JOC The Journal of Organic Chemistry

Article

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Amide-Phosphonium Salt as Bifunctional Phase Transfer Catalyst for Asymmetric 1,6-Addition of Malonate Esters to *para*-Quinone Methides

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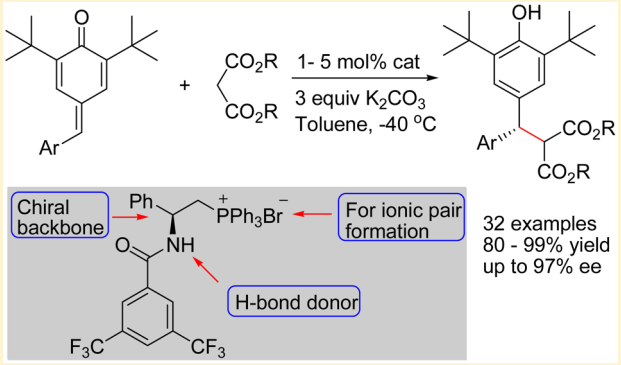
Supporting Information

ABSTRACT: Asymmetric 1,6-addition of malonates to *para*-quinone methides has been developed by using amide-phosphonium salts derived from easily available chiral α-amino acids as bifunctional phase transfer catalysts. Stabilized *para*-quinone methides with various substituents on the phenyl ring were reacted with diphenyl malonates to give functionalized diaryl methines in excellent yields and high to excellent ee's. Furthermore, to show the utility of this methodology, a gram scale synthesis of an 1,6-addition adduct and its further elaboration into the key intermediate for synthesis of GPR40 agonists were also described.



INTRODUCTION

para-Quino methides (*p*-QMs), structurally featuring a cyclohexadiene with the carbonyl group in *para*-conjugation with an *exo* methylene group, exist in a variety of natural products and pharmaceuticals,[1] and have been known as reactive intermediates in many chemical, medicinal, and biological processes.[2] When suitable substituents, typically electron-donating groups, are introduced onto the cyclohexadiene core, typically at α-positions, this type of compounds become stable enough for isolation, and can be handled in further operations, e.g., as a reaction component in organic synthesis.[3−8]

Since 2002, Mayr et al. have published a series of reports, wherein these readily available *p*-QMs were employed as reference electrophiles for establishing the reactivity scale of a variety of nucleophiles including electron rich π-nucleophiles and carbanions generated from active methylene and methine compounds.[4] Despite successful application of *p*-QMs to physical organic chemistry in Mayr's works, the involvement of *p*-QMs in organic synthesis, particularly in asymmetric synthesis, has never been reported until recently. In 2013, Fan et al. reported pioneering studies about asymmetric catalytic 1,6-conjugate addition of diphenyl malonate to *p*-QMs with binaphthyl-modified ammonium bromide as phase transfer catalyst.[5] Soon afterward, Jørgenson and co-workers described chiral secondary amine catalyzed asymmetric 1,6-conjuagate addition of *p*-QMs with aldehyde through enamine catalysis.[6] Following these two pioneering works, several other research groups reported asymmetric 1,6-addition of various nucleophiles to *p*-QMs via the activation modes of either organocatalysis or metal-based catalysis, enantioselectively leading to diaryl methine derivatives.[7] Notably, the diaryl methine motif is found in quite a number of notable pharmaceuticals (e.g., Sertraline[9] and Tolerodine[10]) and natural products (e.g., Podophyllotoxin[11]).

Very recently, in searching for new catalytic system for asymmetric addition of nucleophiles to *p*-QMs, Enders et al.,[7b] Yao et al.,[7c] and Fan et al.[7d] independently reported a dual activation strategy for this type of reaction by using bifunctional organocatalysts (Scheme 1). As claimed by the authors, the nucleophiles were activated by tertiary amine or phosphine moiety of the catalysts, while *p*-QMs were activated by hydrogen bonding between carbonyl groups of *p*-QMs and squaramide or thiourea moiety of the catalysts.

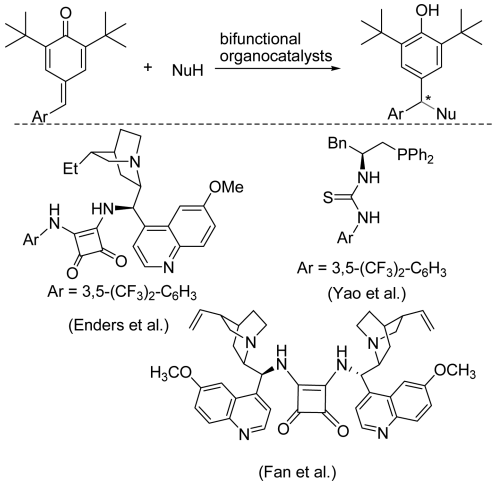
In light of the success of bifunctional catalysts in the chemistry of *p*-QMs,[7b−d] and inspired by Fan and co-workers' pioneering work of asymmetric 1,6-addition of *p*-QMs through phase transfer catalysis,[5,7f] we envisaged that the merging of the dual activation concept with phase transfer catalysis would lead to the development of a new catalytic system for 1,6-addition of *p*-QMs. To our knowledge, this type of bifunctional phase transfer catalysts have not yet been employed in 1,6-addition of *p*-QMs.[12,13]

We have recently developed amide-phosphonium salt based bifunctional phase transfer catalysts from easily available chiral

Received: August 6, 2016
Published: September 15, 2016

DOI: 10.1021/acs.joc.6b01906
J. Org. Chem. 2016, 81, 9315−9325

Scheme 1. Bifunctional Organocatalysts Promoted 1,6-Addition of *para*-Quinone Methides



amino acids, for asymmetric 1,4-addition of 3-monosubstituted oxindoles to acrolein and methyl vinyl ketone, affording 3,3-disubstituted oxindoles enantioselectively in high yields.[13a] In our efforts to further apply this type of catalyst to asymmetric synthesis, we surmised that 1,6-addition of active methylene nucleophiles to *p*-QMs might be feasible through dual activation of reaction components (Figure 1). Thus, similar

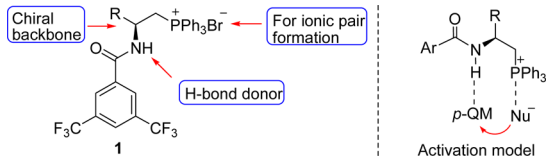


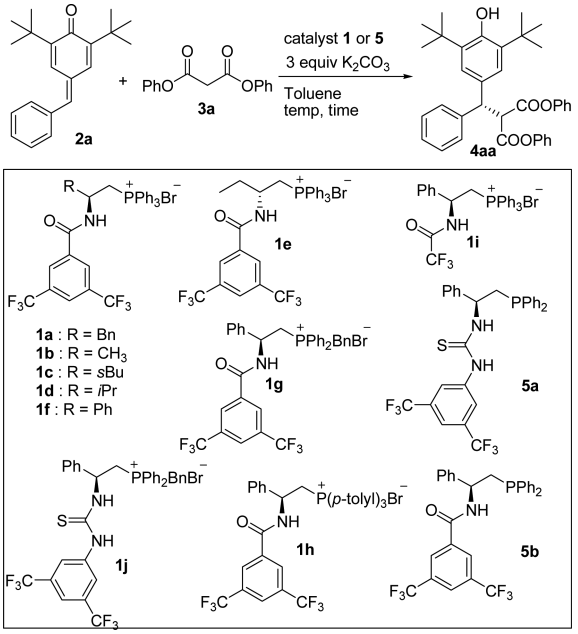
Figure 1. Concept of bifunctional phase transfer catalyst promoted 1,6-addition of *p*-QMs.

to the activation modes of bifunctional tertiary amine or phosphine catalysts,[7b−d] *p*-QMs are activated through hydrogen-bonding, while the active methylene compounds are activated through the formation of ionic pair with phosphonium-moiety of **1**. Hopefully, in this model, the chiral environment and steric encumbrance around the activated reaction components would ensure the stereoselectivity. Herein, we report the successful implementation of this catalytic system for asymmetric 1,6-addition of active malonate esters to *p*-QMs, leading to products bearing diarylmethine stereogenic centers in excellent yields and moderate to excellent stereoselevtivity.

RESULTS AND DISCUSSION

We began our study with the reaction of *p*-QM **2a** with diphenyl malonate **3a**, and tested various amide-phosphonium salts (**1a**−**1i**) and thiourea-phosphonium salt **1j**, and the results were listed in Table 1. Initially, the influence of the R group on the performance of the catalysts **1a**−**1f** derived from commercially available chiral α-amino acids, was probed at −40 °C with K_2CO_3 as the base and toluene as the solvent (entries 1−6). The reactions proceeded smoothly to afford the 1,6-addition products **4aa** in high yields for all catalysts. As far as enantioselectivity was concerned, catalyst **1a** (R = Bn), and catalyst **1b**-**1e** (R = alkyl) with substituents of different steric hindrance gave rather modest ee's. While catalyst **1f** (R = Ph)

Table 1. Screening of Reaction Conditions Concerning the Structure of Catalysts



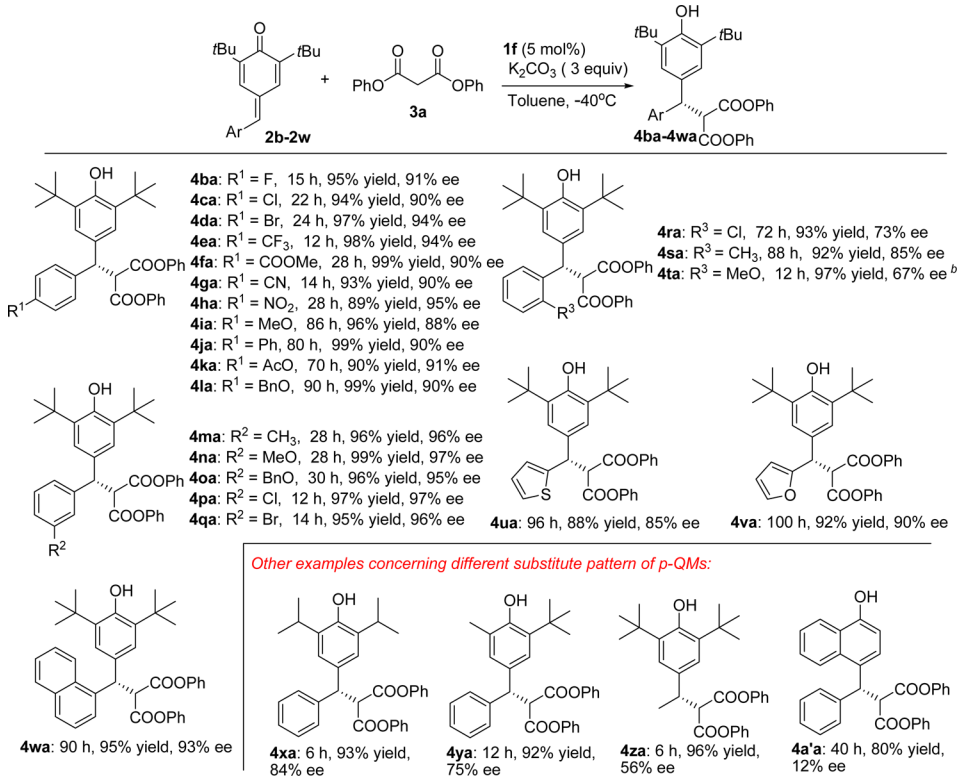
entry	cat (mol %)	temp (°C)	time (h)	yield (%)[b]	ee (%)[c]
1	**1a** (10)	−40	50	70	37
2	**1b** (10)	−40	20	93	40
3	**1c** (10)	−40	40	86	53
4	**1d** (10)	−40	43	82	55
5	**1e** (10)	−40	24	91	−14
6	**1f** (10)	−40	30	98	95
7	**1g** (10)	−40	70	90	89
8	**1h** (10)	−40	60	90	85
9	**1i** (10)	−40	37	79	57
10	**1j** (10)	−40	100	65	28
11	**1f** (5)	−40	40	98	95
12	**1f** (2)	−40	72	95	95
13	**1f** (5)	−20	12	95	88
14	**1f** (5)	20	2	96	77
15[d]	**5a** (10)	−40	48	23	47
16[d,e]	**5a** (10)	−40	48	32	11
17[d]	**5b** (10)	−40	48	31	50
18[d,e]	**5b** (10)	−40	48	40	32

[a]General conditions: **2a** (0.24 mmol), **3a** (0.20 mmol), bifunctional catalyst **1** or **5** (2 to 10 mol %), and K_2CO_3 (3 equiv) in toluene (1 mL) at indicated temperature. [b]Yield referred to isolated pure **4aa**. [c]The ee of **4aa** was determined by chiral HPLC analysis. [d]Reaction quenched after 48 h. [e]Triethyl amine (3 equiv) was employed instead of K_2CO_3.

derived from phenylglycine delivered **4aa** with excellent enantioselectivity (entry 6). Next, the effect of the substituents on the phosphonium center on the performance of the catalysts was surveyed (entries 7, 8). When catalyst **1g** with a benzyl group replacing one of three phenyl groups on phosphonium moiety of **1f** and catalyst **1h** with *p*-tolyl groups replacing phenyl groups on phosphonium moiety of **1f** were employed, the desired **4aa** was obtained in yields and enantioselectivities comparable to those of **1f**, albeit slightly lower and requiring longer reaction time. The presence of 3,5-bis(trifluoromethyl)-benzamide moiety on catalyst **1f** is essential to achieve a high level of enantioselectivity, and replacement of this amide moiety with trifluoroacetamide moiety (**1i**) or with thiourea

DOI: 10.1021/acs.joc.6b01906
J. Org. Chem. 2016, 81, 9315−9325

Scheme 2. Scope of Asymmetric 1,6-Addition of *p*-QMs with Diphenyl Malonate 2a Catalyzed by Amide-Phosphonium Salt 1f



[a]General conditions: **2** (0.24 mmol), **3a** (0.20 mmol), bifunctional catalyst **1** (5 mol %), and K_2CO_3 (3 equiv) in toluene (1 mL) at −40 °C. [b]Reaction performed at 0 °C.

moiety (**1j**), both resulting in lower ee's (entries 9,10). When the loading of the catalyst was reduced to 5 mol %, the reaction performed almost equally well as that of 10 mol % (entry 11). While further reducing to 2 mol % led to slightly lower yield and prolonged reaction time (entry 12). Subsequently, the effect of the temperature on the outcome of the reaction was investigated, and obvious drop in enantioselectivity was observed when the reaction was carried out at elevated temperature of −20 or 20 °C (entries 13, 14). By comparison with Yao's method using thiourea-phosphine organocatlaysts (Scheme 1),[7c] we carried out comparison experiments employing corresponding chiral phosphine catalysts (entries 15−18). However, thiourea-phosphine **5a** and amide-phosphine **5b** both led to low yields and ee's with either K_2CO_3 or TEA as the base. Further attempts to improve the performance of this reaction by screening of the solvents, and the bases were unsuccessful (not shown; see Supporting Information (SI) for details), as no better results were obtained.

With the optimized reaction conditions in hand (Table 1, entry 11), the 1,6-addition reaction catalyzed by amide-phosphonium **1f** was extended to a series of differently arylated *p*-QMs and diphenyl malonate **2a**, and the results are shown in Scheme 2. We first examined *p*-QMs bearing various substituents on the phenyl ring, and it was found that the reactivity and enantioselectivity heavily depend on the position and electronic nature of the substituents. *p*-QMs **2b**-**2l** with either electron-withdrawing or electron-donating substituents on the para-position of the phenyl ring all performed well to deliver *α*-diarylmethine-substituted diphenyl malonates in excellent yields and ee's, albeit prolonged reaction time was required for substrates **2i**−**2l** with electron-donating substituents. *p*-QMs **2m**−**2q** with substituents on the meta-position of the phenyl ring seemed to be more reactive than corresponding *p*-QMs with para-substituted phenyl rings (**2n** vs **2i**, **2o** vs **2l**, **2p** vs **2c**, and **2q** vs **2d**), providing the desired products **4am**−**4aq** in excellent yields and ee's. While in the cases of substrates **2r**−**2t** bearing ortho-substituted phenyl groups, obvious attenuation of reactivity was observed even for **2r** with an electron-withdrawing chloro group. When methoxy-substituted **2t** was employed, the reaction was sluggish at −40 °C, nevertheless 97% yield and 67% ee could be attained at 0 °C for 12 h. Presumably, the repulsion between vicinal substituents on the phenyl ring in **2r**−**2t** would force the phenyl ring out of the plane of the conjugated alkene, therefore prevent the approach of nucleophile to the reaction site of *p*-QMs. Next, *p*-QMs derived from heterocyclic and bulky aromatic aldehydes (**2u**−**2w**) were tested, and also found to be suitable substrates in this study, providing the desired products in excellent yields and ee's. However, replacing the bulky *tert*-butyl (*t*Bu) with smaller *iso*-propyl (*i*Pr) groups led to a decrease in enantioselectivity, despite in a short reaction time of 6 h. *p*-QMs **2y**, **2z**, and **2a′**, whose substitution patterns are different to those of **2a**−**2x**, only gave low to modest enantioselectities.

Next, the scope of malonate esters was investigated briefly. We first examine the reaction between dimethyl malonate **3b** and *p*-QM **2a** using the optimal reaction conditions mentioned above. As expected, the reaction proceeded smoothly to afford the desired product **4ab** in 95% yield after 8 h, albeit in a modest ee of 70% (Table 2, entry 1). Fortunately, when the temperature was lowered from −40 °C to −60 °C, the enantioselectivity was increased substantially from 70% to 85%

DOI: 10.1021/acs.joc.6b01906
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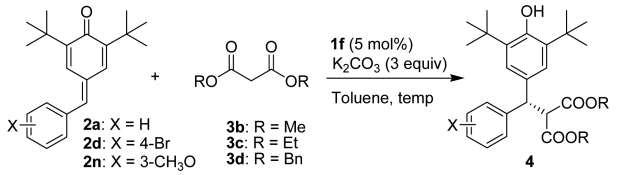
Table 2. Expansion of the Substrate Scope of the Reaction to Dialkyl Malonates



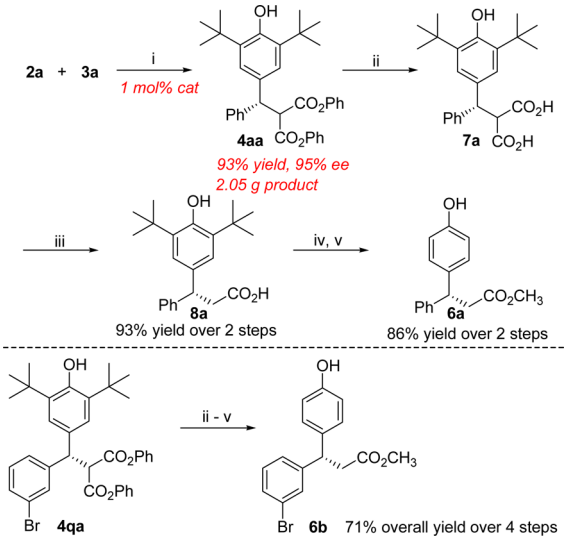
entry	2	3	4	temp (°C)	yield (%)[b]	ee (%)[c]
1	2a	3b	4ab	−40	95	70
2	2a	3b	4ab	−60	90	85
3	2a	3c	4ac	−60	96	87
4	2a	3d	4ad	−60	94	89
5	2d	3b	4db	−60	99	81
6	2d	3c	4dc	−60	95	83
7	2d	3d	4dd	−60	92	92
8	2n	3b	4nb	−60	96	77
9	2n	3c	4nc	−60	99	85
10	2n	3d	4nd	−60	96	83

[a]General conditions: **2** (0.20 mmol), **3** (0.24 mmol), bifunctional catalyst **1** (5 mol %), and K_2CO_3 (3 equiv) in toluene (1 mL) at indicated temperature for 6 to 48 h. [b]Yield referred to isolated pure **4aa**. [c]The ee of **4aa** was determined by chiral HPLC analysis.

ee (entry 2). Using more sterically crowded diethyl malonate **3c** or dibenzyl malonate **3d** provided results slightly better than those of **3b** (entries 3−4). The malonate ester scope was further expanded to the brominated *p*-QM **2d** and methoxylated *p*-QM **2n**. In all cases, the reactions proceeded smoothly, affording diaryl methine products in excellent yields and high ee's (entries 5−10).

The absolute configuration of **4aa**, **4ha**, **4wa**, and **4xa** was determined to be *S* by comparison of specific optical rotation as well as HPLC spectra with those reported in literature.[5] The absolute configuration of other 1,6-addition products could be assigned by analogy. To prove the practicality of our catalytic system, the 1,6-addition between **2a** and **3a** was carried out on a relatively larger scale. To our delight, the catalyst loading could be reduced down to 1 mol % after reoptimization of reaction parameters. Thus, the reaction performed on a 4.0 mmol scale (**3a**, 1.04 g) with 0.04 mmol of catalyst (**1f**, 28 mg) in 10 mL of toluene at −40 °C for 72 h led to **4aa** in a yield of 93% with 95% ee (Scheme 3). Notably, **4aa** is useful in elaborating into a key intermediate **6a** for preparation of GPR40 agonists.[14] In Fan and co-workers' report, de-*tert*-butylated phenol **6a** was obtained by a three-step protocol consisting of the transesterification, Krapcho dealkoxycarbonylation, and $AlCl_3$-mediated trans-*tert*-butylation.[5,15] To avoid the involvement of high temperature (160 °C) in the Krapcho dealkoxycarbonylation procedure, as well as to facilitate easy separation of the reaction mixture, we developed an improved synthetic route for conversion of **4aa** to **6a**. Thus, hydrolysis of **4aa** with LiOH in a solvent mixture of THF and H_2O (4:1) at rt for 30 min, led to malonic acid **7a** after acidification with diluted HCl solution. The crude **7a** was then taken up in a solvent mixture of DMF and H_2O (9:1), and heated at 100 °C for 1 h to afford acid **8a** in 93% yield over two steps.[16] Esterificaiton of **8a** in methanol with catalytic amount of H_2SO_4 at reflux for 12 h gave a crude ester, which after treating with $AlCl_3$ in toluene at 60 °C to remove *tert*-butyl groups delivered **6a** in 86% yield over 2 steps without loss of ee. It was notable that only one chromatographic purification process was

Scheme 3. Gram Scale Preparation of 4aa and Further Elaboration

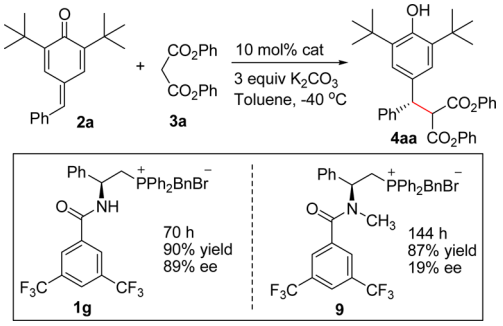


[a]Reagents and conditions: (i) **2a** (4.2 mmol), **3a** (4 mmol), catalyst **1f** (1 mol %), K_2CO_3 (3 equiv), toluene (10 mL), − 40 °C, 72 h; (ii) LiOH, THF/H_2O, rt, 2 h; (iii) DMF/H_2O, 100 °C, 1 h; (iv) H_2SO_4, CH_3OH, reflux, 12 h; and (v) $AlCl_3$, toluene, 60 °C, 1 h.

required in this four-step protocol to provide sufficiently pure target **6a**. Similarly, brominated diaryl methine **4qa** was elaborated into **6b** in an overall yield of 71%.

As mentioned above in Figure 1, it was believed that the secondary amide moiety in the bifunctional amide-phosphonium salts was crucial for the asymmetric induction. To confirm this assumption, we prepared *N*-methylated phosphonium salt **9**, and compared its catalytic performance with that of **1g**. As shown in Scheme 4, with *N*-methylated **9** as a catalyst, the

Scheme 4. Comparison of *N*-Methylated 9 with 1g



reaction proceeded much more slowly as compared with **1g**, delivering **4aa** after 144 h in 87% yield with 19% ee. In comparison, with **1g** as a catalyst, **4aa** was obtained in 90% yield with 89% ee after 70 h. Thus, the hydrogen bonding interaction between amide NH and the carbonyl group of *p*-QM seemed to be crucial for both reactivity and enantioselectivity of this reaction.[17] On the basis of these observations, we proposed a plausible trasnsition-state model to interpret the high level of chiral induction in this reaction (Figure 2).

CONCLUSIONS

In summary, we have developed an asymmetric 1,6-addition of malonate esters to *p*-QMs catalyzed by amide-phosphonium

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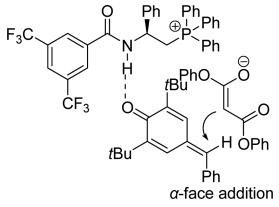

Figure 2. Proposed transition-state model.

salt-based bifunctional PTC. A series of functionalized chiral diaryl methines were obtained in excellent yields and ee's in most cases. The utility of this method was demonstrated by a relatively large scale synthesis of **4aa** with as low as 1 mol % catalyst **1f**, and further transformation of **4aa** into (*R*)-methyl 3-(4-hydroxyphenyl)-3-phenylpropanoate **6a**, which is a key intermediate for preparation of GPR40 agonists. Furthermore, a transition-state model was proposed to interpret the high level of chiral induction in this reaction.

EXPERIMENTAL SECTION

General Information. Thin-layer chromatography (TLC) was carried out on 0.25 mm silica gel plates visualized with UV light and/or by staining with ethanolic phosphomolybdic acid (PMA) or iodine. Flash column chromatography was performed on silica gel H (10−40 μ). ^{1}H NMR spectras were recorded at 500 MHz, and ^{13}C NMR spectras were recorded at 125 MHz. Chemical shifts (δ) are given in ppm relative to TMS, coupling constants (J) in Hz. High-resolution mass spectra were recorded by FTMS. Enantiomeric excesses were determined by HPLC analysis on a chiral stationary phase.

*Preparation of Phosphonium Salts **1a−1j**, **9**, and Phosphine **5a−5b**.* Amide phosphonium salts **1a−1f**, **1h**, and **1i** were synthesized by a known literature procedure,[13a] among them **1b**, **1e**, **1h**, and **1i** are new compounds. Phosphine catalysts **5a** and **5b** are known compounds and were prepared according to the literature procedure.[18] Phosphonium salts **1g** and **1j** were prepared from corresponding phosphine-based compounds **5b** and **5a** according to the literature procedure.[13b] Phosphonium slat **9** was prepared from corresponding *N*-methylated phosphine.[13b]

*(S)-(2-(3,5-Bis(trifluoromethyl)benzamido)propyl)-triphenylphosphonium Bromide (**1b**).* The chromatographic purification (dichloromethane/methanol =20/1) afforded **1b**, white solid, mp 130−132 °C, 1.2 g, 55% yield; ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.59 (d, J = 8.1 Hz, 1H), 8.30 (s, 2H), 7.84−7.79 (m, 7H), 7.57−7.45 (m, 9H), 5.12−4.90 (m, 2H), 3.42 (t, J = 13.4 Hz, 1H), 1.61 (d, J = 3.0 Hz, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 163.2, 134.8, 134.7 (d, J_{CP} = 2.9 Hz), 134.1 (d, J_{CP} = 10.3 Hz), 131.1 (q, J_{CF} = 33.7 Hz), 130.1 (d, J_{CP} = 12.5 Hz), 128.5 (d, J_{CP} = 2.6 Hz), 124.5 (q, J_{CF} = 3.6 Hz), 124.1 (q, J_{CF} = 272.8 Hz), 117.7 (d, J_{CP} = 86.4 Hz), 41.0 (d, J_{CP} = 5.3 Hz), 28.8 (d, J_{CP} = 50.3 Hz), 24.2 (d, J_{CP} = 15.5 Hz); HRMS (ESI) calcd. for $(C_{30}H_{25}F_6NOP)^+$ 560.1572, found 560.1580; $[\alpha]_D^{25}$ + 60 (*c* 0.72, $CHCl_3$).

*(R)-(2-(3,5-Bis(trifluoromethyl)benzamido)butyl)-triphenylphosphonium Bromide (**1e**).* The chromatographic purification (dichloromethane/methanol =20/1) afforded **1e**, white solid, mp 124−126 °C, 0.9 g, 61% yield; ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.50−9.47 (m, 1H), 8.35 (s, 2H), 7.95−7.74 (m, 7H), 7.63−7.42 (m, 9H), 5.21−4.91 (m, 1H), 4.78−4.76 (m, 1H), 3.43 (t, J = 14.2 Hz, 1H), 2.17−2.13 (m, 1H), 1.98−1.91 (m, 1H), 0.89−0.83 (m, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 163.8, 134.7 (d, J_{CP} = 2.9 Hz), 134.1(d, J_{CP} = 10.2 Hz), 131.2 (q, J_{CF} = 33.8 Hz), 130.1 (d, J_{CP} = 12.6 Hz), 128.6 (d, J_{CP} = 2.9 Hz), 124.5 (q, J_{CF} = 3.7 Hz), 123.1 (q, J_{CF} = 273.9 Hz), 118.0 (d, J_{CP} = 86.3 Hz), 46.3 (d, J_{CP} = 5.7 Hz), 31.0 (d, J_{CP} = 14.8 Hz), 27.7 (d, J_{CP} = 50.4 Hz), 10.6 (d, J_{CP} = 1.51 Hz); HRMS (ESI) calcd. for $(C_{31}H_{27}F_6NOP)^+$ 574.1729, found 574.1735; $[\alpha]_D^{25}$ + 72 (*c* 0.85, $CHCl_3$).

*(S)-(2-(3,5-Bis(trifluoromethyl)benzamido)-2-phenylethyl)trip-tolylphosphonium Bromide (**1h**).* The chromatographic purification (dichloromethane/methanol =25/1) afforded **1h**, white solid, mp 138−140 °C, 0.6 g, 50% yield; ^{1}H NMR (500 MHz, $CDCl_3$) δ 10.20 (d, J = 8.3 Hz, 1H), 8.43 (s, 2H), 7.81 (s, 1H), 7.76−7.66 (m, 8H), 7.34 (dd, J = 8.0, 2.8 Hz, 6H), 7.28−7.24 (m, 2H), 7.18 (t, J = 7.3 Hz, 1H), 5.97−7.89 (m, 1H), 5.81−5.60 (m, 1H), 3.09 (dd, J = 15.2, 12.7 Hz, 1H), 2.29 (s, 9H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 163.4, 146.4 (d, J_{CP} = 3.1 Hz), 141.8 (d, J_{CP} = 13.6 Hz), 134.9, 133.8 (d, J_{CP} = 10.7 Hz), 131.3 (q, J_{CF} = 33.6 Hz), 131.0 (d, J_{CP} = 13.4 Hz), 129.1, 128.7 (d, J_{CP} = 2.6 Hz), 128.2, 127.2, 124.6 (q, J_{CF} = 3.7 Hz), 123.1 (q, J_{CF} = 273.6 Hz), 114.3 (d, J_{CP} = 88.9 Hz), 48.8 (d, J_{CP} = 3.3 Hz), 28.4(d, J_{CP} = 49.5 Hz), 21.6 (d, J_{CP} = 1.3 Hz); HRMS (ESI) calcd. for $(C_{38}H_{33}F_6NOP)^+$ 664.2198, 664.2210; $[\alpha]_D^{25}$ − 7 (*c* 0.8, $CHCl_3$).

*(S)-Triphenyl(2-phenyl-2-(2,2,2-trifluoroacetamido)ethyl)-phosphonium Bromide (**1i**).* The crude product was recrystallized from diethyl ether to give pure **1i**, white solid, mp 213−215 °C, 1.4 g, 65% yield; ^{1}H NMR (500 MHz, $CDCl_3$) δ 10.30 (d, J = 8.6 Hz, 1H), 7.84−7.70 (m, 9H), 7.64−7.60 (m, 6H), 7.55 (d, J = 7.4 Hz, 2H), 7.23−7.15 (m, 3H), 5.98 (dt, J = 15.9, 10.9 Hz, 1H), 5.48−5.41 (m, 1H), 3.22 (t, J = 14.3 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 156.5 (q, J_{CF} = 38.4 Hz), 140.4 (d, J_{CP} = 12.3 Hz), 135.5 (d, J_{CP} = 2.9 Hz), 133.8 (d, J_{CP} = 10.1 Hz), 130.5 (d, J_{CP} = 12.6 Hz), 129.3, 128.6, 127.1, 117.0 (d, J_{CP} = 86.1 Hz), 115.3 (q, J_{CF} = 287.8 Hz), 48.5 (d, J_{CP} = 2.9 Hz), 28.3 (d, J_{CP} = 48.5 Hz); HRMS (ESI) calcd. for $(C_{28}H_{24}F_3NOP)^+$ 478.1542, found 478.1536; $[\alpha]_D^{25}$ − 15 (*c* 0.7, $CHCl_3$).

*(S)-Benzyl(2-(3,5-bis(trifluoromethyl)benzamido)-2-phenylethyl)-diphenylphosphonium Bromide (**1g**).* The chromatographic purification (dichloromethane/methanol =25/1) afforded **1g**, white solid, mp 140−142 °C, 1.1 g, 55% yield; ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.86 (d, J = 8.0 Hz, 1H), 8.36 (s, 2H), 7.82−7.86 (m, 3H), 7.71 (dd, J = 12.1, 8.1 Hz, 2H), 7.64−7.59 (m, 3H), 7.51 (td, J = 7.6, 3.2 Hz, 2H), 7.42 (d, J = 2.8 Hz, 3H), 7.29−7.24 (m, 3H), 7.22−7.13 (m, 2H), 7.08 (t, J = 7.6 Hz, 2H), 6.93 (d, J = 7.3 Hz, 2H), 5.67−5.52 (m, 2H), 4.89 (t, J = 14.9 Hz, 1H), 4.32 (t, J = 14.4 Hz, 1H), 2.90 (t, J = 13.9 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 163.4, 141.1 (d, J_{CP} = 13.6 Hz), 135.0 (d, J_{CP} = 2.9 Hz), 134.7 (d, J_{CP} = 2.8 Hz), 134.4, 133.8 (d, J_{CP} = 9.7 Hz), 133.6 (d, J_{CP} = 9.1 Hz), 131.3 (q, J_{CF} = 33.9 Hz), 130.4 (d, J_{CP} = 5.5 Hz), 130.1 (d, J_{CP} = 12.4 Hz), 129.9 (d, J_{CP} = 12.5 Hz), 129.2 (d, J_{CP} = 3.0 Hz), 129.1, 128.7 (d, J_{CP} = 3.7 Hz), 128.6 (d, J_{CP} = 2.8 Hz), 128.4, 127.1, 126.5 (d, J_{CP} = 8.4 Hz), 124.8 (q, J_{CF} = 3.6 Hz), 123.0 (q, J_{CF} = 272.1 Hz), 117.5 (d, J_{CP} = 82.0 Hz), 116.6 (d, J_{CP} = 82.3 Hz), 48.6 (d, J_{CP} = 3.3 Hz), 30.2 (d, J_{CP} = 46.6 Hz), 25.3 (d, J_{CP} = 47.9 Hz); HRMS (ESI) calcd. for $(C_{36}H_{29}F_6NOP)^+$ 636.1885, found 636.1892; $[\alpha]_D^{25}$ − 4 (c 0.56, $CHCl_3$).

*(S)-Benzyl(2-(N-methyl-3,5-bis(trifluoromethyl)benzamido)-2-phenylethyl)diphenylphosphonium Bromide (**9**).* The chromatographic purification (dichloromethane/methanol =20/1) afforded **9**, white solid; mp 128−130 °C, 0.3 g, 45% yield; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.13 (dd, J = 12.2, 7.9 Hz, 2H), 7.88−7.83 (m, 3H), 7.71 (dd, J = 7.4 Hz, 6.7 Hz, 2H), 7.63−7.56 (m, 6H), 7.32 (s, 2H), 7.26 (s, 3H), 7.17−7.14 (m, 1H), 7.07 (t, J = 7.5 Hz, 2H), 7.01 (d, J = 7.0 Hz, 2H), 6.37−6.32 (m, 1H), 5.11 (td, J = 15.6, 9.0 Hz, 1H), 4.96−4.77 (m, 2H), 4.20 (td, J = 15.4, 5.4 Hz, 1H), 2.78 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 168.5, 137.1, 135.9 (d, J_{CP} = 9.2 Hz), 134.9, 134.8 (d, J_{CP} = 7.3 Hz), 134.2 (d, J_{CP} = 9.5 Hz), 133.8 (d, J_{CP} = 9.3 Hz), 131.7 (q, J_{CF} = 33.8 Hz), 130.6 (d, J_{CP} = 5.6 Hz), 130.0 (d, J_{CP} = 12.4 Hz), 129.2, 129.1, 129.0 (d, J_{CP} = 3.5 Hz), 128.9, 128.4 (d, J_{CP} = 3.7 Hz), 127.4, 127.3 (d, J_{CP} = 8.3 Hz), 123.7 (q, J_{CF} = 3.7 Hz), 122.7 (q, J_{CF} = 273.1 Hz), 117.3 (d, J_{CP} = 83.1 Hz), 116.5(d, J_{CP} = 82.5 Hz), 52.1, 33.5, 31.6 (d, J_{CP} = 47.0 Hz), 29.7, 22.4 (d, J_{CP} = 48.5 Hz); HRMS (ESI) calcd. for (C37H31 $F_6NOP)^+$ 650.2042, found 650.2033; $[\alpha]_D^{25}$ + 41 (*c* 0.66, $CHCl_3$).

Preparation of *para*-Quinone Methides 2 and Malonates 3. *para*-Quinone methides **2a−2w** were synthesized by a known literature procedure,[4b] among them **2k**, **2l**, and **2o** are new compounds. **2x**,[8a] **2z**,[8b] **2a′**[5] were prepared using the corresponding literature procedures. Malonate **3a** was prepared according a known literature procedure.[5] Malonates **3b**, **3c** and **3d** are commercially available.

*4-((3,5-Ditert-butyl-4-oxocyclohexa-2,5-dien-1-ylidene)methyl)-phenyl Acetate (**2k**).* The chromatographic purification (petroleum

DOI: 10.1021/acs.joc.6b01906
J. Org. Chem. 2016, 81, 9315−9325

ether/ethyl acetate =100/1) afforded **2k**, yellow solid, mp 141−143 °C, 1.6 g, 45% yield; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.49−7.46 (m, 3H), 7.19 (d, J = 8.6 Hz, 2H), 7.14 (s, 1H), 7.00 (d, J = 2.2 Hz, 1H), 2.33 (s, 3H), 1.33 (s, 9H), 1.30 (s, 9H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 186.6, 169.2, 151.1, 149.6, 147.9, 141.2, 135.1, 133.6, 132.0, 131.5, 127.5, 122.1, 35.5, 35.0, 29.6, 29.5, 21.2; HRMS (ESI) calcd. for $(C_{23}H_{29}O_3)^+$ 353.2111, found 353.2117.

*4-(4-(Benzyloxy)benzylidene)-2,6-ditert-butylcyclohexa-2,5-dien-1-one (**2l**).* The chromatographic purification (petroleum ether/ethyl acetate =80/1) afforded **2l**, yellow solid, mp 98−100 °C, 2.8 g, 70% yield; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.58 (d, J = 2.1 Hz, 1H), 7.51−7.40 (m, 6H), 7.38−7.35 (m, 1H), 7.14 (s, 1H), 7.07 (d, J = 8.7 Hz, 2H), 7.02 (d, J = 2.2 Hz, 1H), 5.14 (s, 2H), 1.36 (s, 9H), 1.34 (s, 9H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 186.5, 159.8, 149.0, 147.2, 142.6, 136.4, 135.4, 132.3, 130.6, 128.9, 128.7, 128.2, 127.8, 127.5, 115.3, 70.2, 35.5, 35.0, 29.6, 29.6; HRMS (ESI) calcd. for $(C_{28}H_{33}O_2)^+$ 401.2475, found 401.2486.

*4-(3-(Benzyloxy)benzylidene)-2,6-ditert-butylcyclohexa-2,5-dien-1-one (**2o**).* The chromatographic purification (petroleum ether/ethyl acetate =100/1) afforded **2o**, yellow solid, mp 104−106 °C, 2.6 g, 66% yield; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.58 (d, J = 1.4 Hz, 1H), 7.49−7.33 (m, 6H), 7.16 (s, 1H), 7.12−6.99 (m, 4H), 5.12 (s, 2H), 1.36 (s, 9H), 1.33 (s, 9H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 186.6, 159.0, 149.4, 147.9, 142.3, 137.3, 136.6, 135.2, 132.2, 129.9, 128.7, 128.2, 127.9, 127.5, 123.2, 116.3, 116.0, 70.2, 35.5, 35.1, 29.6, 29.5; HRMS (ESI) calcd. for $(C_{28}H_{33}O_2)^+$ 401.2475, found 401.2483.

General Procedure for 1,6-Addition of Malonate Esters 3 to *para*-Quinone Methides 2. A mixture of *para*-quinone methides **2a** (71 mg, 0.24 mmol), malonate **3a** (52 mg, 0.2 mmol) and catalyst **1f** (7 mg, 0.01 mmol) in toluene (1 mL) was cooled to −40 °C, and then K_2CO_3 (83 mg, 0.6 mmol) was added. The resulting mixture was stirred vigorously at the same temperature, and monitored by TLC. Upon the complete consumption of **2a**, the reaction mixture was loaded directly onto a column packed with silica gel, and eluted with petroleum ether/ethyl acetate to afford the addition products **4aa** (108 mg, 0.196 mmol) as a white solid in 98% yield with 95% ee.

*Diphenyl (R)-2-((3,5-Ditert-butyl-4-hydroxyphenyl) (phenyl)-methyl)malonate (**4aa**):*[5] The chromatographic purification (petroleum ether/ethyl acetate =20/1) afforded **4aa**, white solid, mp 210−212 °C, 108 mg, 98% yield, 95% ee; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.52 (d, J = 7.5 Hz, 2H), 7.38 (t, J = 7.6 Hz, 2H), 7.33−7.24 (m, 7H), 7.21−7.15 (m, 2H), 6.75 (d, J = 7.8 Hz, 2H), 6.58 (d, J = 7.8 Hz, 2H), 5.18 (s, 1H), 4.90 (d, J = 12.0 Hz, 1H), 4.80 (d, J = 12.0 Hz, 1H), 1.42 (s, 18H); $[\alpha]_D^{23}$ + 20 (c 0.5, EtOAc), lit.[5] data for **4aa** of 98% ee: $[\alpha]_D^{25}$ + 20.9 (c 1, EtOAc); HPLC (Daicel CHIRALPAK IA, Hexane/Isopropanol =98:2, Flow rate =1 mL/min, λ = 235 nm): t_R = 6.51 min (major enantiomer), t_R = 7.74 min (minor enantiomer).

*Diphenyl (R)-2-((3,5-Ditert-butyl-4-hydroxyphenyl)(4-fluorophenyl)methyl)malonate (**4ba**).* The chromatographic purification (petroleum ether/ethyl acetate =15/1) afforded **4ba**, white solid, mp 163−165 °C, 108 mg, 95% yield, 91% ee; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.52 (dd, J = 8.5, 5.3 Hz, 2H), 7.37−7.33 (m, 2H), 7.32−7.27 (m, 4H), 7.25−7.19 (m, 2H), 7.11−7.08 (m, 2H), 6.84 (d, J = 7.7 Hz, 2H), 6.62 (d, J = 7.7 Hz, 2H), 5.24 (s, 1H), 4.94 (d, J = 11.9 Hz, 1H), 4.79 (d, J = 11.9 Hz, 1H), 1.46 (s, 18H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.3, 166.2, 161.0 (d, J = 245.8 Hz), 153.1, 150.4 (d, J = 7.5 Hz), 137.5 (d, J = 3.5 Hz), 136.3, 131.0, 129.6, 129.5, 129.5, 129.4, 126.3, 126.2, 124.8, 121.2, 121.2, 115.8, 115.7 (d, J = 21.5 Hz), 58.3, 51.3, 34.5, 30.3; HRMS (ESI) calcd. for $(C_{36}H_{37}FNaO_5)^+$ 591.2517, found 591.2521; $[\alpha]_D^{23}$ + 23 (c 0.4, EtOAc); HPLC (Daicel CHIRALPAK IA, Hexane/Isopropanol =98:2, Flow rate =1 mL/min, λ = 220 nm): t_R = 7.47 min (major enantiomer), t_R = 9.26 min (minor enantiomer).

*Diphenyl (R)-2-((4-Chlorophenyl)(3,5-ditert-butyl-4-hydroxyphenyl)methyl)malonate (**4ca**).* The chromatographic purification (petroleum ether/ethyl acetate =20/1) afforded **4ca**, white solid, mp 124−126 °C, 110 mg, 94% yield, 90% ee; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.45 (d, J = 8.3 Hz, 2H), 7.36−7.32 (m, 4H), 7.30−7.16 (m, 6H), 6.83 (d, J = 8.4 Hz, 2H), 6.58 (d, J = 8.4 Hz, 2H), 5.21 (s, 1H), 4.88 (d, J = 11.9 Hz, 1H), 4.75 (d, J = 11.9 Hz, 1H), 1.43 (s, 18H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.2, 166.1, 153.2, 150.3, 150.3, 140.2, 136.3, 132.9, 130.6, 129.5, 129.4, 129.2, 129.0, 126.3, 126.2, 124.8, 121.1, 57.9, 51.3, 34.4, 30.2; HRMS (ESI) calcd. for $(C_{36}H_{37}ClNaO_5)^+$ 607.2222, found 607.2229; $[\alpha]_D^{23}$ + 15 (c 0.7, EtOAc); HPLC (Phenomenex cellulose-1, Hexane/Isopropanol =98:2, Flow rate =1 mL/min, λ = 220 nm): t_R = 8.29 min (major enantiomer), t_R = 9.82 min (minor enantiomer).

*Diphenyl (R)-2-((4-Bromophenyl)(3,5-ditert-butyl-4-hydroxyphenyl)methyl)malonate (**4da**):*[5] The chromatographic purification (petroleum ether/ethyl acetate =25/1) afforded **4da**, white solid, mp 132−134 °C, 122 mg, 97% yield, 94% ee; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.51 (d, J = 8.4 Hz, 2H), 7.42−7.13 (m, 10H), 6.83 (d, J = 8.0 Hz, 2H), 6.58 (d, J = 8.0 Hz, 2H), 5.21 (s, 1H), 4.87 (d, J = 12.0 Hz, 1H), 4.75 (d, J = 12.0 Hz, 1H), 1.43 (s, 18H); $[\alpha]_D^{23}$ + 23.5 (c 0.4, EtOAc), lit.[5] data for **4da** of 98% ee: $[\alpha]_D^{25}$ + 23.4 (c 1, EtOAc); HPLC (Daicel CHIRALPAK OD-H, Hexane/Isopropanol =98:2, Flow rate =1 mL/min, λ = 220 nm): t_R = 8.04 min (major enantiomer), t_R = 9.15 min (minor enantiomer).

*Dibenzyl (R)-2-((3,5-Ditert-butyl-4-hydroxyphenyl)(4-(trifluoromethyl)phenyl)methyl)malonate (**4ea**).* The chromatographic purification (petroleum ether/ethyl acetate =20/1) afforded **4ea**, white solid, mp 130−132 °C, 121 mg, 98% yield, 94% ee; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.68 (s, 4H), 7.40−7.28 (m, 6H), 7.27−7.16 (m, 2H), 6.84 (d, J = 7.9 Hz, 2H), 6.63 (d, J = 8.0 Hz, 2H), 5.28 (s, 1H), 5.01 (d, J = 11.9 Hz, 1H), 4.87 (d, J = 11.9 Hz, 1H), 1.47 (s, 18H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.1, 166.0, 153.4, 150.4, 150.2, 145.8, 136.5, 130.2, 129.6, 129.4 (q, J = 32.6 Hz), 128.3, 126.4, 126.3, 125.9 (q, J = 3.5 Hz), 124.9, 124.2 (q, J = 271.7 Hz), 121.1, 121.0, 120.9, 57.8, 51.7, 34.5, 30.3; HRMS (ESI) calcd. for $(C_{37}H_{37}F_3NaO_5)^+$ 641.2485, found 641.2481; $[\alpha]_D^{23}$ + 16.4 (c 0.4, EtOAc); HPLC (Daicel CHIRALPAK IA, Hexane/Isopropanol =98:2, Flow rate =1 mL/min, λ = 220 nm): t_R = 6.92 min (major enantiomer), t_R = 8.08 min (minor enantiomer).

*Diphenyl (R)-2-((3,5-Ditert-butyl-4-hydroxyphenyl)(4-(methoxycarbonyl)phenyl)methyl)malonate (**4fa**).* The chromatographic purification (petroleum ether/ethyl acetate =20/1) afforded **4fa**, white solid, mp 118−120 °C, 121 mg, 99% yield, 90% ee; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.08 (d, J = 8.3 Hz, 2H), 7.60 (d, J = 8.3 Hz, 2H), 7.36−7.24 (m, 6H), 7.20 (q, J = 7.7 Hz, 2H), 6.83 (d, J = 8.3 Hz, 2H), 6.60 (d, J = 8.2 Hz, 2H), 5.24 (s, 1H), 4.98 (d, J = 12.0 Hz, 1H), 4.84 (d, J = 12.0 Hz, 1H), 3.92 (s, 3H), 1.43 (s, 18H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.8, 166.2, 166.0, 153.3, 150.3, 150.3, 146.9, 136.4, 130.3, 130.2, 129.5, 129.4, 129.0, 127.9, 126.3, 126.2, 124.9, 121.1, 121.0, 507.7, 52.2, 51.8, 34.5, 34.5, 30.2; HRMS (ESI) calcd. for $(C_{38}H_{40}NaO_7)^+$ 631.2666, found 631.2672; $[\alpha]_D^{23}$ + 21 (c 0.68, EtOAc); HPLC (Daicel CHIRALPAK IA, Hexane/Isopropanol =90:10, Flow rate =1 mL/min, λ = 220 nm): t_R = 6.90 min (major enantiomer), t_R = 15.00 min (minor enantiomer).

*Diphenyl (R)-2-((4-Cyanophenyl)(3,5-ditert-butyl-4-hydroxyphenyl)methyl)malonate (**4ga**).* The chromatographic purification (petroleum ether/ethyl acetate =15/1) afforded **4ga**, white solid, mp 178−180 °C, 107 mg, 93% yield, 90% ee; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.69 (d, J = 8.2 Hz, 2H), 7.63 (d, J = 8.3 Hz, 2H), 7.35 (t, J = 7.8 Hz, 2H), 7.29 (t, J = 7.8 Hz, 2H), 7.26−7.15 (m, 4H), 6.86 (d, J = 8.3 Hz, 2H), 6.60 (d, J = 8.2 Hz, 2H), 5.28 (s, 1H), 4.97 (d, J = 11.9 Hz, 1H), 4.82 (d, J = 11.9 Hz, 1H), 1.44 (s, 18H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.0, 165.9, 153.4, 150.3, 150.2, 147.2, 136.6, 132.7, 129.7, 129.6, 129.5, 128.7, 126.5, 126.4, 124.9, 121.1, 121.0, 118.7, 111.0, 57.4, 51.7, 34.5, 30.2; HRMS (ESI) calcd. for $(C_{37}H_{37}NNaO_5)^+$ 598.2564, found 598.2560; $[\alpha]_D^{23}$ + 19.5 (c 0.62, EtOAc); HPLC (Daicel CHIRALPAK IA, Hexane/Isopropanol =90:10, Flow rate =1 mL/min, λ = 220 nm): t_R = 9.01 min (major enantiomer), t_R = 12.58 min (minor enantiomer).

*Diphenyl (R)-2-((3,5-Ditert-butyl-4-hydroxyphenyl)(4-nitrophenyl)methyl)malonate (**4ha**):*[5] The chromatographic purification (petroleum ether/ethyl acetate =15/1) afforded **4ha**, white solid, mp 170−172 °C, 106 mg, 89% yield, 95% ee; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.28 (d, J = 8.7 Hz, 2H), 7.71 (d, J = 8.7 Hz, 2H), 7.36 (t, J = 7.9 Hz, 2H), 7.33−7.20 (m, 6H), 6.91 (d, J = 7.7 Hz, 2H), 6.62 (d, J = 7.6 Hz, 2H), 5.30 (s, 1H), 5.05 (d, J = 11.9 Hz, 1H), 4.88

DOI: 10.1021/acs.joc.6b01906
J. Org. Chem. 2016, 81, 9315−9325

(d, J = 11.9 Hz, 1H), 1.46 (s, 18H); $[\alpha]_D^{23}$ + 29.5 (c 0.7, EtOAc), lit.[5] data for **4ha** of 98% ee: $[\alpha]_D^{25}$ + 35.4 (c 1, EtOAc); HPLC (Daicel CHIRALPAK IA, Hexane/Isopropanol =90:10, Flow rate =1 mL/min, λ = 220 nm): t_R = 11.76 min (major enantiomer), t_R = 15.53 min (minor enantiomer).

*Diphenyl (R)-2-((3,5-Ditert-butyl-4-hydroxyphenyl)(4-methoxyphenyl)methyl)malonate (**4ia**):*[5] The chromatographic purification (petroleum ether/ethyl acetate =30/1) afforded **4ia**, white solid, mp 112−114 °C, 112 mg, 96% yield, 88% ee; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.47 (d, J = 8.5 Hz, 2H), 7.37−7.25 (m, 6H), 7.25−7.16 (m, 2H), 6.94 (d, J = 8.5 Hz, 2H), 6.83 (d, J = 7.8 Hz, 2H), 6.60 (d, J = 7.8 Hz, 2H), 5.20 (s, 1H), 4.89 (d, J = 12.0 Hz, 1H), 4.78 (d, J = 12.0 Hz, 1H), 3.81 (s, 3H), 1.45 (s, 18H); $[\alpha]_D^{23}$ + 21.5 (c 0.4, EtOAc), lit.[5] data for **4ia** of 98% ee: $[\alpha]_D^{25}$ + 13.5 (c 1, EtOAc); HPLC (Daicel CHIRALPAK IA, Hexane/Isopropanol =95:5, Flow rate =1 mL/min, λ = 240 nm): t_R = 6.82 min (major enantiomer), t_R = 9.53 min (minor enantiomer).

*Diphenyl (R)-2-([1,1′-Biphenyl]-4-yl(3,5-ditert-butyl-4-hydroxyphenyl)methyl)malonate (**4ja**).* The chromatographic purification (petroleum ether/ethyl acetate =25/1) afforded **4ja**, white solid, mp 176−178 °C, 124 mg, 99% yield, 90% ee; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.68−7.60 (m, 6H), 7.50 (t, J = 7.6 Hz, 2H), 7.41−7.39 (m, 3H), 7.36−7.31 (m, 4H), 7.25−7.22 (m, 2H), 6.85 (d, J = 7.9 Hz, 2H), 6.66 (d, J = 7.9 Hz, 2H), 5.26 (s, 1H), 5.02 (d, J = 12.0 Hz, 1H), 4.91 (d, J = 12.0 Hz, 1H), 1.50 (s, 18H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.4, 166.3, 153.2, 150.5, 150.4, 140.8, 140.7, 140.1, 136.3, 131.1, 129.5, 129.4, 128.9, 128.4, 127.7, 127.4, 127.1, 126.3, 126.2, 124.9, 121.3, 121.2, 58.2, 51.9, 34.5, 30.4; HRMS (ESI) calcd. for $(C_{42}H_{42}NaO_5)^+$ 649.2924, found 649.2930; $[\alpha]_D^{23}$ − 8 (c 0.75, EtOAc); HPLC (Daicel CHIRALPAK IA, Hexane/Isopropanol =98:2, Flow rate =1 mL/min, λ = 215 nm): t_R = 7.97 min (major enantiomer), t_R = 10.10 min (minor enantiomer).

*Diphenyl (R)-2-((4-Acetoxyphenyl)(3,5-ditert-butyl-4-hydroxyphenyl)methyl)malonate (**4ka**).* The chromatographic purification (petroleum ether/ethyl acetate =20/1) afforded **4ka**, white solid, mp 168−170 °C, 110 mg, 90% yield, 91% ee; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.53 (d, J = 8.5 Hz, 2H), 7.35−7.32 (m, 2H), 7.30−7.16 (m, 6H), 7.11 (d, J = 8.5 Hz, 2H), 6.78 (d, J = 8.0 Hz, 2H), 6.60 (d, J = 8.0 Hz, 2H), 5.21 (s, 1H), 4.92 (d, J = 11.9 Hz, 1H), 4.78 (d, J = 11.9 Hz, 1H), 2.31 (s, 3H), 1.44 (s, 18H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 169.4, 166.3, 153.1, 150.4, 150.3, 149.7, 139.1, 136.2, 130.8, 129.5, 129.4, 129.0, 126.3, 126.2, 124.8, 122.0, 121.3, 121.2, 58.2, 51.6, 34.4, 30.3, 21.2; HRMS (ESI) calcd. for $(C_{38}H_{40}NaO_7)^+$ 631.2666, found 631.2660; $[\alpha]_D^{23}$ − 10 (c 0.8, EtOAc); HPLC (Daicel CHIRALPAK OD-H, Hexane/Isopropanol =98:2, Flow rate =1 mL/min, λ = 220 nm): t_R = 14.05 min (major enantiomer), t_R = 23.04 min (minor enantiomer).

*Diphenyl (R)-2-((4-(Benzyloxy)phenyl)(3,5-ditert-butyl-4-hydroxyphenyl)methyl)malonate (**4la**).* The chromatographic purification (petroleum ether/ethyl acetate =20/1) afforded **4la**, white solid, mp 92−94 °C, 130 mg, 99% yield, 90% ee; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.51−7.47 (m, 4H), 7.45 (t, J = 7.4 Hz, 2H), 7.42−7.30 (m, 7H), 7.29−7.18 (m, 2H), 7.06 (d, J = 8.4 Hz, 2H), 6.87 (d, J = 8.2 Hz, 2H), 6.65 (d, J = 8.2 Hz, 2H), 5.24 (s, 1H), 5.12 (s, 2H), 4.94 (d, J = 12.0 Hz, 1H), 4.83 (d, J = 12.0 Hz, 1H), 1.49 (s, 18H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.5, 166.4, 158.0, 153.0, 150.5, 150.4, 137.1, 136.2, 134.1, 131.5, 129.5, 129.4, 129.0, 128.7, 128.1, 127.5, 126.2, 126.1, 124.8, 121.3, 121.2, 115.2, 70.1, 58.5, 51.5, 34.5, 30.4; HRMS (ESI) calcd. for $(C_{43}H_{44}NaO_6)^+$ 679.3030, found 679.3034; $[\alpha]_D^{23}$ + 2 (c 1, EtOAc); HPLC (Daicel CHIRALPAK IA, Hexane/Isopropanol =95:5, Flow rate =1 mL/min, λ = 220 nm): t_R = 8.92 min (major enantiomer), t_R = 13.89 min (minor enantiomer).

*Diphenyl (R)-2-((3,5-Ditert-butyl-4-hydroxyphenyl)(m-tolyl)-methyl)malonate (**4ma**).* The chromatographic purification (petroleum ether/ethyl acetate =20/1) afforded **4ma**, White solid, mp 101−103 °C, 108 mg, 96% yield, 96% ee; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.38−7.27 (m, 9H), 7.24−7.20 (m, 2H), 7.12 (d, J = 7.4 Hz, 1H), 6.82 (d, J = 8.2 Hz, 2H), 6.62 (d, J = 8.2 Hz, 2H), 5.22 (s, 1H), 4.90 (d, J = 12.1 Hz, 1H), 4.84 (d, J = 12.1 Hz, 1H), 2.40 (s, 3H), 1.47 (s, 18H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.5, 166.3, 153.1, 150.4, 141.5, 138.4, 136.1, 131.2, 129.5, 129.4, 129.0, 128.8, 128.0, 126.2, 126.2, 125.0, 124.6, 121.3, 121.2, 58.3, 52.2, 34.5, 30.3, 21.6; HRMS (ESI) calcd. for $(C_{37}H_{40}NaO_5)^+$ 587.2768, found 587.2777; $[\alpha]_D^{23}$ + 17.3 (c 0.4, EtOAc); HPLC (Daicel CHIRALPAK OD-H, Hexane/Isopropanol =98:2, Flow rate =1 mL/min, λ = 220 nm): t_R = 7.96 min (major enantiomer), t_R = 10.18 min (minor enantiomer).

*Diphenyl (S)-2-((3,5-Ditert-butyl-4-hydroxyphenyl)(3-methoxyphenyl)methyl)malonate (**4na**).* The chromatographic purification (petroleum ether/ethyl acetate =20/1) afforded **4na**, white solid, mp 129−131 °C, 115 mg, 99% yield, 97% ee; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.35−7.27 (m, 7H), 7.24−7.18 (m, 2H), 7.08 (s, 1H), 6.84 (d, J = 8.1 Hz, 3H), 6.60 (d, J = 7.7 Hz, 2H), 5.22 (s, 1H), 4.90 (d, J = 12.0 Hz, 1H), 4.82 (d, J = 12.0 Hz, 1H), 3.82 (s, 3H), 1.45 (s, 18H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.4, 166.3, 159.9, 153.1, 150.4, 143.1, 136.1, 131.0, 129.9, 129.5, 129.4, 126.2, 126.1, 124.9, 121.3, 121.2, 120.0, 114.0, 112.4, 58.2, 55.2, 52.1, 34.4, 30.3; HRMS (ESI) calcd. for $(C_{37}H_{40}NaO_6)^+$ 603.2717, found 603.2723; $[\alpha]_D^{23}$ + 10 (c 0.65, EtOAc); HPLC (Phenomenex cellulose-1, Hexane/Isopropanol =98:2, Flow rate =1 mL/min, λ = 220 nm): t_R = 9.78 min (major enantiomer), t_R = 10.87 min (minor enantiomer).

*Diphenyl (S)-2-((3-(Benzyloxy)phenyl)(3,5-ditert-butyl-4-hydroxyphenyl)methyl)malonate (**4oa**).* The chromatographic purification (petroleum ether/ethyl acetate =25/1) afforded **4oa**, white solid, mp 74−76 °C, 126 mg, 96% yield, 95% ee; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.47 (d, J = 7.3 Hz, 2H), 7.41 (t, J = 7.4 Hz, 2H), 7.38−7.28 (m, 8H), 7.26−7.17 (m, 4H), 6.95−6.90 (m, 1H), 6.86 (d, J = 8.1 Hz, 2H), 6.62 (d, J = 8.0 Hz, 2H), 5.23 (s, 1H), 5.10 (s, 2H), 4.92 (d, J = 12.0 Hz, 1H), 4.83 (d, J = 12.0 Hz, 1H), 1.47 (s, 18H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.4, 166.3, 159.1, 153.1, 150.4, 143.2, 137.0, 136.2, 131.0, 129.9, 129.5, 129.4, 128.7, 128.1, 127.6, 126.2, 126.2, 124.9, 121.3, 121.2, 120.3, 115.0, 113.4, 70.0, 58.1, 52.1, 34.5, 30.3; HRMS (ESI) calcd. for $(C_{43}H_{44}NaO_6)^+$ 679.3030, found 679.3036; $[\alpha]_D^{23}$ + 12.7 (c 0.8, EtOAc); HPLC (Daicel CHIRALPAK IA, Hexane/Isopropanol =98:2, Flow rate =1 mL/min, λ = 220 nm): t_R = 10.02 min (major enantiomer), t_R = 11.52 min (minor enantiomer).

*Diphenyl (S)-2-((3-Chlorophenyl)(3,5-ditert-butyl-4-hydroxyphenyl)methyl)malonate (**4pa**).* The chromatographic purification (petroleum ether/ethyl acetate =20/1) afforded **4pa**, white solid, mp 150−152 °C, 114 mg, 97% yield, 97% ee; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.52 (s, 1H), 7.42 (d, J = 7.4 Hz, 1H), 7.39−7.17 (m, 10H), 6.88 (d, J = 7.8 Hz, 2H), 6.60 (d, J = 7.8 Hz, 2H), 5.25 (s, 1H), 4.90 (d, J = 11.9 Hz, 1H), 4.79 (d, J = 12.0 Hz, 1H), 1.45 (s, 18H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.1, 166.1, 153.3, 150.4, 150.3, 143.7, 136.4, 134.6, 130.4, 130.2, 129.6, 129.4, 128.3, 127.4, 126.4, 126.3, 125.9, 124.9, 121.2, 121.2, 57.9, 51.6, 34.5, 30.3; HRMS (ESI) calcd. for $(C_{36}H_{37}ClNaO_5)^+$ 607.2222, found 607.2231; $[\alpha]_D^{23}$ + 24.5 (c 0.4, EtOAc); HPLC (Daicel CHIRALPAK IA, Hexane/Isopropanol =98:2, Flow rate =1 mL/min, λ = 210 nm): t_R = 6.59 min (major enantiomer), t_R = 7.48 min (minor enantiomer).

*Diphenyl (S)-2-((3-Bromophenyl)(3,5-ditert-butyl-4-hydroxyphenyl)methyl)malonate (**4qa**):*[5] The chromatographic purification (petroleum ether/ethyl acetate =30/1) afforded **4qa**, white solid, mp 143−145 °C, 120 mg, 95% yield, 96% ee; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.69 (s, 1H), 7.47 (d, J = 7.7 Hz, 1H), 7.43 (d, J = 7.7 Hz, 1H), 7.38−7.35 (m, 2H), 7.32−7.17 (m, 7H), 6.89 (d, J = 8.4 Hz, 2H), 6.61 (d, J = 8.4 Hz, 2H), 5.26 (s, 1H), 4.90 (d, J = 12.0 Hz, 1H), 4.79 (d, J = 12.0 Hz, 1H), 1.46 (s, 18H); $[\alpha]_D^{23}$ + 25.2 (c 0.4, EtOAc), lit.[5] data for **4qa** of 98% ee: $[\alpha]_D^{25}$ + 31.3 (c 1, EtOAc); HPLC (Daicel CHIRALPAK OD-H, Hexane/Isopropanol =98:2, Flow rate =1 mL/min, λ = 220 nm): t_R = 6.99 min (major enantiomer), t_R = 9.55 min (minor enantiomer).

*Diphenyl (S)-2-((2-Chlorophenyl)(3,5-ditert-butyl-4-hydroxyphenyl)methyl)malonate (**4ra**).* The chromatographic purification (petroleum ether/ethyl acetate =15/1) afforded **4ra**, white solid, mp 100−102 °C, 109 mg, 93% yield, 73% ee; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.66 (d, J = 7.8 Hz, 1H), 7.42 (d, J = 8.0 Hz, 1H), 7.38−7.25 (m, 7H), 7.20 (dd, J = 14.1, 7.3 Hz, 3H), 6.84 (d, J = 7.6 Hz, 2H), 6.61 (d, J = 7.7 Hz, 2H), 5.54 (d, J = 12.3 Hz, 1H), 5.21 (s, 1H), 4.90 (d, J = 12.2 Hz, 1H), 1.43 (s, 18H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.2, 165.9, 153.1, 150.4, 139.3, 136.0, 134.4, 130.4, 129.5,

DOI: 10.1021/acs.joc.6b01906
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129.4, 128.1, 127.3, 127.3, 126.2, 126.1, 125.4, 121.2, 121.1, 57.6, 47.0, 34.4, 30.3; HRMS (ESI) calcd. for $(C_{36}H_{37}ClNaO_5)^+$ 607.2222, found 607.2231; $[\alpha]_D^{26}$ + 22 (*c* 0.75, EtOAc); HPLC (Daicel CHIRALPAK OD-H, Hexane/Isopropanol =98:2, Flow rate =1 mL/min, λ = 220 nm): t_R = 7.81 min (major enantiomer), t_R = 9.47 min (minor enantiomer).

*Diphenyl (S)-2-((3,5-Ditert-butyl-4-hydroxyphenyl)(o-tolyl)-methyl)malonate (**4sa**).* The chromatographic purification (petroleum ether/ethyl acetate =20/1) afforded **4sa**, white solid, mp 121−123 °C, 104 mg, 92% yield, 85% ee; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.68 (d, *J* = 7.7 Hz, 1H), 7.33−7.29 (m, 7H), 7.23−7.20 (m, 4H), 6.78 (d, *J* = 7.8 Hz, 2H), 6.64 (d, *J* = 7.8 Hz, 2H), 5.21 (s, 1H), 5.18 (d, *J* = 12.1 Hz, 1H), 4.91 (d, *J* = 12.1 Hz, 1H), 2.55 (s, 3H), 1.46 (s, 18H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.7, 166.3, 153.0, 150.4, 150.4, 139.9, 136.7, 136.0, 131.1, 130.2, 129.5, 129.4, 126.9, 126.5, 126.2, 126.2, 125.5, 125.4, 121.3, 121.2, 58.3, 47.2, 34.4, 30.3, 20.3; HRMS (ESI) calcd. for $(C_{37}H_{40}NaO_5)^+$ 587.2768, found 587.2773; $[\alpha]_D^{25}$ + 60 (*c* 0.4, EtOAc); HPLC (Daicel CHIRALPAK IA, Hexane/Isopropanol =98:2, Flow rate =1 mL/min, λ = 220 nm): t_R = 5.95 min (major enantiomer), t_R = 6.74 min (minor enantiomer).

*Diphenyl (S)-2-((3,5-Ditert-butyl-4-hydroxyphenyl)(2-methoxyphenyl)methyl)malonate (**4ta**).* The chromatographic purification (petroleum ether/ethyl acetate =10/1) afforded **4ta**, white solid, mp 114−116 °C, 113 mg, 97% yield, 67% ee; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.55 (d, *J* = 7.5 Hz, 1H), 7.43 (s, 2H), 7.30 (dt, *J* = 18.5, 9.2 Hz, 5H), 7.23−7.16 (m, 2H), 7.03 (t, *J* = 7.5 Hz, 1H), 6.92 (d, *J* = 8.2 Hz, 1H), 6.77 (d, *J* = 8.2 Hz, 2H), 6.63 (d, *J* = 8.2 Hz, 2H), 5.30 (d, *J* = 12.3 Hz, 1H), 5.18 (s, 1H), 5.13 (d, *J* = 12.3 Hz, 1H), 3.89 (s, 3H), 1.46 (s, 18H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.9, 166.6, 157.3, 152.8, 150.5, 135.7, 130.9, 129.9, 129.4, 129.4, 128.4, 128.2, 126.1, 125.4, 121.3, 121.3, 120.9, 111.4, 56.6, 55.5, 46.8, 34.4, 30.4; HRMS (ESI) calcd. for $(C_{37}H_{40}NaO_6)^+$ 603.2717, found 603.2725; $[\alpha]_D^{25}$ + 10 (*c* 0.7, EtOAc); HPLC (Daicel CHIRALPAK IA, Hexane/Isopropanol =98:2, Flow rate =1 mL/min, λ = 220 nm): t_R = 8.35 min (major enantiomer), t_R = 9.93 min (minor enantiomer).

*Diphenyl (S)-2-((3,5-Ditert-butyl-4-hydroxyphenyl) (thiophen-2-yl)methyl)malonate (**4ua**).* The chromatographic purification (petroleum ether/ethyl acetate =30/1) afforded **4ua**, white solid, mp 133−135 °C, 98 mg, 88% yield, 85% ee; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.37−7.32 (m, 4H), 7.28−7.21 (m, 4H), 7.17 (t, *J* = 7.4 Hz, 1H), 7.11 (d, *J* = 3.2 Hz, 1H), 6.98 (dd, *J* = 5.0, 3.5 Hz, 1H), 6.91 (d, *J* = 8.1 Hz, 2H), 6.53 (d, *J* = 8.0 Hz, 2H), 5.23 (s, 1H), 5.17 (d, *J* = 11.7 Hz, 1H), 4.68 (d, *J* = 11.7 Hz, 1H), 1.43 (s, 18H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.0, 165.8, 153.3, 150.4, 150.3, 145.2, 136.2, 130.5, 129.5, 129.3, 126.8, 126.2, 126.2, 125.2, 125.1, 124.7, 121.3, 121.1, 59.9, 47.5, 34.4, 30.3; HRMS (ESI) calcd. for $(C_{34}H_{36}NaO_5S)^+$ 579.2176, found 579.2182; $[\alpha]_D^{23}$ + 6 (*c* 0.3, EtOAc); HPLC (Daicel CHIRALPAK OD-H, Hexane/Isopropanol =98:2, Flow rate =1 mL/min, λ = 220 nm): t_R = 6.39 min (major enantiomer), t_R = 7.73 min (minor enantiomer).

*Diphenyl (S)-2-((3,5-Ditert-butyl-4-hydroxyphenyl) (furan-2-yl)-methyl)malonate (**4va**).* The chromatographic purification (petroleum ether/ethyl acetate =25/1) afforded **4va**, white solid, mp 142−144 °C, 100 mg, 92% yield, 90% ee; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.43 (d, *J* = 1.0 Hz, 1H), 7.38 (t, *J* = 7.9 Hz, 2H), 7.31 (s, 2H), 7.29−7.21 (m, 3H), 7.17 (t, *J* = 7.4 Hz, 1H), 7.02 (d, *J* = 7.6 Hz, 2H), 6.56 (d, *J* = 7.9 Hz, 2H), 6.36 (dd, *J* = 3.1, 1.9 Hz, 1H), 6.28 (d, *J* = 3.1 Hz, 1H), 5.24 (s, 1H), 4.96 (d, *J* = 11.6 Hz, 1H), 4.68 (d, *J* = 11.6 Hz, 1H), 1.43 (s, 18H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.1, 165.8, 154.4, 153.4, 150.5, 150.3, 142.1, 136.1, 129.5, 129.3, 128.5, 126.2, 126.2, 125.6, 121.3, 121.2, 110.4, 106.8, 57.4, 45.7, 34.4, 30.3; HRMS (ESI) calcd. for $(C_{34}H_{36}NaO_6)^+$ 563.2404, found 563.2398; $[\alpha]_D^{25}$ + 38.5 (*c* 0.5, EtOAc); HPLC (Daicel CHIRALPAK IA, Hexane/Isopropanol =98:2, Flow rate =1 mL/min, λ = 220 nm): t_R = 7.12 min (major enantiomer), t_R = 7.86 min (minor enantiomer).

*Diphenyl (S)-2-((3,5-Ditert-butyl-4-hydroxyphenyl) (naphthalen-1-yl)methyl)malonate (**4wa**):*[5] The chromatographic purification (petroleum ether/ethyl acetate =25/1) afforded **4wa**, white solid, mp 160−162 °C, 114 mg, 95% yield, 93% ee; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.47 (d, *J* = 8.6 Hz, 1H), 7.86 (d, *J* = 8.0 Hz, 1H), 7.80 (d, *J* = 7.7 Hz, 2H), 7.55 (dd, *J* = 14.2, 6.6 Hz, 2H), 7.48 (t, *J* = 7.3 Hz, 1H), 7.37 (s, 2H), 7.29 (t, *J* = 7.8 Hz, 2H), 7.20 (t, *J* = 7.6 Hz, 3H), 7.12 (t, *J* = 7.3 Hz, 1H), 5.80 (d, *J* = 11.9 Hz, 1H), 5.14 (s, 1H), 5.00 (d, *J* = 11.9 Hz, 1H), 1.39 (s, 18H); $[\alpha]_D^{25}$ + 68 (*c* 0.6, EtOAc), lit.[5] data for **4wa** of 98% ee: $[\alpha]_D^{25}$ + 72.9 (*c* 1, EtOAc); HPLC (Daicel CHIRALPAK IA, Hexane/Isopropanol =90:10, Flow rate =1 mL/min, λ = 220 nm): t_R = 9.75 min (major enantiomer), t_R = 21.51 min (minor enantiomer).

*Diphenyl (R)-2-((4-Hydroxy-3,5-diisopropylphenyl) (phenyl)-methyl)malonate (**4xa**):*[5] The chromatographic purification (petroleum ether/ethyl acetate =10/1) afforded **4xa**, white solid, mp 126−128 °C, 97 mg, 93% yield, 84% ee; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.51 (d, *J* = 7.7 Hz, 2H), 7.38 (t, *J* = 7.5 Hz, 2H), 7.34−7.25 (m, 5H), 7.22−7.18 (m, 4H), 6.76 (d, *J* = 8.3 Hz, 2H), 6.69 (d, *J* = 8.3 Hz, 2H), 4.94 (d, *J* = 12.0 Hz, 1H), 4.86 (s, 1H), 4.83 (d, *J* = 12.0 Hz, 1H), 3.21−3.09 (m, 2H), 1.26 (dd, *J* = 6.7, 3.0 Hz, 12H); $[\alpha]_D^{25}$ + 7.2 (*c* 0.68, EtOAc), lit.[5] data for **4xa** of 95% ee: $[\alpha]_D^{25}$ + 7.2 (*c* 1, EtOAc); HPLC (Daicel CHIRALPAK IA, Hexane/Isopropanol =90:10, Flow rate =1 mL/min, λ = 220 nm): t_R = 9.75 min (major enantiomer), t_R = 21.51 min (minor enantiomer).

*Diphenyl (S)-2-((3-(tert-Butyl)-4-hydroxy-5-methylphenyl) (phenyl)methyl)malonate (**4ya**):*[5] The chromatographic purification (petroleum ether/ethyl acetate =10/1) afforded **4ya**, white solid, mp 130−132 °C, 99 mg, 95% yield, 75% ee; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.50 (d, *J* = 7.4 Hz, 2H), 7.37 (t, *J* = 7.6 Hz, 2H), 7.34−7.25 (m, 6H), 7.22−7.18 (m, 2H), 7.09 (s, 1H), 6.74 (d, *J* = 8.1 Hz, 4H), 4.90 (d, *J* = 12.0 Hz, 1H), 4.79 (d, *J* = 12.0 Hz, 2H), 2.20 (s, 3H), 1.42 (s, 9H); $[\alpha]_D^{25}$ + 5 (*c* 0.64, EtOAc), lit.[5] data for **4ya** of 98% ee: $[\alpha]_D^{25}$ + 10 (*c* 1, EtOAc); HPLC (Daicel CHIRALPAK IA, Hexane/Isopropanol =93:7, Flow rate =1 mL/min, λ = 220 nm): t_R = 15.03 min (major enantiomer), t_R = 20.32 min (minor enantiomer).

*Diphenyl (S)-2-(1-(3,5-Ditert-butyl-4-hydroxyphenyl)ethyl)-malonate (**4za**):*[5] The chromatographic purification (petroleum ether/ethyl acetate =25/1) afforded **4za**, white solid, mp 98−100 °C, 94 mg, 96% yield, 56% ee; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.46−7.43 (m, 2H), 7.33−7.24 (m, 3H), 7.23−7.16 (m, 5H), 6.58−6.56 (m, 2H), 5.23 (s, 1H), 4.11 (d, *J* = 10.7 Hz, 1H), 3.74 (dq, *J* = 10.7, 6.9 Hz, 1H), 1.59 (d, *J* = 6.9 Hz, 3H), 1.47 (s, 18H); $[\alpha]_D^{25}$ + 35.5 (*c* 0.4, EtOAc), lit.[5] data for **4za** of 89% ee: $[\alpha]_D^{25}$ + 57.9 (*c* 1, EtOAc); HPLC (Daicel CHIRALPAK OD-H, Hexane/Isopropanol =99:1, Flow rate =1 mL/min, λ = 220 nm): t_R = 7.44 min (major enantiomer), t_R = 11.12 min (minor enantiomer).

*Diphenyl (R)-2-((4-Hydroxynaphthalen-1-yl) (phenyl)methyl)-malonate (**4a′a**):*[5] The chromatographic purification (petroleum ether/ethyl acetate =3/1) afforded **4a′a**, pale yellow solid, mp 160−162 °C, 78 mg, 80% yield, 12% ee; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.30 (d, *J* = 8.5 Hz, 1H), 8.23 (d, *J* = 8.5 Hz, 1H), 7.57−7.44 (m, 5H), 7.34−7.31 (m, 4H), 7.26−7.18 (m, 4H), 7.12 (t, *J* = 7.4 Hz, 1H), 6.77 (dd, *J* = 11.7, 8.1 Hz, 3H), 6.62 (d, *J* = 8.1 Hz, 2H), 5.81 (d, *J* = 11.8 Hz, 2H), 4.95 (d, *J* = 11.8 Hz, 1H); $[\alpha]_D^{25}$ + 0.5 (*c* 0.4, EtOAc); HPLC (Daicel CHIRALPAK IA, Hexane/Isopropanol =90:10, Flow rate =1 mL/min, λ = 220 nm): t_R = 22.76 min (major enantiomer), t_R = 19.22 min (minor enantiomer).

*Dimethyl (R)-2-((3,5-Ditert-butyl-4-hydroxyphenyl) (phenyl)-methyl)malonate (**4ab**):*[5] The chromatographic purification (petroleum ether/ethyl acetate =25/1) afforded **4ab**, white solid, mp 90−92 °C, 81 mg, 95% yield, 85% ee; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.30−7.24 (m, 4H), 7.18−7.15 (m, 1H), 7.05 (s, 2H), 5.06 (s, 1H), 4.67 (d, *J* = 12.1 Hz, 1H), 4.29 (d, *J* = 12.1 Hz, 1H), 3.53 (s, 6H), 1.38 (s, 18H); $[\alpha]_D^{25}$ + 7 (*c* 0.54, EtOAc); HPLC (Daicel CHIRALPAK OD-H, Hexane/Isopropanol =99:1, Flow rate =1 mL/min, λ = 220 nm): t_R = 7.34 min (major enantiomer), t_R = 8.36 min (minor enantiomer).

*Diethyl (R)-2-((3,5-Ditert-butyl-4-hydroxyphenyl) (phenyl)-methyl)malonate (**4ac**).* The chromatographic purification (petroleum ether/ethyl acetate =20/1) afforded **4ac**, white solid, mp 110−112 °C, 87 mg, 96% yield, 87% ee; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.32 (d, *J* = 7.7 Hz, 2H), 7.25 (t, *J* = 7.6 Hz, 2H), 7.15 (t, *J* = 7.3 Hz, 1H), 7.08 (s, 2H), 5.06 (s, 1H), 4.64 (d, *J* = 12.2 Hz, 1H), 4.27 (d, *J* = 12.2 Hz, 1H), 4.03−3.89 (m, 4H), 1.38 (s, 18H), 0.99 (t, *J* = 7.1 Hz, 3H), 0.94 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 167.9,

DOI: 10.1021/acs.joc.6b01906
J. Org. Chem. 2016, 81, 9315−9325

167.9, 152.6, 142.0, 135.7, 131.7, 128.5, 127.8, 126.7, 124.4, 61.4, 61.3, 58.2, 51.5, 34.3, 30.3, 13.8, 13.8; HRMS (ESI) calcd. for $(C_{28}H_{38}NaO_5)^+$ 477.2611, found 477.2617; $[\alpha]_D^{25}$ + 8 (*c* 0.4, EtOAc); HPLC (Daicel CHIRALPAK IA, Hexane/Isopropanol =98:2, Flow rate =1 mL/min, λ = 220 nm): t_R = 7.33 min (major enantiomer), t_R = 5.97 min (minor enantiomer).

*Dibenzyl (R)-2-((3,5-Ditert-butyl-4-hydroxyphenyl) (phenyl)-methyl)malonate (**4ad**):*[5] The chromatographic purification (petroleum ether/ethyl acetate =20/1) afforded **4ad**, white solid, mp 150−152 °C, 109 mg, 94% yield, 89% ee; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.33−7.23 (m, 10H), 7.19 (t, *J* = 7.2 Hz, 1H), 7.11 (s, 2H), 7.06 (dd, *J* = 7.4, 1.8 Hz, 2H), 7.00 (dd, *J* = 6.4, 2.9 Hz, 2H), 5.11 (s, 1H), 5.03−4.88 (m, 4H), 4.76 (d, *J* = 12.2 Hz, 1H), 4.44 (d, *J* = 12.2 Hz, 1H), 1.38 (s, 18H); $[\alpha]_D^{25}$ + 18.2 (*c* 0.4, EtOAc); HPLC (Daicel CHIRALPAK OD-H, Hexane/Isopropanol =99:1, Flow rate =1 mL/min, λ = 220 nm): t_R = 9.26 min (major enantiomer), t_R = 10.34 min (minor enantiomer).

*Dimethyl (R)-2-((4-Bromophenyl)(3,5-ditert-butyl-4-hydroxyphenyl)methyl)malonate (**4db**).* The chromatographic purification (petroleum ether/ethyl acetate =15/1) afforded **4db**, white solid, mp 146−148 °C, 100 mg, 99% yield, 81% ee; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.40 (d, *J* = 8.2 Hz, 2H), 7.17 (d, *J* = 8.2 Hz, 2H), 7.01 (s, 2H), 5.09 (d, *J* = 1.0 Hz, 1H), 4.64 (d, *J* = 12.0 Hz, 1H), 4.25 (d, *J* = 12.0 Hz, 1H), 3.56 (s, 3H), 3.53 (s, 3H), 1.38 (s, 18H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 168.1, 168.0, 152.7, 141.0, 135.9, 131.7, 130.9, 129.5, 124.2, 120.6, 57.6, 52.7, 52.5, 50.6, 34.4, 30.3; HRMS (ESI) calcd. for $(C_{26}H_{33}BrNaO_5)^+$ 527.1404, found 527.1409; $[\alpha]_D^{25}$ + 12.8 (*c* 0.42, EtOAc); HPLC (Daicel CHIRALPAK IC, Hexane/Isopropanol =99:1, Flow rate =0.8 mL/min, λ = 220 nm): t_R = 9.85 min (major enantiomer), t_R = 10.74 min (minor enantiomer).

*Diethyl (R)-2-((4-Bromophenyl)(3,5-ditert-butyl-4-hydroxyphenyl)methyl)malonate (**4dc**).* The chromatographic purification (petroleum ether/ethyl acetate =20/1) afforded **4dc**, white solid, mp 92−94 °C, 101 mg, 95% yield, 83% ee; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.40 (d, *J* = 8.4 Hz, 2H), 7.19 (d, *J* = 8.4 Hz, 2H), 7.03 (s, 2H), 5.08 (s, 1H), 4.61 (d, *J* = 12.1 Hz, 1H), 4.22 (d, *J* = 12.1 Hz, 1H), 4.05−3.92 (m, 4H), 1.38 (s, 18H), 1.06 (t, *J* = 7.1 Hz, 3H), 0.95 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 167.7, 167.6, 152.7, 141.2, 135.9, 131.6, 131.4, 129.5, 124.3, 120.5, 61.6, 61.4, 57.9, 50.8, 34.3, 30.3, 13.9, 13.8; HRMS (ESI) calcd. for $(C_{28}H_{37}BrNaO_5)^+$ 555.1717, found 555.1711; $[\alpha]_D^{25}$ + 16.0 (*c* 0.44, EtOAc); HPLC (Daicel CHIRALPAK IA, Hexane/Isopropanol =94:6, Flow rate =1 mL/min, λ = 220 nm): t_R = 6.45 min (major enantiomer), t_R = 5.21 min (minor enantiomer).

*Dibenzyl (R)-2-((4-Bromophenyl)(3,5-ditert-butyl-4-hydroxyphenyl)methyl)malonate (**4dd**).* The chromatographic purification (petroleum ether/ethyl acetate =20/1) afforded **4dd**, white solid, mp 120−122 °C, 121 mg, 92% yield, 92% ee; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.33−7.21 (m, 8H), 7.14 (d, *J* = 8.4 Hz, 2H), 7.08−7.02 (m, 4H), 7.02−6.94 (m, 2H), 5.12 (s, 1H), 5.03−4.89 (m, 4H), 4.70 (d, *J* = 12.2 Hz, 1H), 4.36 (d, *J* = 12.2 Hz, 1H), 1.37 (s, 18H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 167.5, 167.4, 152.8, 140.8, 136.0, 135.1, 135.0, 131.7, 131.0, 129.5, 128.5, 128.5, 128.4, 128.3, 128.2, 127.7, 124.3, 120.7, 67.4, 67.3, 58.0, 50.8, 34.4, 30.3; HRMS (ESI) calcd. for $(C_{38}H_{41}BrNaO_5)^+$ 679.2030, found 679.2038; $[\alpha]_D^{25}$ + 10.5 (*c* 0.52, EtOAc); HPLC (Daicel CHIRALPAK IA, Hexane/Isopropanol =98:2, Flow rate =1 mL/min, λ = 220 nm): t_R = 21.63 min (major enantiomer), t_R = 12.23 min (minor enantiomer).

*Dimethyl (S)-2-((3,5-Ditert-butyl-4-hydroxyphenyl)(3-methoxyphenyl)methyl)malonate (**4nb**).* The chromatographic purification (petroleum ether/ethyl acetate =20/1) afforded **4nb**, white solid, mp 100−102 °C, 86 mg, 96% yield, 77% ee; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.20 (t, *J* = 7.9 Hz, 1H), 7.06 (s, 2H), 6.89 (d, *J* = 7.5 Hz, 1H), 6.84 (s, 1H), 6.71 (dd, *J* = 8.2, 2.1 Hz, 1H), 5.06 (s, 1H), 4.64 (d, *J* = 12.1 Hz, 1H), 4.28 (d, *J* = 12.1 Hz, 1H), 3.76 (s, 3H), 3.56 (s, 3H), 3.52 (s, 3H), 1.39 (s, 18H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 168.2, 168.2, 159.6, 152.6, 143.4, 135.7, 131.3, 129.5, 124.4, 119.9, 113.8, 112.0, 57.9, 55.1, 52.6, 52.4, 51.2, 34.4, 30.3; HRMS (ESI) calcd. for $(C_{27}H_{36}NaO_6)^+$ 479.2404, found 479.2408; $[\alpha]_D^{25}$ + 13.9 (*c* 0.54, EtOAc); HPLC (Daicel CHIRALPAK IC, Hexane/Isopropanol =99:1, Flow rate =1 mL/min, λ = 220 nm): t_R = 12.40 min (major enantiomer), t_R = 15.28 min (minor enantiomer).

*Diethyl (S)-2-((3,5-Ditert-butyl-4-hydroxyphenyl)(3-methoxyphenyl)methyl)malonate (**4nc**).* The chromatographic purification (petroleum ether/ethyl acetate =25/1) afforded **4nc**, white solid, mp 125−127 °C, 96 mg, yield 99%, 85% ee; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.18 (t, *J* = 7.9 Hz, 1H), 7.08 (s, 2H), 6.92 (d, *J* = 7.6 Hz, 1H), 6.86 (s, 1H), 6.71 (dd, *J* = 8.2, 2.2 Hz, 1H), 5.05 (s, 1H), 4.61 (d, *J* = 12.2 Hz, 1H), 4.25 (d, *J* = 12.2 Hz, 1H), 4.02 (q, *J* = 7.1 Hz, 2H), 3.96 (qd, *J* = 7.1, 2.9 Hz, 2H), 1.39 (s, 18H), 1.04 (t, *J* = 7.1 Hz, 3H), 0.94 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 167.9, 167.8, 159.6, 152.6, 143.6, 135.7, 131.5, 129.4, 124.4, 120.0, 113.8, 112.0, 61.4, 61.3, 58.1, 55.1, 51.5, 34.3, 30.3, 13.8, 13.8; HRMS (ESI) calcd. for $(C_{29}H_{40}NaO_6)^+$ 507.2717, found 507.2727; $[\alpha]_D^{25}$ + 14.4 (*c* 0.54, EtOAc); HPLC (Daicel CHIRALPAK OD-H, Hexane/Isopropanol =98:2, Flow rate =1 mL/min, λ = 220 nm): t_R = 5.77 min (major enantiomer), t_R = 6.46 min (minor enantiomer).

*Dibenzyl (S)-2-((3,5-Ditert-butyl-4-hydroxyphenyl)(3-methoxyphenyl)methyl)malonate (**4nd**).* The chromatographic purification (petroleum ether/ethyl acetate =20/1) afforded **4nd**, white solid, mp 147−149 °C, 116 mg, 96% yield, 83% ee; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.30−7.23 (m, 6H), 7.18 (t, *J* = 7.9 Hz, 1H), 7.13−7.05 (m, 4H), 7.01−6.96 (m, 2H), 6.92 (d, *J* = 7.7 Hz, 1H), 6.85 (s, 1H), 6.73 (dd, *J* = 8.2, 2.1 Hz, 1H), 5.11 (s, 1H), 5.00−4.91 (m, 4H), 4.72 (d, *J* = 12.2 Hz, 1H), 4.42 (d, *J* = 12.2 Hz, 1H), 3.73 (s, 3H), 1.38 (s, 18H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 167.80, 167.6, 159.7, 152.7, 143.3, 135.8, 135.2, 135.2, 131.5, 129.6, 128.5, 128.5, 128.2, 128.2, 128.1, 127.7, 124.4, 120.0, 113.7, 112.3, 67.2, 67.1, 58.2, 55.1, 51.4, 34.4, 30.3; HRMS (ESI) calcd. for $(C_{39}H_{44}NaO_6)^+$ 631.3030, found 631.3036; $[\alpha]_D^{25}$ + 13.2 (*c* 0.8, EtOAc); HPLC (Daicel CHIRALPAK IA, Hexane/Isopropanol =95:5, Flow rate =1 mL/min, λ = 220 nm): t_R = 9.88 min (major enantiomer), t_R = 8.22 min (minor enantiomer).

Gram Scale Preparation of 4aa. A mixture of *para*-quinone methides **2a** (1.24 g, 4.2 mmol), malonate **3a** (1.04 g, 4 mmol), and catalyst **1f** (28 mg, 0.04 mmol) in toluene (10 mL) was cooled to −40 °C, and then K_2CO_3 (1.65 g, 12 mmol) was added. The resulting mixture was stirred vigorously at the same temperature and monitored by TLC. Upon complete consumption of malonate **3a**, the reaction was quenched with a saturated aqueous solution of NH_4Cl (30 mL), extracted with ethyl acetate (3 × 20 mL). The combined organic layers were dried over anhydrous Na_2SO_4 and filtered. The volatile solvent of filtrate was evaporated under reduced pressure, and the resulting residue was purified by flash column chromatography on silica gel eluting with petroleum ether/ethyl acetate to afford the addition product **4aa** (2.05 g, 3.73 mmol) in 93% yield with 95% ee.

Further Elaboration of 4aa and 4qa. To a solution of **4aa** (2.05 g, 3.73 mmol) in THF (32 mL) at rt was added LiOH·H_2O (0.78 g, 18.6 mmol, 5 equiv) in H_2O (8 mL). Stirring was maintained for 2 h whereupon the reaction mixture was diluted with H_2O (50 mL) and washed with Et_2O (2 × 50 mL). The aqueous layer was acidified to pH 2 using 1 M HCl (aq) and extracted with CH_2Cl_2 (3 × 50 mL). The combined organic layers were washed with brine (30 mL), dried over anhydrous Na_2SO_4 and filtered. The volatile solvent of filtrate was evaporated under reduced pressure, and the residue was purified by flash column chromatography on silica gel eluting with petroleum ether/ethyl acetate to afford crude malonic acid **7a** (1.45 g) as yellow oil, which was sufficiently pure for next step. An analytical pure sample for characterization was obtained by flash column chromatography on silica gel eluting with petroleum ether/ethyl acetate (1/2).

*(R)-2-((3,5-Ditert-butyl-4-hydroxyphenyl) (phenyl)methyl)-malonic Acid (**7a**).* Yellow oil, 1.45 g, 95% yield; ^{1}H NMR (500 MHz, DMSO) δ 12.61 (br, 2H), 7.35 (d, *J* = 7.6 Hz, 2H), 7.25 (t, *J* = 7.6 Hz, 2H), 7.13 (t, *J* = 7.6 Hz, 1H), 7.07 (s, 2H), 6.78 (s, 1H), 4.46 (d, *J* = 12.2 Hz, 1H), 4.25 (d, *J* = 12.2 Hz, 1H), 1.34 (s, 18H); ^{13}C NMR (125 MHz, DMSO) δ 169.6, 169.4, 152.7, 143.7, 139.3, 133.5, 128.8, 128.1, 126.6, 124.3, 57.7, 51.0, 35.00, 30.9; HRMS (ESI) calcd. for $(C_{24}H_{30}NaO_5)^+$ 421.1985, found 421.1993.

A solution of **7a** (1.40 g, 3.51 mmol) in DMF (18.0 mL) and H_2O (2.0 mL) was heated at 100 °C for 1 h. The mixture was cooled to

DOI: 10.1021/acs.joc.6b01906
J. Org. Chem. 2016, 81, 9315−9325

room temperature, and Et_2O (50 mL) was added. The organic phase was washed with saturated with half saturated aqueous brine (3 × 30 mL). The aqueous phase was separated and extracted with Et_2O (50 mL). The combined organic phases were washed with half saturated brine (30 mL), dried over anhydrous Na_2SO_4 and filtered. The volatile solvent was removed under reduced pressure to afford mono acid **8a** (1.18 g) as pale yellow oil with 93% yield over 2 steps. An analytical pure sample for characterization was obtained by flash column chromatography on silica gel eluting with petroleum ether/ethyl acetate (3/1).

*(R)-3-(3,5-Ditert-butyl-4-hydroxyphenyl)-3-phenylpropanoic Acid (**8a**).* Pale yellow oil, 1.18 g, 98% yield; ^{1}H NMR (500 MHz, $CDCl_3$) δ7.28−7.22 (m, 4H), 7.18−7.15 (m, 1H), 7.00 (s, 2H), 6.05 (br, 1H), 5.07 (s, 1H), 4.42 (t, *J* = 7.6 Hz, 1H), 3.13−2.92 (m, 2H), 1.39 (s, 18H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 178.2, 152.3, 143.8, 135.8, 134.0, 128.5, 127.7, 126.4, 124.2, 46.7, 41.2, 34.4, 30.3; HRMS (ESI) calcd. for $(C_{23}H_{30}NaO_3)^+$ 377.2087, found 377.2088.

To a solution of mono acid **8a** (1.10 g, 3.10 mol) in anhydrous methanol (15 mL), concentrated H_2SO_4 (30 μL) was added. The resulting solution was refluxed for 12 h and then allowed to cool to room temperature. The reaction mixture was concentrated under reduced pressure. The residue was redissolved in ethyl acetate (50 mL), and washed with saturated aqueous sodium bicarbonate (30 mL), brine (30 mL) and dried over Na_2SO_4. After filtration, the volatile solvents were removed under reduced pressure to afford crude ester (1.09 g) as light yellow oil. To a solution of the crude ester in dry toluene (40 mL) was added $AlCl_3$ (1.81 g, 13.55 mol) in one portion while stirring under an atomosphere of argon. The reaction mixture was then heated in an oil bath of 60 °C for 1 h. Then H_2O (30 mL) was added to quench the reaction, and the resulting mixture was extracted with ethyl acetate (3 × 30 mL). The combined extracts were dried over anhydrous Na_2SO_4. The solvent of filtrate was concentrated under reduced pressure. The residue obtained was purified by flash column chromatography on silica gel to afford the **6a** (0.687 g, 2.68 mmol) as a pale yellow solid with 86% yield over 2 steps.

*Methyl (R)-3-(4-Hydroxyphenyl)-3-phenylpropanoate (**6a**):*[5] The chromatographic purification (petroleum ether/ethyl acetate =3/1) afforded 6a, pale yellow solid, mp 65−67 °C, 0.687 g, 86% yield, 95% ee; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.29−7.17 (m, 5H), 7.08 (d, *J* = 8.5 Hz, 2H), 6.71 (d, *J* = 8.5 Hz, 2H), 5.60 (s, 1H), 4.49 (t, *J* = 8.0 Hz, 1H), 3.59 (s, 3H), 3.04 (d, *J* = 8.0 Hz, 2H); $[\alpha]_D^{25}$ + 0.2 (*c* 0.6, EtOAc), lit.[5] data for **6a** of 98% ee: $[\alpha]_D^{25}$ + 10 (*c* 1, EtOAc); HPLC (Daicel CHIRALPAK IA, Hexane/Isopropanol =90:10, Flow rate =1 mL/min, λ = 220 nm): t_R = 11.69 min (major enantiomer), t_R = 10.48 min (minor enantiomer).

*Methyl (S)-3-(3-Bromophenyl)-3-(4-hydroxyphenyl)propanoate (**6b**).* This compound was prepared from **4qa** according to the procedure for **6a**; the chromatographic purification (petroleum ether/ethyl acetate =3/1) afforded **6b**, pale yellow solid, mp 56−58 °C, actual mass 237 mg, 71% overall yield; ^{1}H NMR (500 MHz, DMSO) δ 9.26 (s, 1H), 7.46 (s, 1H), 7.35−7.17 (m, 3H), 7.10 (d, *J* = 8.5 Hz, 2H), 6.64 (d, *J* = 7.4 Hz, 2H), 4.33 (t, *J* = 8.0 Hz, 1H), 3.47 (s, 3H), 3.12−2.95 (m, 2H); ^{13}C NMR (125 MHz, DMSO) δ 172.1, 156.4, 147.9, 133.9, 131.0, 130.6, 129.5, 128.9, 128.8, 127.8, 126.9, 122.2, 115.7, 51.8, 45.9; HRMS (ESI) calcd. for $(C_{16}H_{15}BrNaO_3)^+$ 357.0097, found 357.0093; $[\alpha]_D^{32}$ − 3.2 (*c* 0.76, EtOAc); HPLC (Daicel CHIRALPAK IA, Hexane/Isopropanol =93:7, Flow rate =1 mL/min, λ = 220 nm): t_R = 16.38 min (major enantiomer), t_R = 15.16 min (minor enantiomer).

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.joc.6b01906.

Details of optimization of reaction conditions, NMR and HPLC spectra of the isolated compounds (PDF)

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Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

The generous financial support from the National Natural Science Foundation of China (No. 21272150 and No. 21672137) is acknowledged.

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