (m, 2H), 7.45-7.42 (m, 1H), 7.27 (d, *J* = 7.2 Hz, 1H), 6.50 (d, *J* = 5.6 Hz, 1H), 5.05-5.00 (m, 1H), 4.00 (d, *J* = 18.6 Hz, 1H), 2.55 (d, *J* = 18.6 Hz, 1H), 1.17 (d, *J* = 6.3 Hz, 3H), 0.88 (d, *J* = 6.3 Hz, 3H). **^{13}C NMR** (100 MHz, $CDCl_3$, ppm): δ 207.3, 172.2, 163.3, 138.4, 135.0, 134.3, 130.7, 129.3, 128.7, 126.6, 125.9, 125.0, 124.4, 123.7, 70.1, 60.4, 46.3, 21.5, 21.1. **HRMS** (ESI): calcd for $C_{19}H_{18}O_3Na$ $[M+Na]^+$ 317.1148, found 317.1166.

*(R)-isopropyl-1-(naphthalene-2-yl)-4-oxocyclopent-2-ene-1-carboxylate (**3t**).* Colorless oil, 27.3 mg, yield: 93%. R_f = 0.5 (petroleum ether/ethyl acetate 5:1), $[\alpha]_D^{25}$ = 27.9 (c = 0.47, $CHCl_3$), 91% *ee,* determined by HPLC analysis (chiralpak IC column, 10% IPA in hexane, rate: 1.0 mL/min, 254 nm). Retention time: t (minor) = 18.6 min, t (major) = 28.2 min. **IR** (KBr): ν_{max} 3058, 2925, 1724, 1634, 1504, 1461, 1383, 1100, 1036, 915, 789, 749, 676 cm^{-1}. **^{1}H NMR** (400 MHz, $CDCl_3$, ppm): δ 8.08 (d, *J* = 5.6 Hz, 1H), 7.88-7.81 (m, 3H), 7.65 (d, *J* = 1.5 Hz, 1H), 7.54-7.51 (m, 2H), 7.37-7.35 (m, 1H), 6.42 (d, *J* = 5.6 Hz, 1H), 5.17-5.08 (m, 1H), 3.60 (d, *J* = 18.8 Hz, 1H), 2.67 (d, *J* = 18.8 Hz, 1H), 1.26 (d, *J* = 6.3 Hz, 3H), 1.20 (d, *J* = 6.3 Hz, 3H). **^{13}C NMR** (100 MHz, $CDCl_3$, ppm): δ 207.3, 171.3, 163.3, 138.4, 134.2, 133.2, 132.5, 129.0, 128.0, 127.6, 126.7, 126.5, 124.7, 123.9, 70.0, 60.2, 46.7, 21.6, 21.4. **HRMS** (ESI): calcd for $C_{19}H_{18}O_3Na$ $[M+Na]^+$ 317.1148, found 317.1147.

*(R)-isopropyl-1-([1,1'-biphenyl]-4-yl)-4-oxocyclopent-2-ene-1-carboxylate (**3u**).* Colorless oil, 31.1 mg, yield: 97%. R_f = 0.5 (petroleum ether/ethyl acetate 5:1), $[\alpha]_D^{25}$ = 34.1 (c = 0.43, $CHCl_3$), 90% *ee,* determined by HPLC analysis (chiralpak IC column, 10% IPA in hexane, rate: 1.0 mL/min, 254 nm). Retention time: t (minor) = 18.4 min, t (major) = 28.0 min. **IR** (KBr): ν_{max} 3031, 2980, 2953, 1719, 1486, 1459, 1382, 1337, 1242, 1187, 1147, 1102, 1033, 915, 874, 837, 796, 760, 697, 624 cm^{-1}. **^{1}H NMR** (400 MHz, $CDCl_3$, ppm): δ 8.00 (d, *J* = 5.6 Hz, 1H), 7.61-7.59 (m, 4H), 7.49-7.45 (m, 2H), 7.40-7.36 (m, 1H), 7.31 (d, *J* = 8.4 Hz, 2H), 6.37 (d, *J* = 5.6 Hz, 1H),

5.16-5.07 (m, 1H), 3.54 (d, *J* = 18.9 Hz, 1H), 2.65 (d, *J* = 18.9 Hz, 1H), 1.28 (d, *J* = 6.3 Hz, 3H), 1.24 (d, *J* = 6.3 Hz, 3H). **^{13}C NMR** (100 MHz, $CDCl_3$, ppm): δ 207.3, 171.3, 163.4, 140.6, 140.2, 140.0, 133.9, 128.9, 127.7, 127.6, 127.1, 126.3, 69.9, 59.8, 46.8, 21.6, 21.5. **HRMS** (ESI): calcd for $C_{21}H_{20}O_3Na$ $[M+Na]^+$ 343.1305, found 343.1323.

Isopropyl-2-(2-methoxy-5-methylphenyl)acetate (***4***)[19a]. Conc. H_2SO_4 (0.4 mL) was added dropwise to a stirring solution of **4'** (0.60 g, 3.3 mmol) in ^{i}PrOH (5 mL) before allowing the solution to reflux for 8 hours. The solution was cooled to room temperature, extracted with diethyl ether (3 x 5 ml) and the combined organic fractions were then washed with H_2O (5 ml), saturated $NaHCO_3$ (5 ml) and brine (5 ml). The organic layer was dried with Na_2SO_4, filtered and concentrated in vacuo to afford the **4**, which was used in future steps without further purification. Yellow liquid, yield: 89%. R_f = 0.7 (petroleum ether/ethyl acetate 5:1). **IR** (KBr): ν_{max} 2978, 2928, 1734, 1638, 1505, 1461, 1381, 1620, 1255, 1171, 1107, 1034, 968, 807 cm^{-1}. **^{1}H NMR** (400 MHz, CDCl3, ppm): δ 7.06 (d, *J* = 8.3 Hz, 1H), 7.02 (s, 1H), 6.79 (d, *J* = 8.3 Hz, 1H), 5.11-5.02 (m, 1H), 3.81 (s, 3H), 3.58 (s, 2H), 2.30 (s, 3H), 1.26 (d, *J* = 6.2, 6H). **^{13}C NMR** (151 MHz, DMSO, ppm): δ 170.6, 155.2, 131.4, 128.7, 128.4, 122.9, 110.6, 67.1, 55.3, 35.7, 21.5, 19.9. **HRMS** (ESI): calcd for $C_{13}H_{18}O_3Na$ $[M+Na]^+$ 245.1148, found 245.1153.

Isopropyl-2-diazo-2-(2-methoxy-5-methylphenyl)acetate (***5***)[17]. To a solution of **4** (10 mmol, 1.0 equiv) and *p*-ABSA (15 mmol, 1.5 equiv) in dry CH_3CN (50 mL) was added DBU (15 mmol, 1.5 equiv) dropwise at 0 °C. Then the mixture was stirred 18h at room temperature. The reaction was then quenched with aqueous ammonium chloride solution, followed by extraction with CH_2Cl_2 (2 × 20 mL). The combined organic extracts were dried with anhydrous Na_2SO_4, filtered and concentrated under reduced pressure. The yellow crude product was purified by column chromatography (silica gel, petroleum ether/ethyl acetate = 50:1) to give the **5**. Yellow liquid, yield: 83%. R_f = 0.7 (petroleum ether/ethyl acetate 6:1). **IR** (KBr): ν_{max} 2979, 2929, 2096, 1816, 1696, 1503, 1462, 1381, 1292, 1253, 1179, 1147, 1107, 1135, 917, 805, 744, 670 cm^{-1}. **^{1}H NMR** (600 MHz, CDCl3, ppm): δ 7.40 (d, J = 1.8 Hz, 1H), 7.06-7.05 (m, 1H), 6.80 (d, J = 8.4 Hz, 1H), 5.22-5.16 (m, 1H), 3.84 (s, 3H), 2.32 (s, 3H), 1.33 (d, J = 6.2, 6H). **^{13}C NMR** (151 MHz, CDCl3, ppm): δ 165.8, 153.4, 130.5, 130.4, 128.8, 113.7, 110.9, 68.4, 55.6, 22.1, 20.5. **HRMS** (ESI): calcd for $C_{13}H_{16}N_2O_3Na$ $[M+Na]^+$ 271.1053, found 271.1051.

(R)-isobutyryl-1-(2-methoxy-5-methylpheny)-4-oxocyclopent-2-ene-1-carboxylate (***6***). Colorless oil, yield: 95%. R_f = 0.50 (petroleum ether/ethyl acetate 5:1), $[\alpha]_D^{25}$ = -23.6 (c = 0.25, $CHCl_3$), 81% *ee,* determined by HPLC analysis (Cellulose-2 column, 10% IPA in hexane, rate: 1.0 mL/min, 254 nm). Retention time: t (minor) = 20.3 min, t (major) = 14.6 min. **IR** (KBr): ν_{max} 2955, 2924, 2855, 1729, 1634, 1499, 1460, 1381, 1239, 1107, 1032, 806 cm^{-1}. **^{1}H NMR** (400 MHz, $CDCl_3$, ppm): δ 7.82 (d, *J* = 5.6 Hz, 1H), 7.10-7.08 (m, 1H), 6.83-6.78 (m, 2H), 6.37 (d, *J* = 5.6 Hz, 1H), 5.07-5.00 (m, 1H), 3.78 (s, 3H), 3.61 (d, *J* = 18.9 Hz, 1H), 2.33 (d, *J* = 18.9 Hz, 1H), 2.30 (s, 3H), 1.21 (d, *J* = 6.2 Hz, 3H), 1.15 (d, *J* = 6.2 Hz, 3H). **^{13}C NMR** (100 MHz, $CDCl_3$, ppm): δ 208.3, 171.8, 162.9, 154.3, 134.9, 130.5, 129.7, 129.0, 127.3, 110.6, 69.1, 58.0, 55.2, 46.0, 21.6, 21.3, 20.6. **HRMS** (ESI): calcd for $C_{17}H_{20}O_4Na$ $[M+Na]^+$ 311.1254, found 311.1254.

(R)-isobutyryl-1-(2-methoxy-5-methylpheny)-5,5-diamethyl-4-oxocyclopent-2-ene-1-carboxylate (***6'***)[19b]. A solution of **6** (23.5 mg, 0.082 mmol) in DME (1 mL) was added to a magnetically stirred suspension of NaH (20 mg, 60% dispersion in oil, 0.50 mmol) in DME (1 mL) and stirred for 20 min at room temperature. MeI (0.03 mL, 0.50 mmol) was added to the reaction mixture, which was stirred at room temperature. for 12 h. It was then quenched with water (2 mL) and extracted with diethyl ether (2 x 2 mL). The combined diethyl ether extract was washed with brine and dried (Na_2SO_4). Evaporation of the solvent and purification of the residue over a silica-gel column using petroleum petroleum ether/ethyl acetate = 7:1 as eluents to give the **6'**. Colorless oil, yield: 70%. R_f = 0.5 (petroleum ether/ethyl acetate 5:1), $[\alpha]_D^{20}$ = –2.0 (c = 0.26, $CHCl_3$), 80% ee, determined by HPLC analysis (Cellulose-2 column, 5% IPA in hexane, rate: 1.0 mL/min, 254 nm). Retention time: t (minor) = 13.2 min, t (major) = 16.0 min. **IR** (KBr): ν_{max} 2978, 2934, 1727, 1635, 1502, 1461, 1381, 1244, 1217, 1141, 1106, 1033, 841, 810, 767, 727, 692 cm^{-1}. **^{1}H NMR** (400 MHz, $CDCl_3$, ppm): δ 7.61 (d, *J* = 5.9 Hz, 1H), 7.10-7.07 (m, 1H), 6.79 (d, *J* = 8.0 Hz, 2H), 6.33 (d, *J* = 5.9 Hz, 1H), 5.05-5.00 (m, 1H), 3.73 (s, 3H), 2.30 (s, 3H), 1.49 (s, 3H), 1.18 (d, *J* = 6.3 Hz, 3H), 1.15 (d, *J* = 6.3 Hz, 3H), 0.70 (s, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$, ppm): δ 212.6, 170.9, 159.4, 155.0, 131.8, 130.1, 129.4, 129.0, 126.7, 110.7, 68.8, 66.9, 54.8, 52.8, 26.4, 21.6, 21.4, 21.2, 20.6. **HRMS** (ESI): calcd for $C_{19}H_{24}O_4Na$ $[M+Na]^+$ 339.1567, found 339.1570.

(R)-isobutyryl-1-(2-methoxy-5-methylpheny)-2,2 diamethyl-3-oxocyclopent-1-carboxylate. A solution of enone **6'** (19.8 mg, 0.063 mmol) in ethanol (2 mL) was added to 5% Pd-C (5 mg). The reaction mixture was stirred for 3 h at 50 °C, in an atmosphere of hydrogen, then the catalyst was filtered off. The residue obtained after evaporation of the solution was chromatographed over silica gel column to give the title cyclopentanone. Colorless oil, yield: 87%. R_f = 0.5 (petroleum ether/ethyl acetate 5:1), $[\alpha]_D^{25}$ = –0.6 (c = 0.23, $CHCl_3$). **IR** (KBr): ν_{max} 2975, 2930, 1744, 1719, 1499, 1464, 1380, 1253, 1188, 1108, 1033, 987, 952, 921, 865, 808, 729, 702, 662 cm^{-1}. **^{1}H NMR** (400 MHz, $CDCl_3$, ppm): δ 7.07 (d, *J* = 8.2 Hz, 1H), 6.99 (s, 1H), 6.78 (d, *J* = 8.2 Hz, 1H), 5.10-5.01 (m, 1H), 3.70 (s, 3H), 2.63-2.55 (m, 1H), 2.45-2.35 (m, 3H), 2.32 (s, 3H), 1.22 (s, 3H), 1.19-1.15 (m, 6H), 0.83 (s, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$, ppm): δ 219.0, 174.0, 155.0, 129.0, 128.5, 127.4, 110.7, 67.8, 59.1, 54.4, 52.6, 32.9, 29.7, 27.6, 21.6, 21.5, 21.0, 20.8. **HRMS** (ESI): calcd for $C_{19}H_{26}O_4Na$ $[M+Na]^+$ 341.1723, found 341.1723.

(R)-2',2',5-trimethyl-2H-spiro[benzofuran-3,1' cyclopentane]-2,3'-dione[19b]. A solution of BBr_3 (1 M in CH_2Cl_2, 1.52 mL, 1.52 mmol) was added dropwise to a solution of the above cyclopentanone (17.3 mg, 0.054 mmol) in CH_2Cl_2

(1.5 mL) at -40 °C and the reaction mixture was stirred for 6 h at room temperature. It was then quenched with saturated aqueous $NaHCO_3$ solution and extracted with CH_2Cl_2 (3 x 6 mL). The combined organic layer was washed with brine and dried (Na_2SO_4). Evaporation of the solvent and purification of the residue over a silica-gel column using petroleum petroleum ether/ethyl acetate = 7:1 as eluents to give the title benzofuranone. Colorless oil, yield: 90%. R_f = 0.5 (petroleum ether/ethyl acetate 5:1), $[\alpha]_D^{25}$ = −0.8 (c = 0.20, $CHCl_3$). **IR** (KBr): ν_{max} 2966, 2925, 2855, 1792, 1743, 1487, 1466, 1383, 1263, 1237, 1195, 1138, 1078, 1038, 975, 886, 866, 815, 747, 68cm^{-1}. **^{1}H NMR** (400 MHz, $CDCl_3$, ppm): δ 7.17 (d, *J* = 8.4 Hz, 1H), 7.05 (d, *J* = 8.1 Hz, 2H), 2.96-2.86 (m, 1H), 2.67-2.60 (m, 1H), 2.45-2.32 (m, 5H), 1.15 (s, 3H), 1.00 (s, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$, ppm): δ 217.4, 178.9, 151.5, 133.8, 129.9, 127.1, 125.3, 110.5, 57.2, 52.6, 33.2, 28.6, 21.2, 20.9, 18.4. **HRMS** (ESI): calcd for $C_{15}H_{16}O_3Na$ $[M+Na]^+$ 267.0992, found 267.0993.

(R)-2′,2′,5-trimethyl-2H-dispiro[benzofuran-3,1′-cyclopentane-3′,2″-[1,3]dithiolan]-2-one[19b]. A solution of the above benzofuranone (36 mg, 0.15 mmol), ethanedithiol (0.038 mL, 0.45 mmol) and $BF_3 \cdot Et_2O$ (10 drop) in dry benzene (1 mL) was magnetically stirred at 10 °C to room temperature for 12 h. The reaction was then quenched with aqueous $NaHCO_3$ solution and extracted with diethyl ether. The diethyl ether extract was washed with 5% aqueous NaOH solution and brine and dried (Na_2SO_4). Evaporation of the solvent and purification of the residue over a silica-gel column using petroleum ether:EtOAc= 25:1 as eluents to give the title protected cyclopentanone. Colorless oil, yield: 85%. R_f = 0.8 (petroleum ether/ethyl acetate 5:1), $[\alpha]_D^{25}$ = −0.2 (c = 0.24, $CHCl_3$). **IR** (KBr): ν_{max} 2962, 2924, 2862, 1798, 1734, 1484, 1386, 1261, 1233, 1094, 1038, 964, 939, 892, 810, 742, 696 cm^{-1}. **^{1}H NMR** (400 MHz, $CDCl_3$, ppm): δ 7.33 (s, 1H), 7.08 (d, *J* = 8.1 Hz, 1H), 6.95 (d, *J* = 8.2 Hz, 1H), 3.35-3.22 (m, 4H), 2.79-2.71 (m, 1H), 2.55-2.41 (m,2H), 2.38 (s, 3H), 2.17-2.09 (m, 1H), 1.33 (s, 3H), 1.01 (s, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$, ppm): δ 180.0, 150.9, 133.0, 131.0, 129.0, 126.9, 109.8, 81.9, 58.6, 52.6, 44.8, 38.9, 38.8, 36.4, 26.6, 25.9, 21.3. **HRMS** (ESI): calcd for $C_{17}H_{20}S_2O_2Na$ $[M+Na]^+$ 343.0797, found 343.0790.

(R)-2′,2′,5-trimethyl-2H-spiro[benzofuran-3,1′-cyclopentane]-2,3′-dione[19b]. An excess of Raney nickel was added to a magnetically stirred solution of the above protected cyclopentanone (34.1 mg, 0.106 mmol) in dry ethanol (4 mL) and refluxed for 5 h, in an atmosphere of hydrogen. The reaction mixture was cooled and filtered through a short silica-gel column to remove the catalyst. Evaporation of the solvent and purification of the residue over a silica-gel column using petroleum ether/ethyl acetate = 50:1 as eluent furnished the title cyclopentane. Colorless oil, yield: 85%. R_f = 0.6 (petroleum ether/ethyl acetate 10:1), $[\alpha]_D^{25}$ = −0.4 (c = 0.18, $CHCl_3$). **IR** (KBr): ν_{max} 2963, 2926, 2868, 1793, 1621, 1482, 1385, 1263, 1044, 971, 885, 810, 692 cm^{-1}. **^{1}H NMR** (600 MHz, $CDCl_3$, ppm): δ 7.09-7.08 (m, 1H), 7.02-7.02 (m, 1H), 6.98 (d, *J* = 8.2 Hz, 1H), 2.37 (s, 3H), 2.29-2.23 (m, 2H), 2.19-2.14 (m, 1H), 2.13-2.06(m, 1H), 2.03-1.96(m, 1H), 1.76-1.72(m, 1H), 1.03(s, 3H), 0.94 (s, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$, ppm): δ 180.2, 151.4, 132.9, 129.2, 125.6, 109.9, 60.2, 47.6, 38.7, 34.6, 25.2, 23.5, 23.5, 21.2, 20.9. **HRMS** (ESI): calcd for $C_{15}H_{18}O_2Na$ $[M+Na]^+$ 253.1199, found 253.1198.

(R)-(-)-1,13-Herbertenediol (7)[5]. To a solution of above cyclopentane (16 mg, 0.068 mmol) in THF (3 mL) was added $LiAlH_4$ (0.3 mL, 1.0 M). The reaction mixture was stirred at room temperature for 2 h. The reaction was terminated by adding ethyl acetate and the solution was acidified with 2 M HCl, and then extracted with ether. The organic layer was washed with water and saturated NaCl solution, dried over Na_2SO_4. Evaporation of the solvent and purification of the residue over a silica-gel column using petroleum ether/ethyl acetate = 5:1 as eluents to give 7. Colorless oil, yield: 91%. R_f = 0.3 (petroleum ether/ethyl acetate 5:1), $[\alpha]_D^{20}$ = -20.1 (c = 0.18, $CHCl_3$), 80% *ee*, determined by HPLC analysis (Cellulose-2 column, 5% CH_2Cl_2 in hexane, rate: 1.0 mL/min, 281 nm). Retention time: t (minor) = 15.4 min, t (major) = 12.5 min. **IR** (KBr): ν_{max} 3426, 2960, 2925, 2857, 1460, 1410, 1383, 1261, 1097, 1021, 867, 801, 698 cm^{-1}. **^{1}H NMR** (400 MHz, $CDCl_3$, ppm): δ 7.03 (s, 1H), 6.93 (d, *J* = 8.0 Hz, 1H), 6.70 (d, *J* = 8.0 Hz, 1H), 4.42 (d, *J* = 10.6 Hz, 1H), 3.77 (d, *J* = 10.6 Hz, 1H), 2.44-2.35 (m, 1H), 2.29 (s, 3H), 2.07-2.01 (m, 1H), 1.88-1.80 (m, 2H), 1.65-1.58 (m, 1H), 1.54-1.48 (m, 1H), 1.28 (s, 1H), 1.23 (s, 3H), 0.87 (s, 3H). **^{13}C NMR** (100 MHz, $CDCl_3$, ppm): δ 152.8, 130.7, 129.1, 128.3, 127.9, 117.0, 68.6, 56.4, 45.2, 41.3, 35.8, 26.2, 24.4, 20.9, 20.7. HRMS (ESI): calcd for $C_{15}H_{22}O_2Na$ $[M+Na]^+$ 257.1512, found 257.1511.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at http://pubs.acs.org.
Copies of ^{1}H and ^{13}C NMR spectra for all compounds, HPLC spectral for chiral compounds.

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Notes

The authors declare no competing financial interests.

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