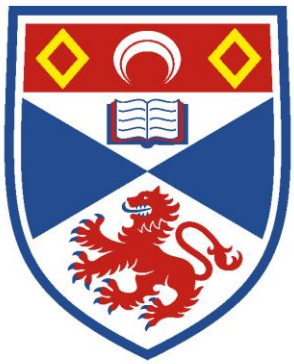
Acylative Kinetic Resolution of Biaryl Alcohols Using Isothiourea Catalysis

Shen Qu



University of St Andrews

This thesis is submitted in partial fulfilment for the degree of MPhil

at the

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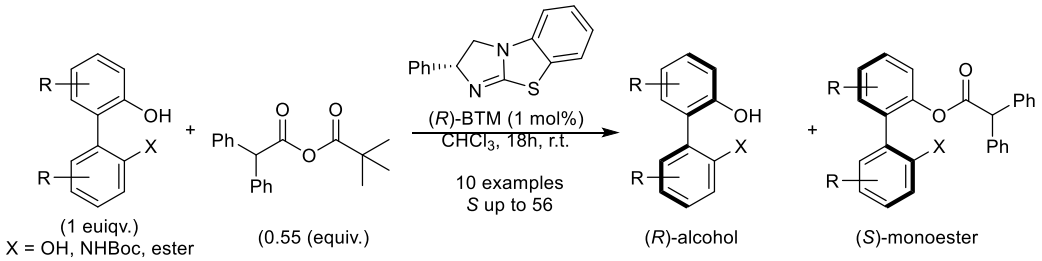
Abstract

This project aims to develop the first isothiourea-catalyzed acylative kinetic resolution (KR) of biaryl diols. To place this work in context, a brief introduction to chirality and its importance, an overview of methods for isolating enantiopure compounds, as well as an introduction to, and theories behind, KR is given in the Chapter 1. This chapter finishes by summarising previous publications concerning the KR of biaryl compounds and the use of isothiourea catalysts. Chapter 2 details the optimization of the model KR of (±)-BINOL, which includes screenings 3 isothiourea catalysts, 10 bench-stable solvents, 21 anhydrides as acyl donors, 3 catalyst loadings and 4 different temperatures to deliver optimal selectivity. The optimized conditions for the KR of BINOL was found to be: BTM (1 mol%); 2,2-diphenylacetic pivalic anhydride (0.55 equiv.); room temperature for 18 hours, giving high selectivity (*S* = 55) at 50% conversion while minimizing the formation of an unwanted diacylated side-product. The scope and limitation of this procedure were evaluated in Chapter 3, which details the synthesis and attempted KR of 13 biaryl compounds aimed to test the generality of the procedure established in Chapter 2 (Scheme 1). It was found that the selectivity of the KR is sensitive to the steric bulk and/or electronic property of the substituents on the biaryl rings. While 6/6'- and 7,7'- substitution on BINOL are well-tolerated, as well as the 4/4', 5/5' and 6/6'-substitution on 2,2'-biphenol, substrates bearing 3/3'-substitution could not be tolerated by this procedure. The successful KR of *N*-Boc-NOBIN and unsuccessful KR of mono-*O*-protected BINOL derivatives, suggests that two H-bond donors are required within the substrate to have good selectivity and reactivity in acylative KR. A proposed catalytic cycle, as well as a simple stereochemical model that can be used to rationalise the observed sense of asymmetric induction, is discussed in Chapter 4.



Scheme 1. General procedure for the developed KR of biaryl alcohols

Abbreviation

Ar	Aromatic
aq	Aqueous
ASAP	Atmospheric solids analysis probe
BINOL	[1,1'-Binaphthalene]-2,2'-diol
BINAP	2,2'-*Bis*(diphenylphosphanyl)-1,1'-binaphthalene
Boc	*Tert*-butyloxycarbonyl
br	Broad
BTM	Benzotetramisole
Bu	Butyl
Bz	Benzoyl
c	Conversion
°C	Celsius degrees
Cat.	catalyst
cm^{-1}	Wave number
CV	Column volume
d	Doublet
dba	Tris(dibenzylideneacetone)
DCC	*N,N'*-Dicyclohexylcarbodiimide
DHIP	2,3-Dihydroimidazo-[1,2-α]pyridine
DHPB	3,4-Dihydro-2H-pyrimido[2,1-b]benzothiazole
DI	Deionized
DKR	Dynamic kinetic resolution
DMAP	4-Dimethylaminopyridine
ee	Enantiomeric excess
EDCI	3-(Ethyliminomethyleneamino)-*N*,*N*-dimethylpropan-1-amine
equiv.	Equivalent(s)
er	Enantiomeric ratio
Et	Ethyl
g	Gram(s)
h	Hour(s)
HBTM	Homobenzotetramisole
het	Heteroatom
HMPA	Hexamethylphosphoramide
HPLC	High performance liquid chromatography
HRMS	High resolution mass spectrometry
Hz	Hertz
i	*Ipso*
*i*Pr	*Iso*-propyl
IR	Infrared
J	Coupling constant
k	Rate constant
KR	Kinetic resolution
M	Molar
m	Multiplet
m	*Meta*
m/z	Mass to charge ratio
Me	Methyl

mg	Milligram(s)
min	Minute(s)
mL	Millilitre(s)
mol	Mole(s)
mmol	Millimole(s)
mp	Melting point
NHC(s)	N-Heterocyclic carbine(s)
NMR	Nuclear magnetic resonance
NOBIN	2'-Amino-[1,1'-binaphthalen]-2-ol
NSI	Nanospray ionization
o	*Ortho*
p	*Para*
Ph	Phenyl
piv	Pivalic
ppm	Parts per million
q	Quartet
QUINAP	1-(2-(Diphenylphosphanyl)naphthalen-1-yl)isoquinoline
r.t.	Room temperature
s	Singlet
S	*S* factor
Sat.	Saturated
t	Triplet
T	Temperature
*t*AmOH	*Tert*-Amyl alcohol
*t*Bu	tert-butyl
TLC	Thin layer chromatography
TM	Tetramisole
TMEDA	*N*,*N*,*N*',*N*'-Tetramethylethane-1,2-diamine
TMS	Trimethylsilyl
TS	Transition state
t_R	Retention time
VAPOL	3,3'-diphenyl-[2,2'-binaphthalene]-1,1'-diol
δ	NMR chemical shift
ν_{max}	Infrared absorption

Chapter 1: Introduction

1.1 Chirality

The term chiral, coming from the Greek word *χειρ* which means *hand*, is used to describe a geometric property of the asymmetric nature of a given object.[1] In chemistry, a chiral structure can exist in two distinct configurations, where one is a non-superimposable mirror-image of the other. Opposite configurations of a chiral molecule are referred to as the two enantiomers. A chiral molecule does not have any plane of symmetry or inversion centre. Other than optical rotation dispersion, and unless in a chiral environment, a pair of enantiomers possess identical chemical and physical properties. Chiral molecules are optically active and a pair of enantiomers can rotate plane-polarised light with the same degree of rotation in opposite directions, one being dextrorotatory ((+)-rotation) and the other being levorotatory ((-)-rotation).[1] Ever since Louis Pasteur separated the two enantiomers of the sodium ammonium salt of tartaric acid in 1848,[2] chirality has become a very interesting and important topic among chemistry researchers.

The many different types of chirality can be subclassified depending on the spatial arrangements of the atoms within a molecule (Figure 1).[3] The most common type is point chirality (Figure 1a), where a stereogenic centre is present in the molecule. This is most commonly observed for a tetrahedral carbon atom that bears four different substituents as observed in amino acids such as serine (Figure 1a). Another common classification is that of axial chirality, where two non-superimposable configurations, referred to as atropisomers of one another, are present due to the restricted rotation about a bond in the molecule. This type of chirality is commonly found in biaryl compounds (as exemplified by BINOL (Figure 1b)) and allenes. Planar chirality is present when two non-coplanar rings cannot rotate easily about the chemical bonds connecting them, and the plane of symmetry is lost by adding substituents to the rings. This type of chirality is commonly found in monosubstituted paracyclophanes (Figure 1c). Helical chirality results from helicity itself and commonly presents in DNA and proteins (as exemplified by hexahelicene (Figure 1d)). The absolute configuration of enantiomers are assigned using Cahn–Ingold–Prelog (CIP) priority rules.[4]

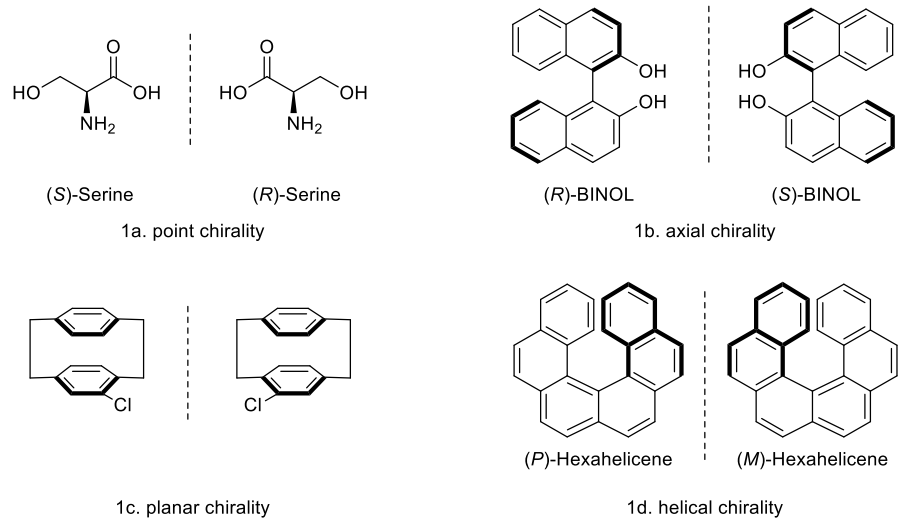


Figure 1. Examples of different types of chirality

Our biosphere is a chiral world, with many natural organic molecules associated with life are often found to be chiral. Moreover, homochirality is a fascinating feature developed over the evolution of life on earth.[5] All the basic chiral building blocks are almost exclusively one of the possible stereoisomers. For example, only D-ribose and 2-deoxy-D-ribose are found to be monomer units of RNA and DNA polymers respectively, while D-glucose is found as the exclusive monomer of glycogen, cellulose and starch. Similarly, natural building blocks for proteins are mostly found as L-amino acids, which makes proteins inherently chiral. Consequently, protein receptors can target one structurally specific molecule, and hence can bind specifically to a single enantiomer to generate responses.

The chirality of proteins therefore has great biological significance. For example, odour perception is closely linked to chirality.[6] The olfactory protein receptors in the nasal cavity are each highly specialised in differentiating structures and configurations.[7] Because of the specificity of these interactions and their corresponding signal responses, enantiomers can have different scents. For example, (*R*)-carvone has a minty smell while (*S*)-carvone smells of caraway,[8] (*R*)-limonene smells of oranges while (*S*)-limonene smells of lemon (Figure 2).

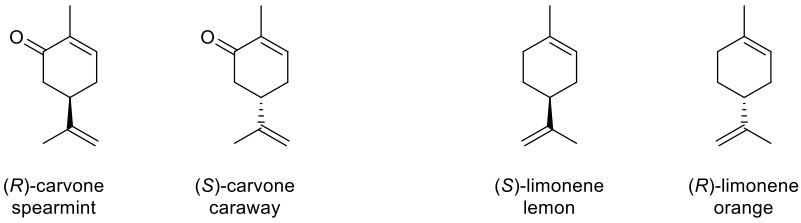


Figure 2. Structures and scents of enantiomers of carvone and limonene

Likewise, chirality also plays a vital role in drug design. The incorporation of stereogenic centres gives molecules higher structural complexity and may lead to the desired physical properties or biological selectivities.[9] Again, based on the interactions between chiral molecules and chiral protein receptors, a pair of enantiomers could trigger different biological effects. While one enantiomer triggers a beneficial effect, the other could be differently beneficial, inactive or even harmful.[10] For example, the two enantiomers of Methorphan (Figure 3) have different beneficial effects. Dextromethorphan **2a** is an over-the-counter cough suppressant whilst levomethorphan **2b** is a potent opioid analgesic.[11] L-DOPA **3a** helps to replenish the brain's supply of dopamine, hence used to treat Parkinson's disease,[12] while D-DOPA **3b** is inactive. (*S*)-Naproxen **4a** is known to have beneficial anti-inflammatory effects while (*R*)-Naproxen **4b** causes liver poisoning.[13]

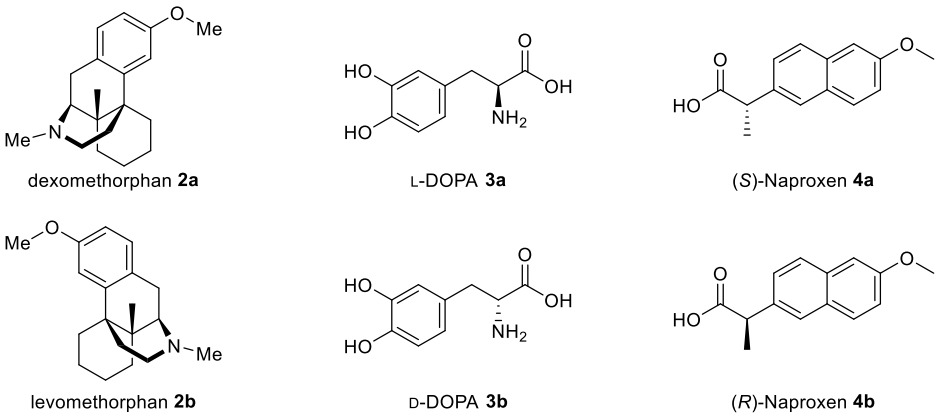


Figure 3. Enantiomers of methorphan (**2a**, **2b**), DOPA (**3a**, **3b**) and Naproxen (**4a**,**4b**)

1.1.1 Biaryl compounds

Overview: This thesis is concerned with studies towards the enantioselective acylative KR of biaryl diols using Lewis base catalysis. As such, the remainder of this introduction chapter will aim to place this work in context by summarising the inherent chirality of biaryl diols, their utility in synthesis and catalysis, as well as methods for their preparation.

Chiral biaryls are found in many bioactive structures and natural products. For example, gossypol **5a** (yellow pigment; antimalarial) and isokotanin A **5b** (Figure 4) both contain a chiral biaryl motif. Similarly, the structure of vancomycin **5c** (a potent antibiotic),[14] contains a biaryl motif, with derivatives of interest for continued pharmaceutical research and development.[15]

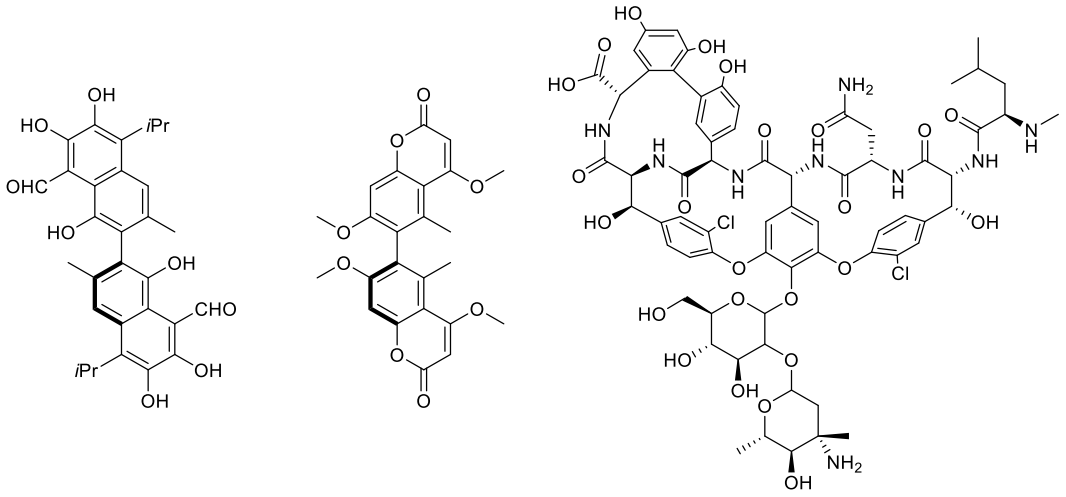


Figure 4. Gossypol **5a**, isokotanin A **5b** and vancomycin **5c**

In chiral biaryl structures, the stereogenicity is a consequence of restricted rotation about the C(sp^2)-C(sp^2) single bond separating the biaryl units. The high energy barrier of rotation is usually a result of the steric effects of the 2/2' and 6/6' substitutions, which puts the biaryl structure into an orthogonal orientation (Figure 5). Theoretically, if enough energy is provided, the two atropisomers can interconvert by rotating about the C(sp^2)-C(sp^2) single bond that connects the two aryl groups. Isolation of the two atropisomers is possible only if a high enough energy barrier can be provided by the restricted rotation about that single bond.[16] Analytical separation is only possible if the interconversion of the two enantiomers has a half-life of 1000 s or longer.[17]

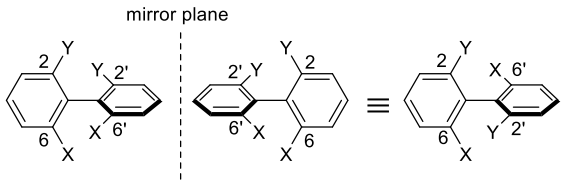


Figure 5. Non-superimposable mirror images of chiral biaryl

Based on their structural features, biaryl compounds can also be used as auxiliaries, ligands or catalysts in asymmetric synthesis to direct the generation of new chiral elements.[18] Many biaryl compounds have been employed for such purposes. Representative examples include, but are not limited to, [1,1'-binaphthalene]-2,2'-diol (BINOL) **6**, 2,2'-*bis*(diphenylphosphanyl)-1,1'-binaphthalene (BINAP) **7**, 2'-amino-[1,1'-binaphthalen]-2-ol (NOBIN) **8**, 3,3'-diphenyl-[2,2'-binaphthalene]-1,1'-diol (VAPOL) **9** and 1-(2-(diphenylphosphanyl)naphthalen-1-

yl)isoquinoline (QUINAP) **10** (Figure 6). The ready modification of the BINOL[19] and BINAP[20] skeletons has ensured that these are the most widely used. As a representative example, in 1979, Noyori showed that BINOL is a highly competent chiral ligand for the reduction of ketones using $LiAlH_4$, giving the alcohol products in up to 99% *ee*.[21] He subsequently used BINAP as a chiral ligand in metal-catalysed asymmetric hydrogenation reactions and allylic hydrogen shift reactions.[22,23] Noyori was co-awarded the Nobel Prize in Chemistry in 2001 for his work with BINAP-derived highly selective chiral catalysts.[24] The wide use of chiral biaryl compounds in reactions such as Diels-Alder reactions, ene reactions, carbonyl reductions, Michael addition reactions, metal-catalysed allylic allylations and more[25] is demanding more efficient methods with lower costs for the synthesis and/or isolation of enantiomerically pure forms of biaryl compounds.

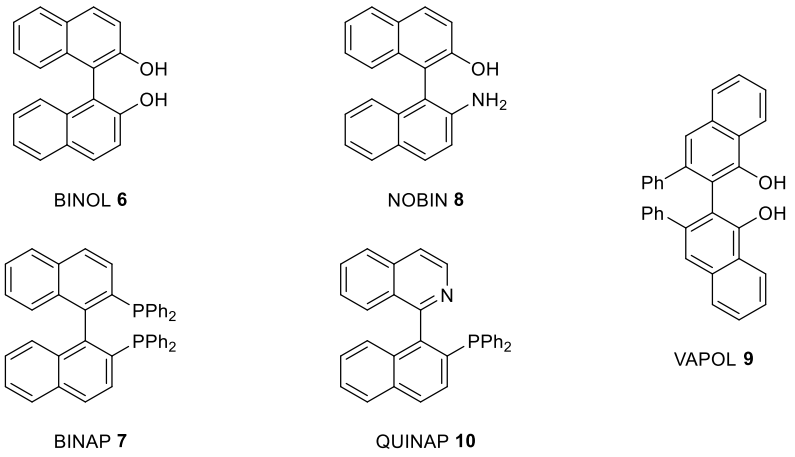


Figure 6. Structures of BINOL **6**, BINAP **7**, NOBIN **8**, VAPOL **9** and QUINAP **10**

1.2 Methods for obtaining enantioenriched compounds

The traditional methods for obtaining enantioenriched compounds can be classified into three general types: chiral pool, which starts from naturally-occurring chiral compounds; enantioselective synthesis, which starts from prochiral compounds and encompasses chiral auxiliary and chiral catalytic methods; and resolution, which starts from racemates (Figure 7).

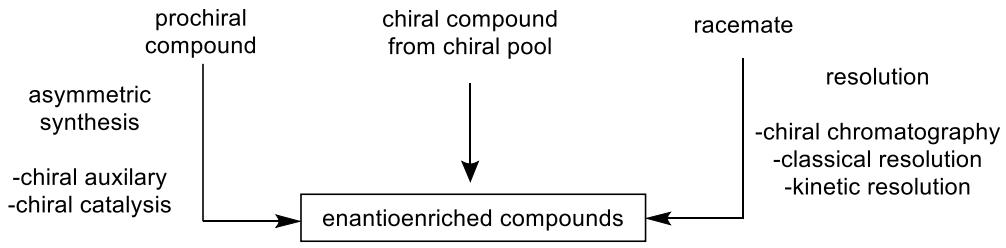


Figure 7. Three general types of methods for obtaining enantioenriched compounds

The chiral pool: Syntheses employing the chiral pool approach choose a suitable chiral starting material from a collection of cheap and readily available natural products, such as amino acids, sugars or metabolites from plants and microorganisms. The stereogenic centre(s) within the starting material will be maintained or used to relay stereochemical information throughout the whole process. Although this method usually has fairly low cost, it is heavily limited by the number, structure, and quantity of naturally-occurring chiral structures. Despite these limitations, this method is employed in the synthesis of an antiinfluenza drug Olsetamivir (Tamiflu®), starting from shikimic acid - originally found as a metabolite of Chinese star anise (Figure 8).[26] This drug was widely used and stocked in 2005 during the H5N1 Avian influenza 'Bird flu' epidemic in Southeast Asia. Due to the lack of availability of naturally-occurring biaryl compounds, the chiral pool strategy is not commonly employed in the synthesis of enantioenriched biaryls.

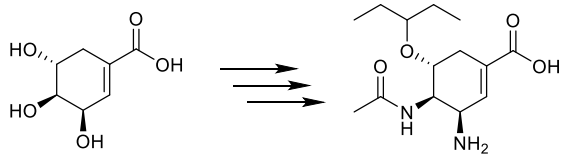
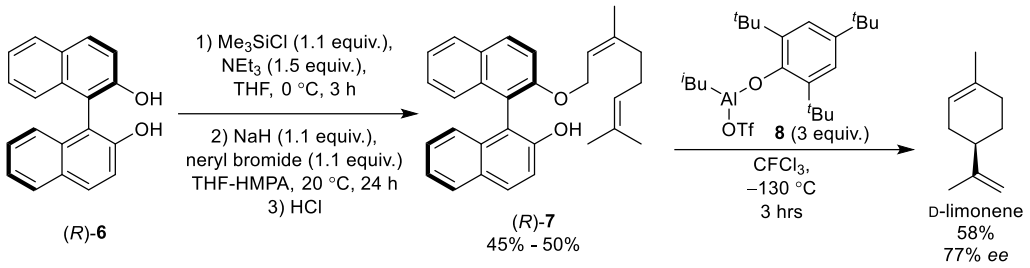


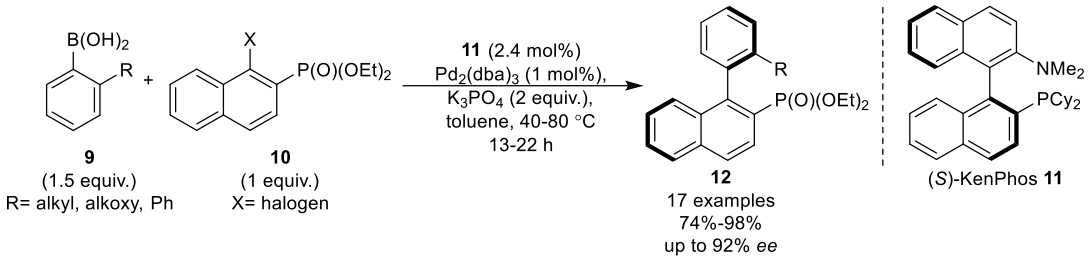
Figure 8. Structures of Shikimic acid and Olsetamivir

Asymmetric Synthesis: Asymmetric synthesis, or stereoselective synthesis, creates new stereogenic elements with control of configuration from a prochiral starting material through the use of either chiral auxiliaries or chiral catalysis. The chiral auxiliary approach requires a functional group that can be covalently bound to a given (usually achiral) starting material. Chiral auxiliaries can direct the stereochemical course of subsequent reactions on the substrate, selectively generating a preferred product diastereoisomer. However, the auxiliary needs to be incorporated into a synthesis in a stoichiometric manner, and removed at the end of the synthesis in order to obtain the target compound, which inherently increases the cost of the process and generates more waste unless the auxiliary can be readily recycled. As a representative example of this approach, in 1983, Yamamoto and co-workers reported an asymmetric synthesis of D-limonene, where (*R*)-BINOL (*R*)-**6** was utilised as a chiral auxiliary for the first time.[27] (*R*)-BINOL (*R*)-**6** was attached through monosilylation and alkylation, and D-limonene was isolated in moderate yield and moderate enantiopurity after a cyclisation mediated by organoaluminium reagent **8** (Scheme 2). (*S*)-BINOL (*S*)-**6** has also been reported to be used as a chiral auxiliary in the synthesis of uncommon (*R*)-α-amino acids.[28]



Scheme 2. (*R*)-BINOL (*R*)-**6** as chiral auxiliary in the asymmetric synthesis of D-limonene

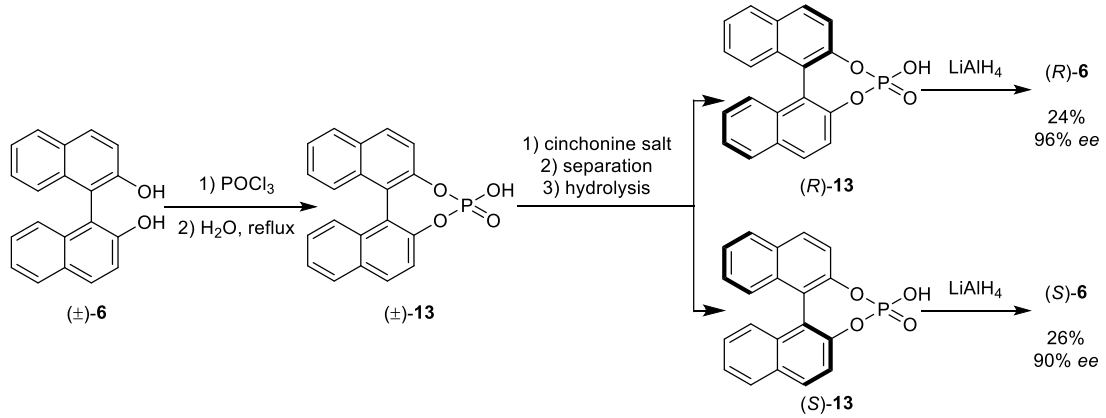
Enantioselective catalysis, in contrast, uses only a substoichiometric amount of a chiral catalyst to direct the formation of the new stereogenic centre or element. The catalysts used in such processes can usually be classified as being based upon enzymes (biocatalysis), metal complexes (metal catalysis) or organic structures (organocatalysis). While using non-stoichiometric quantities of a chiral catalyst can help reduce the costs of a given process, syntheses are however limited by the availability, stability, recyclability and specificity of the catalysts. A number of enantioselective metal catalysed synthetic routes have been developed for obtaining enantioenriched biaryl compounds.[29] For example, Buchwald and co-workers reported one of the earliest cases to isolate enantioenriched biaryl compounds using an enantioselective Suzuki-Miyaura coupling reaction (Scheme 3).[30] A number of biaryl phosphonates **12** were successfully isolated in high yields and high enantiopurity using a Pd catalyst with an (*S*)-KenPhos ligand **11**.



Scheme 3. Synthesis of biaryl phosphonates through Suzuki-Miyaura coupling reactions

Resolution: The resolution strategy can be subdivided into three groups: chiral chromatography, classical resolution and kinetic resolution (KR). Chiral chromatography uses columns with a chiral stationary phase, with the separation of the enantiomers achieved based on the differences in the affinity between the enantiomers and the chiral stationary phase. This results in different retention times for each enantiomer. The high cost of chiral columns, however, makes this method non-ideal for large-scale synthesis.

Classical resolution uses a stoichiometric amount of a chiral enantiopure reagent to convert a racemic mixture into a mixture of two diastereoisomers. Separation then relies on the different physical properties of the diastereoisomers, such as solubility and melting/boiling points.[31] Jacques and co-workers were the first to report the chemical resolution of BINOL (±)-**6** through the cyclic binaphthyl phosphoric acids **13**. The racemic acid **13** reacts with cinchonine salt to give two diastereomeric salts, which were then separated and hydrolysed back to enantioenriched acids (*R*)/(*S*)-**13**. Enantioenriched BINOL (*R*)/(*S*)-**6** were isolated after treating the enantioenriched acids (*R*)/(*S*)-**13** with $LiAlH_4$ (Scheme 4).[32]



Scheme 4. Chemical resolution of BINOL (±)-**6** by Jacques and co-workers

In contrast, KR separates a racemate based on the different reaction rates between the two enantiomers and a chiral enantiopure reagent or catalyst-derived species, ideally transforming only one enantiomer, resulting in easier separation of the mixture. More details on KR will be discussed in the next section.

The choice of the most suitable methodology for obtaining a given enantioenriched compound should be made specific to the case. A collection of factors should be taken into account in order to find the best methodology, such as the efficiency and the costs of the process; the costs, availability, stability and toxicity of the reagents; the reaction conditions and even the expertise of the chemists involved. Although asymmetric synthesis is arguably the most popular method for obtaining enantioenriched compounds in academia, resolution remains an area of interest in research from an industrial and academic point of view. This project focuses on KR of biaryl compounds in order to contribute to the collection of methodologies for the preparation/isolation of enantioenriched biaryls.[33]

1.2.1 Kinetic resolution

The first reported KR was enzyme-catalysed and was performed by Pasteur in 1858.[34] He reported that by performing fermentation on an aqueous solution of racemic ammonium tartrate using *Penicillium glaucum* mould, the unreacted starting material was optically active. This indicated that the two enantiomers of ammonium tartrate were consumed with different rates by the mould.

A successful KR relies on the difference in the rate constants (*k*) for the reaction of each enantiomer of a racemate with an enantiopure catalyst or reagent. A KR can only happen when the rate constants are different, i.e. $k_R \neq k_S$. In the ideal scenario, the rates would be so different ($k_R >> k_S$) that one of the enantiomers (SM_R) is completely transformed into the product (P_R) while the other enantiomer (SM_S) shows no reactivity, thus providing a mixture of 50% SM_S and 50% P_R at the end of the reaction. However, in reality, both enantiomers usually show some reactivity and the reaction therefore provides scalemic product and recovered SM. In this case, a compromise on either the enantiomeric purity or yield of the recovered SM would have to be made (Figure 9).

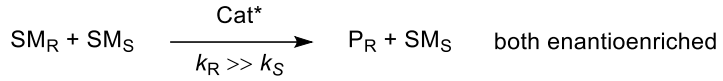


Figure 9. A general scheme of a KR process

The enantiomeric purity of a chiral structure is usually assessed by measurement of its enantiomeric composition or ratio (er) which can be readily converted into an enantiomeric excess (*ee*), which indicates the excess of one enantiomer over the other (Figure 10. Equation A). In a KR process, the relative rate constants for the reaction of a pair of enantiomers with the same chiral catalyst or reagent can be assessed using the selectivity factor, *S*, which is related to the difference between the activation energies ($\Delta\Delta G^{\ddagger}$) of the two diastereomeric transition states (TS) (Figure 10. Equation B). It is assumed that *S* is applicable in the cases where the resolution is pseudo-first-order in respect to the substrate. A larger energy gap of $\Delta\Delta G^{\ddagger}$ results in a larger difference in the rate constants for the reaction of the two enantiomers, hence a bigger *S* factor, and a more efficient KR. A schematic free energy diagram is given below for clarity (Figure 11).

equation A $$\%\ ee = \frac{[R] - [S]}{[R] + [S]} \times 100$$

equation B $$S = k_{rel} = \frac{k_{fast}}{k_{slow}} = e^{\Delta\Delta G^{\ddagger} / RT}$$

T = temperature, K
R = gas constant, 8.314 $JK^{-1}mol^{-1}$

Figure 10. Equations for *ee* and *S* factor

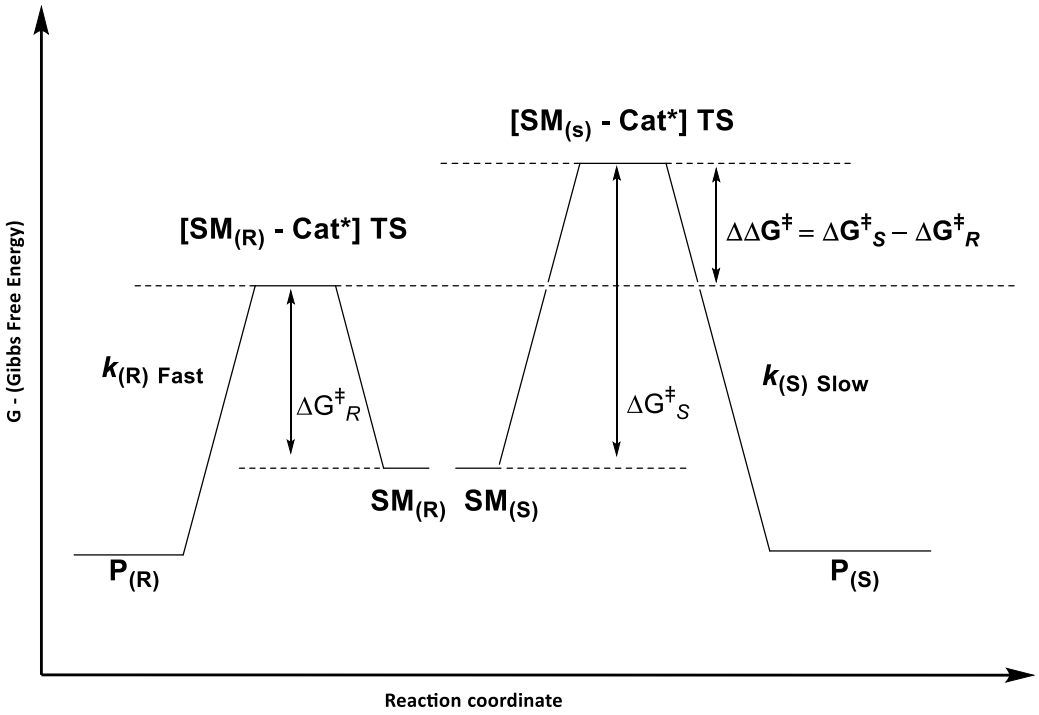


Figure 11. A schematic free energy diagram for KR

Equations that enable the experimental determination of the *S* factor using enantiomeric excess (*ee*) and conversion (*c*) were first developed by Kagan[35] and are shown below (Figure 11). A representative KR plot showing the *ee* of substrate and product throughout a reaction with *S* = 10 is also shown below (Figure 12). It can be seen that as the reaction proceeds, the *ee* of the remaining substrate increases as one enantiomer is being selectively transformed. The product, however, starts with a high *ee* that gradually decreases throughout the reaction. As shown in the plot, enantiopure product can be obtained at low conversion, and can only be isolated in high enantiopurity upon full conversion of the reaction if a very big *S* factor is present. In contrast enantiopure recovered substrates are usually obtained at c > 50%. It is therefore easier to obtain highly enantioenriched recovered substrate than product with good yield.

$$S = \frac{\ln[(1 - c)(1 - ee_{SM})]}{\ln[(1 - c)(1 + ee_{SM})]} = \frac{\ln[1 - c(1 + ee_P)]}{\ln[1 - c(1 - ee_P)]}$$

$$\text{where } c = \frac{ee_{SM}}{ee_P + ee_{SM}}$$

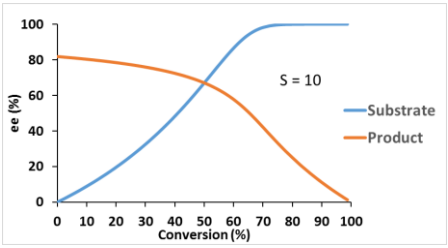


Figure 12. Equations relating *S*, *ee* and *c*; plot of *ee* v.s. *c* throughout a reaction (*S* = 10)

The KR plot below shows the relationship between *ee* and *c* for the recovered substrate for resolutions with different *S* values (Figure 13). It can be seen that the bigger the *S* value, the steeper the curve. The trend in the curves indicates that with bigger *S* values, it is easier to obtain recovered substrate in high *ee* at lower conversion. For example, with *S* = 10, the *ee* of the substrate reaches 90% at around 60% conversion, i.e. 40% maximum yield; while the same level of enantiopurity can be reached at around 50% conversion with *S* = 20. A KR is generally considered synthetically useful only if it has *S* > 10.

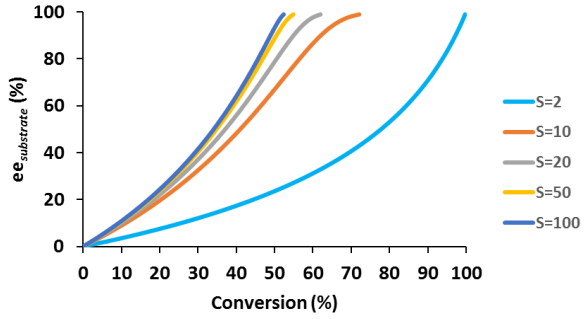


Figure 13. *ee* against conversion plot with different *S* factors for recovered substrate

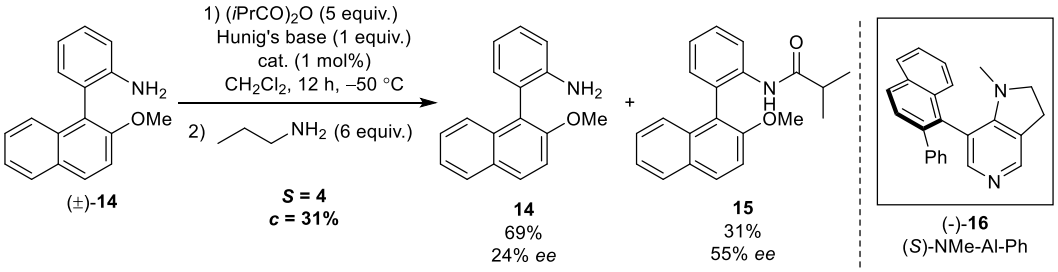
The inherent disadvantage of KR is that the maximum yield of either enantiomer is only 50%. This can be overcome by using dynamic kinetic resolution (DKR), where the starting material is concurrently racemised under the reaction conditions. Ideally, one single enantiomer could be isolated with high yield and enantiopurity upon completion of the reaction. This technique is not employed in this project.

Just like asymmetric syntheses employing chiral catalysis, KR can be achieved through using biocatalysis, metal catalysis or organocatalysis. Although enzymatic KR has been widely investigated to show high levels of selectivity, the substrate scope is usually limited by the availability and specificity of the enzymes used. Alternative non-enzymatic KR processes, especially organocatalytic routes, are still challenging and are attracting more attention in the research community.

1.3 Organocatalytic kinetic resolution of biaryl compounds

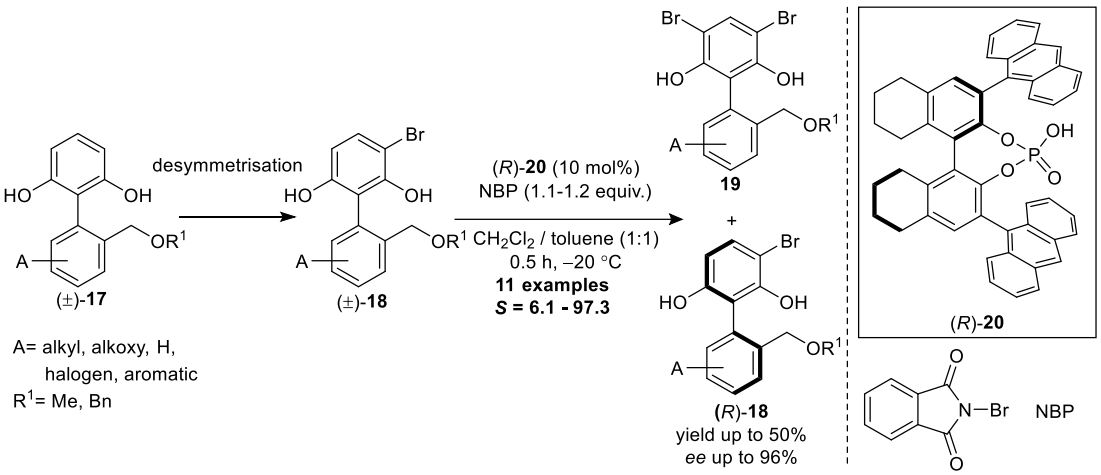
Although rapid progress in KR has been made in recent years, the KR of biaryl compounds still remains challenging. The first example of enzymatic KR of biaryls was reported by Ikekawa and co-workers in 1985, employing microbial asymmetric hydrolysis of diesters of BINOL **6**.[36] Further biocatalysed KR of biaryl compounds was later reported by Myano[37, 38], Ayogi[39, 40, 41] and Seki[42, 43] with moderate to high selectivity. Metal catalysed KR of biaryl compounds has also been reported by Tsuji (Palladium)[44] and Schlosser (Titanium, Sharpless–Katsuki epoxidation)[45] with good selectivities. To date, however, there are only 7 publications regarding organocatalytic KR of biaryl compounds.

The first organocatalytic KR of biaryl compounds was reported by Spivey in 2011.[46] The acylative KR of two NOBIN derivatives was attempted using 11 different pyridine-derived chiral catalysts (1 mol%). Although suitable conditions were found for obtaining good conversions, only one substrate (±)-**14** was successfully resolved through *N*-acylation catalysed by (-)-**16**, albeit with a low *S* factor of 4. The absolute configuration of neither the recovered starting material **14** nor the product **15** was determined (Scheme 5).



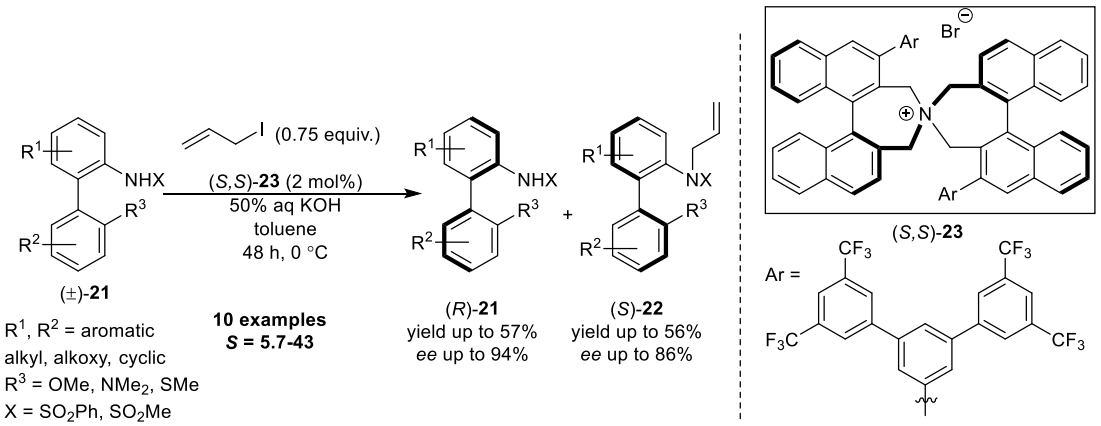
Scheme 5. The first organocatalytic KR case of biaryl compounds by Spivey

In 2013, a very interesting case of a chiral phosphoric acid (*R*)-**20** catalysed desymmetrisation/KR sequence of biaryl substrates (±)-**17** through bromination was reported by Akiyama and co-workers.[47] It was found that the desymmetrised monobrominated product (±)-**18** can undergo a second bromination through a KR under the optimal reaction condition, giving enhanced overall selectivity with a slight sacrifice on the yield. A collection of substrates (±)-**18** was tested in the KR to give *S* factor up to 97.3 with high enantiopurity of (*R*)-**18**. The methoxymethyl group at the 6'-position of the bottom aryl ring (as drawn) was found to be essential for obtaining good selectivity and reactivity through control experiments. It was also shown that both electron-donating and electron-withdrawing substituents on the bottom aryl ring were well tolerated. (Scheme 6).



Scheme 6. Enantioselective desymmetrisation/KR sequence by Akiyama

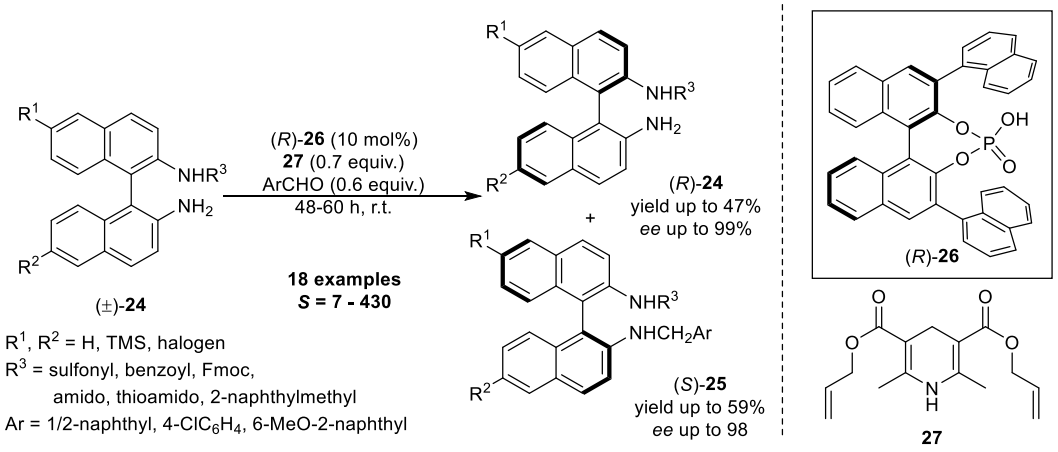
Maruoka and co-workers reported a phase-transfer-catalysed KR of *N*-sulfonyl anilines (±)-**21** through *N*-allylation in the same year (Scheme 7).[48] They proposed that direct interaction between deprotonated chiral biaryl amino compound (±)-**21** and the phase-transfer catalyst (*S,S*)-**23** would result in efficient chiral recognition through the formation of an ion pair. The procedure showed good tolerance to various substituents on the biaryl backbone, giving good reactivity (combined yield up to 98%) and high selectivity (*S* factor up to 43). It was also shown that the *N*-sulfonyl protecting groups on the enantioenriched starting material and product could be easily removed using trimethylsilyl chloride, magnesium powder and Ti(O*i*Pr)$_4$ generated *in-situ* from titanium(IV) isopropoxide.



Scheme 7. KR of biaryl compounds by phase-transfer-catalysed *N*-allylation

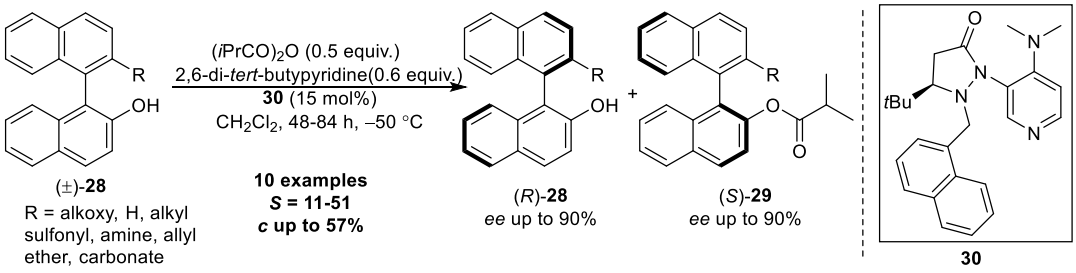
In 2014, Tan and co-workers reported a very efficient chiral phosphoric acid catalysed enantioselective KR of BINAM derivatives, using aryl aldehydes and Hantzsch ester as a hydride source.[49] Variations of both the phosphoric acid catalyst and Hantzsch ester were tested to give the optimal conditions. It was found that a bulky protecting group on one of

the amines of BINAM was required to provide an effective energy barrier to rotation, rendering the biaryl structure chiral. A collection of protecting groups were tested and well tolerated to give good reactivity (yield up to 99%) and good to excellent selectivity (*S*= 7-340). Further studies showed that very poor selectivity was observed by replacing Hantzsch ester with $NaBH_4$, suggesting that the KR was not controlled by the imine formation, but by the cooperation of phosphoric acid catalyst and Hantzsch ester in the transfer hydrogenation (Scheme 8).



Scheme 8. Brønsted acid catalysed KR of BINAM derivatives

Sibi and co-workers reported a case of chiral DMAP **30** catalysed acylative KR of biaryl compounds later in the same year.[50] A low temperature of −50 °C was required for optimal selectivity, requiring a high catalyst loading (15 mol%), addition of base and long reaction time was required for good conversion. A collection of mono-protected BINOL derivatives and an *N*-methylated NOBIN derivative were resolved, giving moderate to high selectivity (*S* = 11-51) (Scheme 9).



Scheme 9. Chiral DMAP catalysed acylative KR of biaryl compounds by Sibi

A stereochemical model was proposed by Sibi to explain the enantioselectivity observed (Figure 14). The fluxional naphthylmethyl group of the catalyst is proposed to adopt a conformation *anti*- to the adjacent *tert*-butyl group in order to minimise steric repulsion. This naphthylmethyl unit effectively blocks the "bottom" face of the pyridine core as drawn, with the biaryl substrate forced to approach from the opposite "top" face. The interactions that lead to selectivity between the two isomers of the biaryl and the catalyst **30** are shown below. A proposed π-π/π-cation interaction between the pyridine and ring A was suggested to stabilise the complex. In order to minimise the steric repulsion between the catalyst **30** and ring B, the OR group was oriented toward the catalyst rather than the ring B, resulting in a more stable transition state TS-**31** for the *S* isomer than the *R* isomer (TS-**32**).

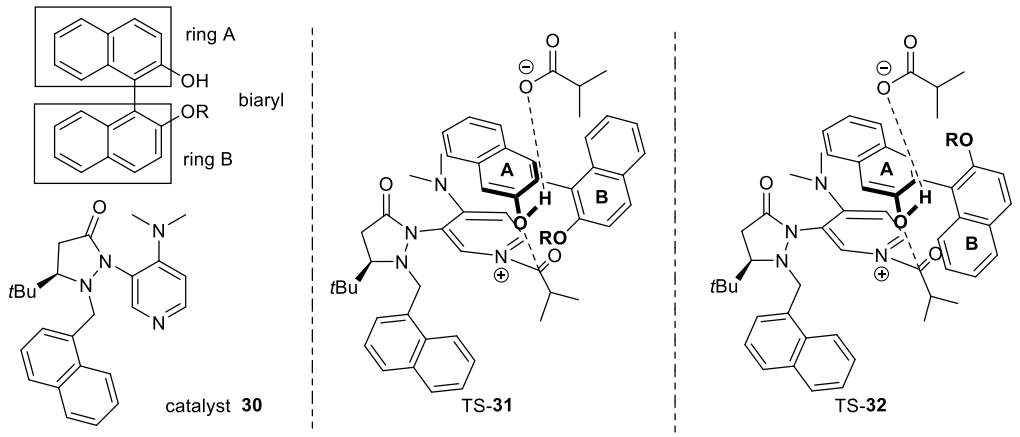
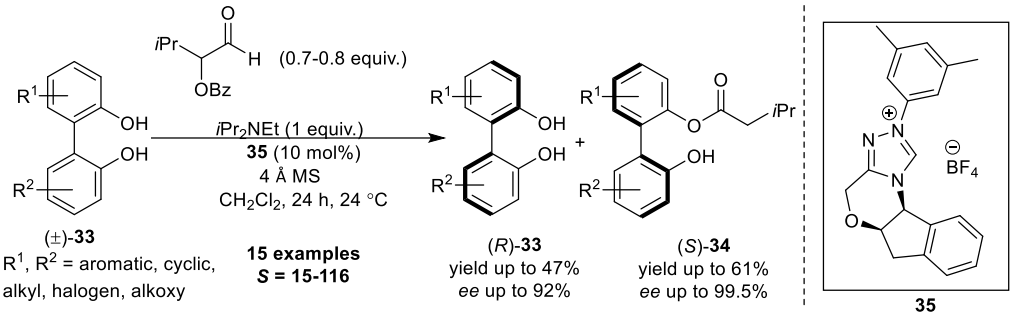


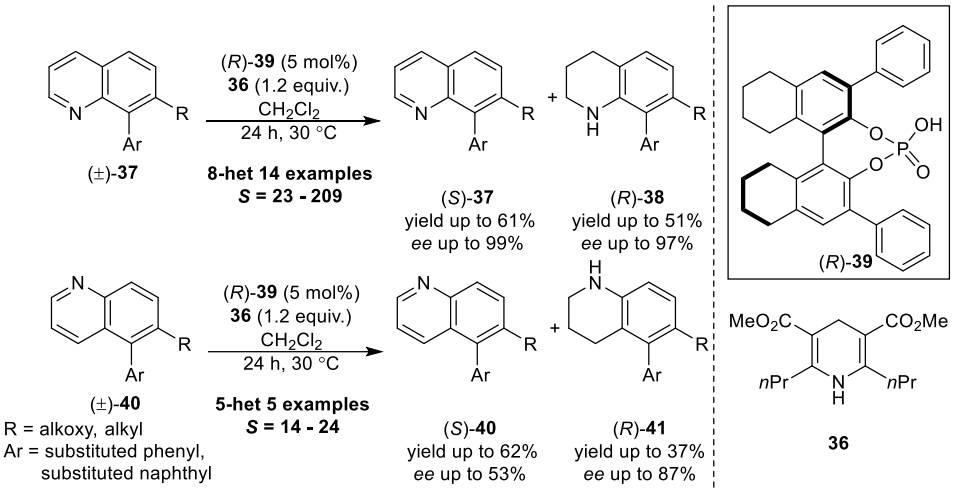
Figure 14. Proposed DMAP-biaryl interaction model by Sibi

An NHC-catalysed acylative KR of biaryl compounds was also reported by Zhao and co-workers[51] at the same time as Sibi. The *S* factor was found to be sensitive to the substituents on the aldehyde used. A very broad range of substrates were tolerated by this procedure, including binaphthyl and biphenyl diols as well as NOBIN derivatives, giving very good selectivity (*S* = 15-116) with good yields at a high catalyst loading of 10 mol%. It was shown that the procedure can be performed well at gram-scale with *S* > 25. Further tests on monomethylated BINOL and di-*N*-methylated NOBIN lead to very low selectivity (*S* < 2) and reduced reactivity. It was suggested that the good selectivity of the system might be related to the H-bonding nature of the hydroxy groups in the biaryl structures (Scheme 10).



Scheme 10. NHC catalysed acylative KR of biaryl compounds by Zhao

The first case of KR of axially chiral heteroaromatics was reported in 2016 by Zhou and co-workers.[52] Chiral phosphoric acid (*R*)-**39** and Hantzsch ester **36** were employed for the enantioselective transfer hydrogenation of axially chiral 8- or 5- substituted quinolines (±)-**37**/(±)-**40**. A wide collection of substrates was tested and excellent selectivities were observed (*S* = 13-209). It was shown that 8-substituted quinolines generally gave better selectivities than 5-substituted quinolines, with the selectivity very sensitive to the substitution on the aromatic moiety without nitrogen (Scheme 11). A few examples of the products were shown to be thermally stable at 80 °C.



Scheme 11. KR of heteroaromatics reported by Zhou

1.4 Isothioureas in kinetic resolution of alcohols

Acylation is probably the most often used technique for the KR of alcohols and amines since Wegler reported the first KR using organocatalysis in 1932.[53] Other than the families of DMAPs and NHCs, which have been used in the KR of biaryl compounds, isothioureas are another family of Lewis base catalysts often used in acylation reactions and for the acylative KR of alcohols.[54-56]

The family of isothioureas developed from the structure of amidine 2,3-dihydroimidazo-[1,2-*α*]pyridine (DHIP) **42** introduced by Birman and co-workers as enantioselective acyl transfer catalysts.[57] Modification of the structure to incorporate an adjacent sulphur atom led to the use of the commercially available isothiourea tetramisole (TM) **43** by Birman in 2006 for the KR of aryl alkyl secondary alcohols, with a modified benzannulated version, benzotetramisole (BTM) (*R*)-**44**, showed increased selectivity.[58] Around the same time, Okamoto and Kobayashi developed a related catalyst 3,4-dihydro-2*H*-pyrimido[2,1-*b*]benzothiazole (DHPB) **45**, which contains a 6-membered ring. DHPB **45** was shown to be more efficient as an acyl transfer catalyst relative to the amidine and isothiourea catalysts studied by Birman, which contained 5-membered rings.[59] Building upon the structure of DHPB **45**, a family of isothiourea catalysts soon emerged. Birman developed (*S*)-HBTM **46** in 2008, which gave *S* factors up to 122 for the resolution of aryl-cycloalkanols.[60] In 2009, Birman developed further modified isothiourea catalyst HBTM 2.0 (2*S*,3*R*)-**47**,[61] while at the same time, independent work by Smith developed the catalyst HyperBTM (2*S*,3*R*)-**48**,[62] both finding that substitution in the 3-position gave improved selectivities and allowed lower catalyst loadings to be used in catalytic applications (Figure 15).

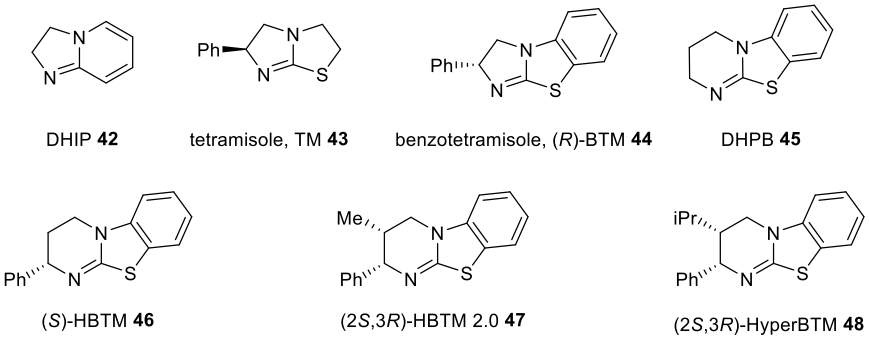
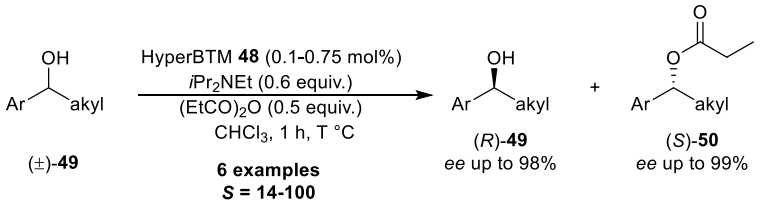


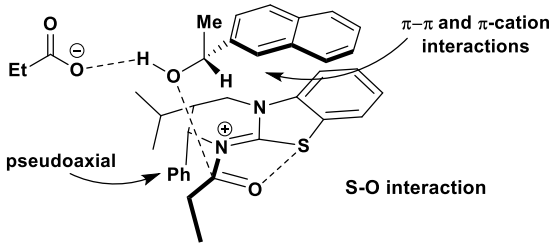
Figure 15. Structures of different isothiourea catalysts

Isothiourea catalysis has been a research focus within the Smith group for close to a decade. HyperBTM **48** was first reported for the enantioselective Steglich reaction, and first used in the KR in 2011, in which aryl alkyl alcohols could be resolved with excellent selectivity with *S* > 100 at very low catalyst loadings (< 1 mol%).[56]



Scheme 12. KR of aryl alkyl alcohols **49** catalysed by HyperBTM **48**

The proposed transition state is shown below (Figure 16). *N*-acylation of the isothiourea by the anhydride gives an *N*-acyl ammonium ion, with the adjacent phenyl group forced to adopt a pseudoaxial conformation to avoid 1,2-interactions. This effectively blocks the bottom face of the acylated catalyst and directs the approach of the alcohol from the top face as drawn. The conformation of the acylated catalyst is locked by the non-bonding O-S interaction (n_O to $\sigma^*_{C\text{-}S}$).[63] The good selectivity is proposed to be due to the π-cation interactions between the aromatic moieties of the (*R*)-isomer of the alcohol and the positively charged isothiouronium, which further stabilises the transition state.



TS 51

Figure 16. Proposed TS for isothiourea catalysis

Over the years, different isothioureas have been used to resolve a wide range of secondary alcohols, including aryl-alkyl alcohols, alkenyl-alkyl alcohols, alkynyl-alkyl alcohols, aryl-alkenyl and cycloalkanols, with good to excellent selectivity (Figure 17).[56,64] Challenging tertiary alcohol also have recently been resolved using HyperBTM **48** giving good selectivity.[65] However, among all the cases that have been reported so far, only alcohols with C(sp^3)-OH bonds possessing point chirality have been resolved. The resolution of alcohols with C(sp^2)-OH bonds bearing axial chirality has not been attempted using any isothiourea to date.

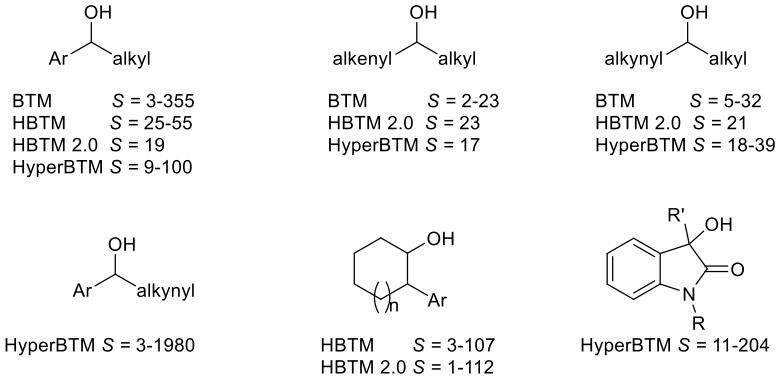
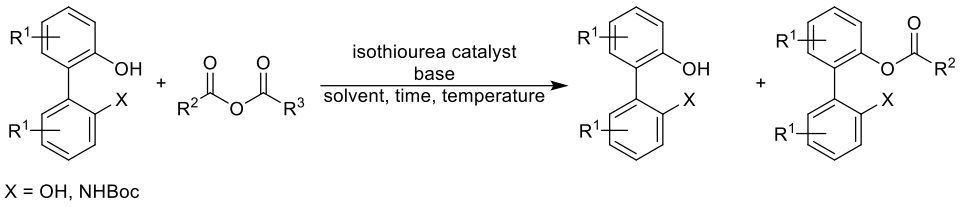


Figure 17. KR of alcohols using isothioureas

1.5 Aims and Objectives



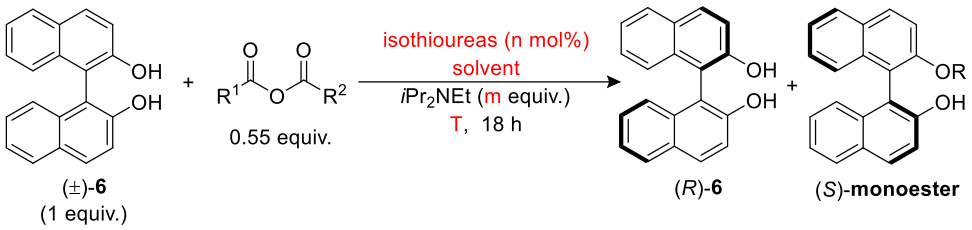
Scheme 13. Proposed project aims

Although various pathways have been reported for obtaining enantioenriched biaryl products, the organocatalytic KR of these compounds still remains very challenging. The aim of this project is to develop a new isothiourea-catalysed acylative method for the KR of biaryl compounds. As the KR of this class of compounds has not been attempted before using isothioureas, optimisation of this process will require successive screening of catalyst, solvent and anhydride in order to generate a successful procedure. Following optimisation of the KR reaction conditions, a range of racemic biaryl compounds will be synthesised to investigate the generality of the developed process.

Chapter 2: Reaction optimisation

Overview

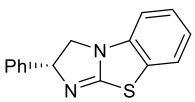
This chapter details work concerned with the optimisation of reaction conditions to allow an isothiourea catalysed enantioselective acylative KR of (±)-BINOL (±)-**6**. The screenings of catalyst, solvent, acyl donor, catalyst loading and temperature are reported and discussed in the following sections that lead to optimal selectivity (Scheme 14).



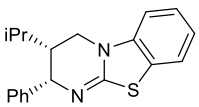
Scheme 14. General scheme for reaction optimisation

2.1 Catalyst and solvent

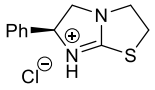
Initial studies focused on the acylative KR of (±)-BINOL as a model substrate using isobutyric anhydride **53** (0.55 equiv) as an acyl donor. Three isothiourea catalyst candidates (*R*)-BTM **44**, (2*R*,3*S*)-HyperBTM **48** and (*S*)-TM·HCl **52** that are either readily prepared or commercially available were tested for their ability to promote the acylation in $CHCl_3$ over 18 h (Table 1, entries 1-3). A relatively low catalyst loading of 1 mol% was used as standard with the aim to develop an effective resolution procedure. In all cases three products of the reaction were observed; enantioenriched BINOL **6**, monoester **54** as well as small amounts (<2%) of diester **55**. While all three catalysts were able to promote the reaction close to 55% conversion at room temperature, very different selectivities were observed. (*R*)-BTM **44** gave the highest *S* factor of 26 giving recovered BINOL in 98% *ee* and 47% isolated yield, followed by TM·HCl **52** (*S* = 12) with HyperBTM **48** giving the lowest selectivity (*S* = 5). Therefore (*R*)-BTM **44** was chosen to be the optimal catalyst for further optimisation work. It was also found that (*R*)-BTM **44** gave the opposite enantiomers of BINOL **6** and monoester **54** than (2*R*,3*S*)-HyperBTM **48** and (*S*)-TM·HCl **52**. By comparing the specific rotation of (*R*)-BINOL **6** reported by literature,[66] the major enantiomer of recovered BINOL **6** catalysed by (*R*)-BTM **44** was found to be (*R*)-**6** while the monoester being (*S*)-**54**.



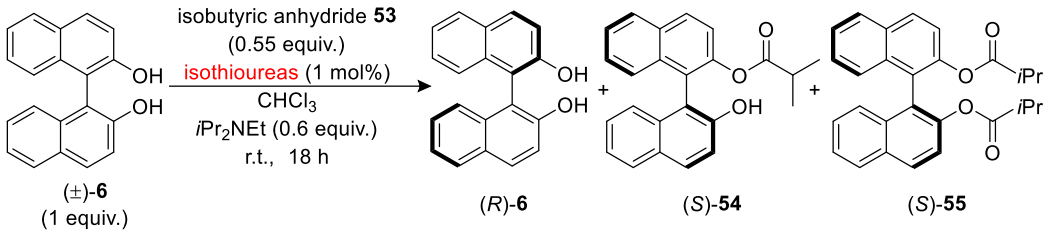
(*R*)-BTM **44**



(2*S*,3*R*)-HyperBTM **48**



(*S*)-TM·HCl **52**

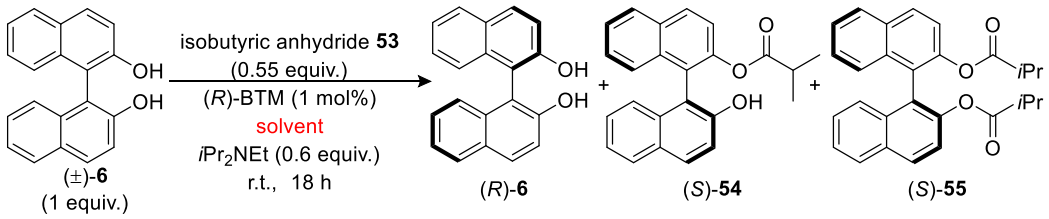


Entry	catalyst	**6** : **54**: **55**[a,b]	*ee*% **6**[c]	%**6**[d]	*ee*% **54**[c]	%**54**[d]	c* (%)[c]	*S*[c]
1	(2*R*,3*S*)-HyperBTM **48**	46.5: 53: 0.5	58	39	50	31	54	5
2	(*S*)-TM·HCl **52**	44: 55: 1	83	37	66	21	55	12
3	(*R*)-BTM **44**	44.5: 53.5: 2	98	47	71	30	55	26

*conversion; a)Ratios determined by ^{1}H NMR spectroscopy b) **55** not isolated; c)*ee*, c and *S* determined by HPLC analysis; racemic sample prepared using DMAP catalysis; d) isolated yields;

Table 1. Catalyst screening

Subsequent studies tested a further range of 9 common solvents in this reaction process, with all giving close to 55% conversion (Table 2). Interestingly, significant changes in selectivity (*S* value) as well as variation in the ratio of monoester **54**: diester **55** was observed upon changing the solvent. A wide range of selectivity (*S* = 1.7-37) was observed (Table 2, entries 1-10), with CH_2Cl_2, THF, EtOAc, MeCN and acetone all giving very low selectivity (*S* < 10). Whilst Et_2O, PhMe and *i*Pr2O gave reasonable selectivity (*S* = 17-21), *tert*-amyl alcohol was the only solvent (*S* = 37) that showed higher selectivity than chloroform although 4% of diester was observed.

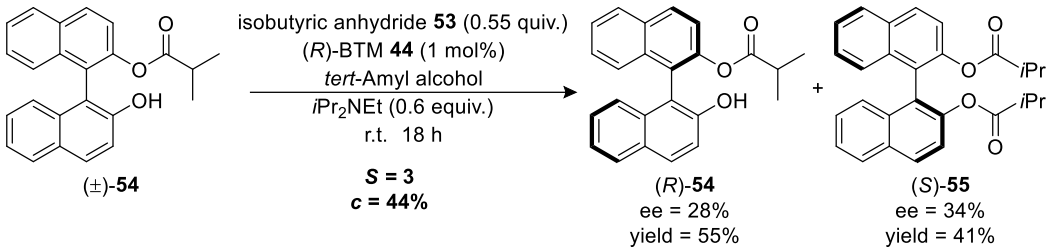


Entry	solvent	**6** : **54**: **55**[a]	**6**(*ee*%[b], %[c])		**54**(*ee*%[b], %[c])		**55**(*ee*%[b], %[c])		c (%)[b]	*S*[b,d]
1	$CHCl_3$	44.5: 53.5: 2	98	47	71	30	-	-	55	26
2	CH_2Cl_2	48: 51: 1	55	42	50	31	-	-	52	5
3	THF	51: 44: 5	61	38	60	45	72	4	50	7
4	EtOAc	53: 42: 5	64	41	69	38	68	6	48	10
5	MeCN	50: 46.5: 3.5	31	34	28	33	63	4	53	2
6	Et_2O	55: 39: 6	73	31	82	38	93	3	47	21
7	PhMe	48: 50: 2	81	34	76	49	-	-	52	18
8	*Tert*-amyl alcohol	49: 47: 4	88	37	86	30	94	8	50	37
9	iPr_2O	51.5: 42: 6.5	74	30	77	30	91	4	49	17
10	acetone	50.5: 40: 9.5	67	32	53	33	77	5	55	6

a)Ratios determined by ^{1}H NMR spectroscopy; b)*ee*, c and *S* determined by HPLC analysis; racemic sample prepared using DMAP catalysis; c)isolated yields; d)using only data of **6** and **54**, diester **55** not taken into account

Table 2. Solvent screening

Assuming that the formation of diester in this resolution approach proceeds by initial mono-acylation of (±)-BINOL, this second acylation could also proceed enantioselectivity. In principle this second-acylation could either enhance or reduce the observed enantioselectivity of the mono-acylated species via a second KR. To test the selectivity observed in the formation of diester, the KR of racemic monoester (±)-**54** was investigated under the same reaction conditions. Although the reaction proceeded to 44% conversion under the same amount of time, a very low *S* factor of 3 was obtained. This indicated that the KR of monoester **54** is not effective under these reaction conditions (Scheme 15). Furthermore, hydrolysis of diester **55** gave (*S*)-BINOL **6** with retained *ee* confirmed the configuration of the major enantiomer of diester as (*S*)-**55**, the same as the fast-reacting monoester (*S*)-**54**.



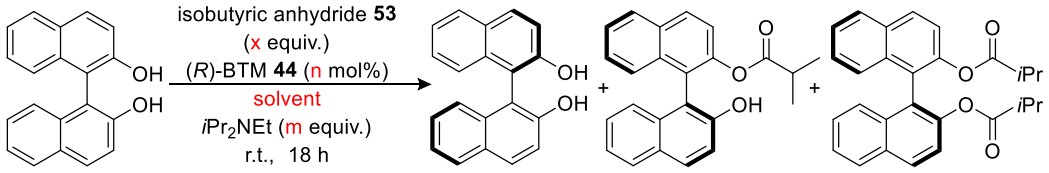
Scheme 15. KR of racemic monoester (±)-**54**

Using the product ratio and *ee* of all 3 products, a new *S* factor that includes a correction for the selective generation of monoester **54** can be back calculated. However, this correction only resulted in a small change in *S* (from 43 to 45 in *tert*-amyl alcohol) and so does not play a significant role on the selectivity of the process.

Control reactions in both chloroform and *tert*-amyl alcohol were then carried out to monitor the background acylations (Table 3). In the absence of both catalyst and *i*Pr_2NEt in chloroform no conversion was observed after 18 hours (Table 2, entry 1). The reaction performed with only *i*Pr_2NEt (without catalyst) in chloroform gave almost full conversion (Table 2, entry 2), indicating a strong and potentially competitive base-mediated background reaction. This conclusion was further confirmed by the big difference in *S* factor obtained in the KR performed with and without *i*Pr_2NEt, giving *S* = 26 and *S* = 36 respectively (Table 3, entries 3 & 4). Interestingly, 30% conversion was observed when the reaction was performed in *tert*-amyl alcohol in the absence of both catalyst and *i*Pr_2NEt (Table 3, entry 5). A 64% conversion was observed in the reaction performed with only *i*Pr_2NEt (without

catalyst), which agrees with the observations in chloroform (Table 3, entry 6). The catalysed KR showed that *i*Pr_2NEt does not have a big effect on the selectivity of KR in *tert*-amyl alcohol (Table 3, entries 7 & 8). The results obtained in both solvents indicate that *i*Pr_2NEt has either a negative or no effect on the selectivity of the KR, so therefore it is decided that further reactions would be carried out in the absence of *i*Pr_2NEt.

The data obtained also shown that only small amounts of diester **55** were generated in the KR process (< 3%). Interestingly, *i*Pr_2NEt has little or no effect on the generation of diester **55**, while more significant diacylation was observed in *tert*-amyl alcohol with excess of anhydride **53**.



(±)-**6** (1 equiv.) | (*R*)-**6** | (*S*)-**54** | (*S*)-**55**

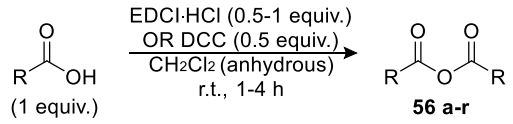
Entry	Solvent	Anhydride	Cat.	*i*Pr_2NEt	c (%) [a]	*S* [a]	**6**: **54**: **55** [b]
1	$CHCl_3$	1.5 equiv.	-	-	0	-	-
2			-	0.6 equiv.	94	-	6: 89: 5
3		0.55 equiv.	1 mol%	-	49	36	44: 55 : 1
4			1 mol%	0.6 equiv.	58	26	36: 63 : 1
5	*Tert*-amyl alcohol	1.5 equiv.	-	-	30	-	46.5: 34 : 19.5
6			-	0.6 equiv.	64	-	45: 36 : 19
7		0.55 equiv.	1 mol%	-	52	35	50: 47 : 3
8			1 mol%	0.6 equiv.	50	38	48: 50 : 2

a) c and *S* determined by HPLC analysis; racemic sample prepared using DMAP catalysis; b)Ratios determined by ^{1}H NMR spectroscopy

Table 3. Background reactions and effects of base

2.2 Homoanhydrides

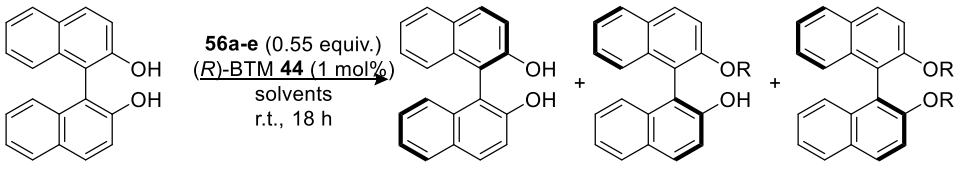
Having demonstrated promising reactivity with BTM **44** as the catalyst in $CHCl_3$ and *tert*-amyl alcohol as solvents, variation of the acyl donor was next investigated. Other than isobutyric anhydride **53**, 18 other homoanhydrides **56 a-r** that varied in alkyl or aryl substitution, as well as branching, were tested for selectivity in this KR process. Commercially available homoanhydrides (**56a, 56b, 56i & 56l**) were used without further purification, with the remainder synthesised either through DCC- or EDCI-mediated coupling from their corresponding carboxylic acid (Scheme 16).



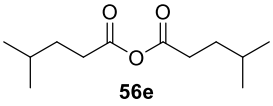
monoalkyl-α-subsitution			aromatic-α-subsitution			dialkyl-α-subsitution		
R = $CH_2CH(CH_3)_2$	**56d**	32%	Ar = *p*-Br-C_6H_4	**56j**	52%	R = $CHEt_2$	**56n**	78%
R = $CH_2CH_2CH(CH_3)_2$	**56e**	60%	Ar = *p*-NO_2-C_6H_4	**56k**	56%	R = CH(*n*Pr)$_2$	**56o**	82%
R = CH_2Ph	**56f**	62%	Ar = 3-pyridine	**56m**	44%	R = $CHPh_2$	**56p**	59%
R = CH_2CH_2Ph	**56g**	55%				R = cyclopentyl	**56q**	58%
R = CHCHPh	**56h**	29%				R = cyclohexyl	**56r**	32%

Scheme 16. Synthesis of homoanhydride **53 a-r**

The screening started by varying the bulkiness of the homoanhydride (Table 4, **56 a-c**). The use of acetic anhydride **56a** shown high conversion, however, the monoester **57a** and BINOL **6** could not be separated using chromatography, and HPLC conditions to separate the 4 molecules could also not be found, hence no *S* factor could be obtained in this case. Increasing the steric bulk of the anhydride from propionic anhydride **56b** (*S* =12/13) to isobutyric anhydride **53** (*S* = 36/35) resulted in a big improvement in selectivity of the KR in both solvents and a slight drop in the yield (Table 4, **56b, 53**). Further increasing the steric bulk to pivalic anhydride (**56c**) resulted in only 2% conversion in chloroform and 16% in *tert*-amyl alcohol, with an *S* factor of 11 in *tert*-amyl alcohol. Significantly diminished selectivity was observed when using the β- or γ-branched anhydride (**56d** and **56e** respectively), giving *S* = 8/6 and *S* = 11/13 respectively.



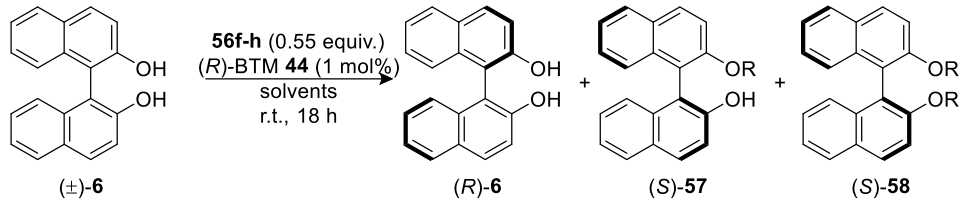
anhydride	solvent	*ee*% **6**[a]	%**6**[b]	*ee*% **57**[a]	%**57**[b]	c [a]	*S* [a]	**6**: **57**: **58**[c]
56a	$CHCl_3$	-	-	-	-	45[b]	-	55: 44: 1
	*t*AmOH	-	-	-	-	48[b]	-	51.5: 41: 7.5
56b	$CHCl_3$	91	29	61	38	59	12	40.5: 56.5: 3
	*t*AmOH	84	30	67	22	54	13	45.5: 45.5: 9
53	$CHCl_3$	83	41	87	36	49	36	47: 53: -
	*t*AmOH	87	37	86	28	50	35	50: 47: 3
56c	$CHCl_3$	-	-	-	-	2[b]	-	98: 2: -
	*t*AmOH	16	46	80	13	16	11	84: 16: -
56d	$CHCl_3$	58	40	64	40	47	8	52: 46: 2
	*t*AmOH	64	34	53	32	54	6	46: 49: 5

 **56e**	$CHCl_3$	34	30	78	21	31	11	70: 30: -
	*t*AmOH	36	60	80	40	31	13	69: 31: -

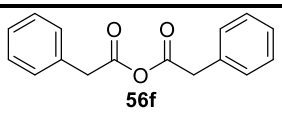
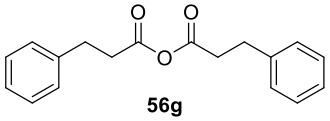
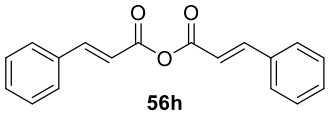
a)*ee*, c and *S* determined by HPLC analysis; b)all isolated yields; c)Ratios determined by ^{1}H NMR spectroscopy;

Table 4: Data using homoanhydrides **53** & **56 a-e**

Further work investigated the incorporation of aryl substituents on the α- or β-positions, with **56f** giving improved selectivity of (*S* = 25/17) and **56g** giving similar selectivity to **56e**. An *S* factor of only 3 at c=32% in chloroform was observed when using cinnamic anhydride **56h** (Table 5).



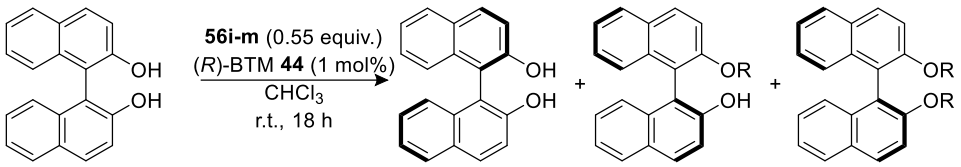
(±)-**6** (*R*)-**6** (*S*)-**57** (*S*)-**58**

anhydride	solvent	*ee*% **6**[a]	%**6**[b]	*ee*% **57**[a]	%**57**[b]	c [a]	*S* [a]	**6**: **57**: **58**[c]
 **56f**	$CHCl_3$	75	45	84	29	47	25	52: 47: 1
	*t*AmOH	67	54	79	26	46	17	55: 41: 4
 **56g**	$CHCl_3$	53	46	75	29	41	12	58: 41: 1
	*t*AmOH	50	37	75	13	40	12	53: 40.5: 6.5
 **56h**	$CHCl_3$	21	63	45	12	32	3	66.5: 32: 1.5
	*t*AmOH	44	38	49	28	46	4	54: 41: 5

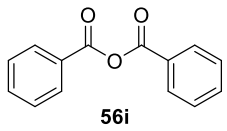
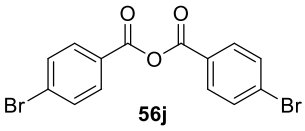
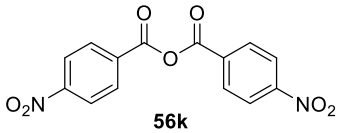
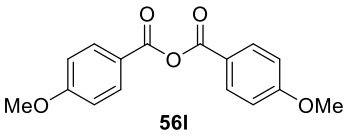
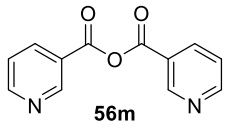
a)*ee*, c and *S* determined by HPLC analysis; b)all isolated yields; c)Ratios determined by ^{1}H NMR spectroscopy;

Table 5: Data using homoanhydrides **56 f-h**

Further work tested a small number of benzoic anhydrides. Benzoic anhydride **56i** gave moderate selectivities (*S* = 15/16) at c < 50% in both solvents, with *p*-Br and *p*-NO2 derivatives (**56j** and **56k**) groups giving similar results. Using the *p*-OMe derivative led to 100% conversion using DMAP catalysis. However, the monoester **57l** could not be separated from BINOL **6**, hence KR was not performed and no data was obtained in this case. Nicotinic anhydride **56m** was also tested to give *S* = 25 at c = 53% in chloroform and *S* = 13 at c = 42% in *tert*-amyl alcohol (Table 6).



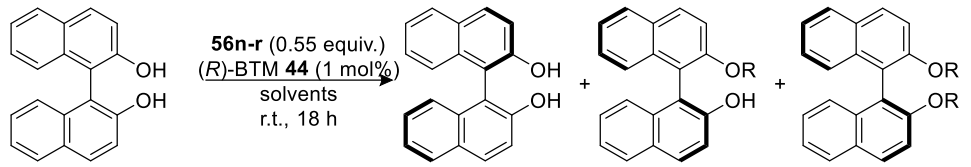
(±)-**6** (*R*)-**6** (*S*)-**57** (*S*)-**58**

anhydride	solvent	*ee*% **6**[a]	%**6**[b]	*ee*% **57**[a]	%**57**[b]	c [a]	*S* [a]	**6**: **57**: **58**[c]
 **56i**	$CHCl_3$	45	40	81	28	36	15	54: 46: -
	*t*AmOH	73	43	77	41	49	16	52: 46: 2
 **56j**	$CHCl_3$	84	41	72	44	54	16	49: 50.5: 0.5
	*t*AmOH	54	35	80	45	40	15	40.5: 53: 6.5
 **56k**	$CHCl_3$	77	37	75	32	51	16	48.5: 51.5: -
	*t*AmOH	77	35	74	29	51	15	47.5: 52.5: -
 **56l**	$CHCl_3$	-	-	-	-	-	-	-
	*t*AmOH	-	-	-	-	-	-	-
 **56m**	$CHCl_3$	89	32	79	44	53	25	31: 66: 3
	*t*AmOH	56	29	80	47	42	13	37.5: 57.5: 5

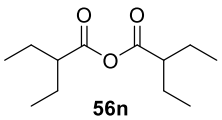
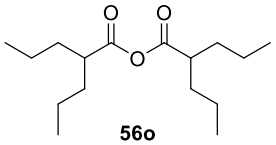
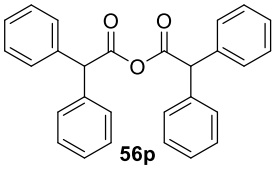
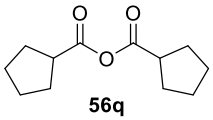
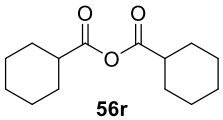
a)*ee*, c and *S* determined by HPLC analysis; b)all isolated yields; c)Ratios determined by ^{1}H NMR spectroscopy;

Table 6: Data using homoanhydrides **56 i-m**

As isobutyric anhydride **53** (*S* = 36/35) gave the best selectivity by far, alternative α,α-branched substituted homoanhydrides were investigated. Both diethylacetic anhydride **56n** and dipropylacetic anhydride **56o** showed similar selectivities in chloroform (*S* = 34, *S* = 38 respectively), however low conversions (c = 15%, c = 12% respectively) were observed due to low solubility. Lower selectivity was observed in *tert*-amyl alcohol (*S* = 27, *S* = 25 respectively) while both proceeded to good conversion (c = 48%). Diphenylacetic anhydride **56p** gave, at 52% conversion, *S* = 43 in chloroform and *S* = 33 in *tert*-amyl alcohol. Cyclopentylcarboxylic anhydride **56q** gave similar selectivities in both solvents (*S* = 23/22) at c > 50%. Cyclohexylcarboxylic anhydride **56r** gave *S* = 39 in chloroform and *S* = 10 in *tert*-amyl alcohol with good conversion, however the anhydride itself was not bench-stable (Table 7). It is worth commenting that anhydrides **56o** and **56p** showed no trace of diester product in the ^{1}H NMR spectroscopy, which might suggest that the bulky di-α-substituents on homoanhydride help to avoid the formation of the minor diester product **58**.



(±)-**6** (*R*)-**6** (*S*)-**57** (*S*)-**58**

anhydride	solvent	*ee*% **6**[a]	%**6**[b]	*ee*% **57**[a]	%**57**[b]	c [a]	*S* [a]	**6**: **57**: **58**[c]
 **56n**	$CHCl_3$	16	70	93	7	15	34	86: 14: -
	*t*AmOH	78	38	84	37	48	27	51: 47: 2
 **56o**	$CHCl_3$	13	77	94	10	12	38	88.5: 11.5: -
	*t*AmOH	76	39	84	29	48	25	53: 47: -
 **56p**	$CHCl_3$	93	26	85	34	52	43	46: 54: -
	*t*AmOH	85	33	86	38	52	33	48: 52: -
 **56q**	$CHCl_3$	88	28	78	30	53	23	47: 52: 1
	*t*AmOH	84	35	79	35	51	22	48: 47: 5
 **56r**	$CHCl_3$	72	41	89	29	45	39	55.5: 43.5: 1
	*t*AmOH	55	41	71	39	44	10	55.5: 42.5: 2

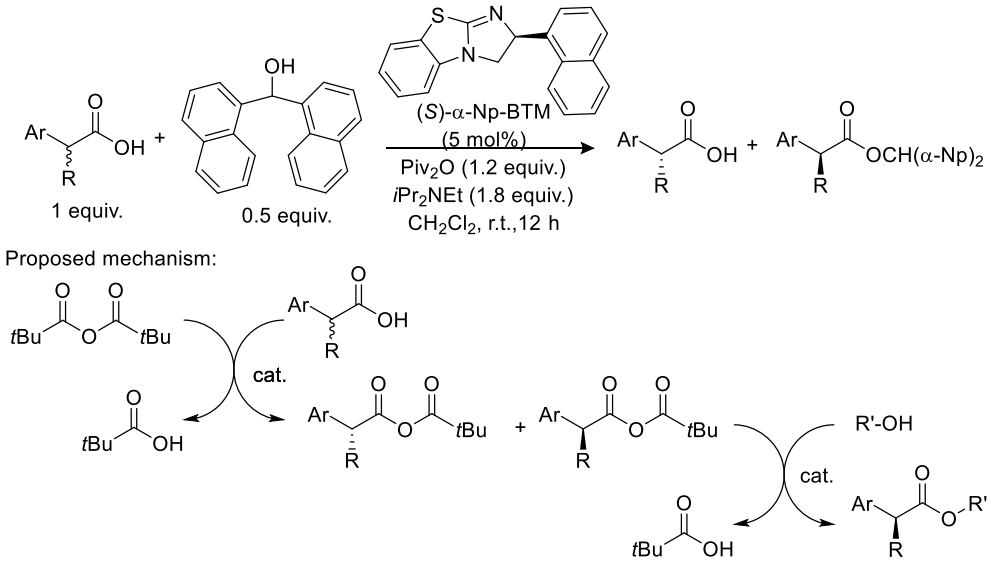
a)*ee*, c and *S* determined by HPLC analysis; b)all isolated yields; c)Ratios determined by ^{1}H NMR spectroscopy;

Table 7: Data using homoanhydrides **56 n-r**

Based on the results obtained (Tables 4-7), chloroform gave similar or better selectivity than *tert*-amyl alcohol in all cases. Some low conversions observed with chloroform were either due to steric bulkiness (**56c**) or low solubility (**56i** & **56j**). The KRs performed in chloroform are also less likely to give diester **58**. Diphenylacetic anhydride **56k** was the best performing homoanhydride to give *S* = 43 at c = 52%.

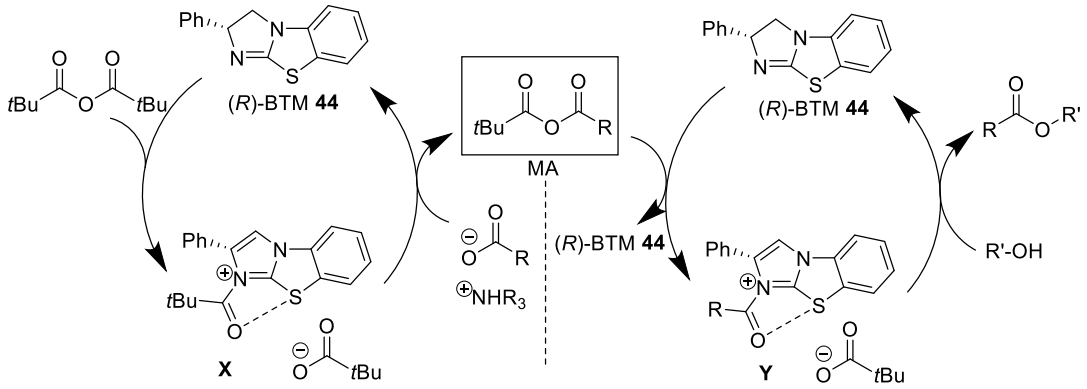
2.3 Mixed anhydride and catalyst loading

Many publications have reported the use of mixed anhydrides in the selective acylation of alcohols.[66] For example, Shiina and co-workers reported an efficient KR method to resolve racemic α-arylalkanoic acids using achiral alcohols and mixed anhydrides (Scheme 17). It was proposed that by generating the mixed anhydride using a bulky homoanhydride and a carboxylic acid *in situ* through a catalysed reaction, the mixed anhydride would remain at low concentration throughout the reaction. Hence, less background reaction would be observed with the mixed anhydride than with the use of homoanhydride, giving better selectivity in the KR.



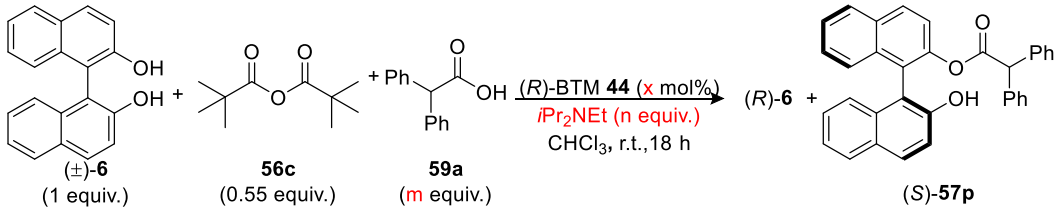
Scheme 17. KR of carboxylic acids reported by Shiina

A similar strategy could be employed in the KR of biaryl diols (Scheme 18). Based on the previous results (Table 4), pivalic anhydride **56c** gave only 2% conversion to the monoester **57c** over 18 hours in chloroform, making it an ideal candidate for synthesising mixed anhydrides as the background reaction can be kept minimum.



Scheme 18. Proposed catalytic cycle using mixed anhydride strategy

Since diphenylacetic anhydride **56p** was the best performing homoanhydride (Table 7), the first attempt was made by generating the mixed anhydride *in situ* using pivalic anhydride **56c** and diphenylacetic acid **59a** with the aid of *i*Pr_2NEt. Although high *S* factor (around 55) was observed, inconsistent conversion over multiple repeats, ranging from 7% to 40% indicated this method was not appropriate (Table 8, entries 1-6). Further attempts to improve the conversion by either increasing the catalyst loading or the equivalents of the acid did not provide any improvements (Table 8, entries 7-9). Interestingly, the base did not seem to have any effect on the selectivity of the reaction. It is worth noticing that diester **58p** is not observed in these reactions.

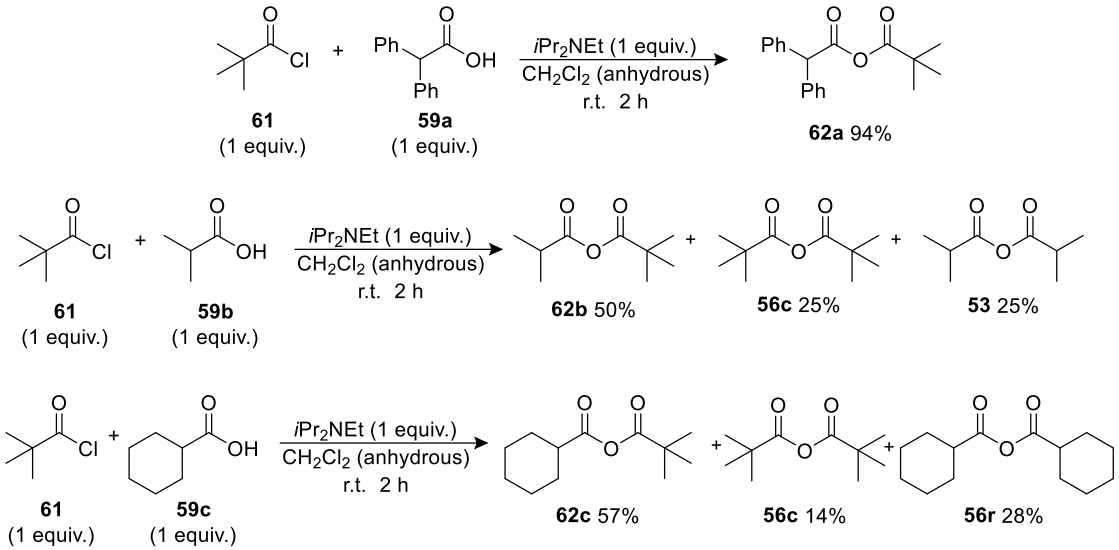


Entry	**44**	*i*Pr_2NEt equiv.	**59** equiv.	*ee*% **6**[a]	% **6** [b]	*ee*% **57p**[a]	% **57p**[b]	c (%)[a]	*S* [a]
1	1%	0.55	0.55	8	41	96	4	7.6	57
2	1%	0.55	0.55	28	30	95	31	22	54
3	1%	0.55	0.55	33	60	95	13	26	55
4	1%	-	0.55	63	38	94	31	40	64
5	1%	-	0.55	50	70	94	10	35	55
6	1%	-	0.55	11	65	96	13	11	54
7	5%	-	0.55	57	32	94	35	38	56
8	5%	-	1.1	33	54	95	16	26	51
9	10%	-	0.55	67	44	92	31	42	50

a)*ee*, c and *S* determined by HPLC; b)all isolated yields

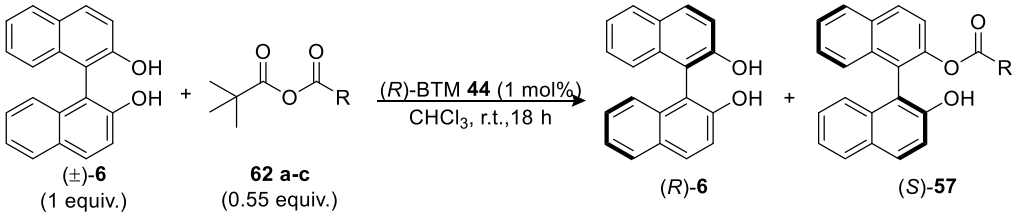
Table 8. KR using mixed anhydride generated *in situ*

Since generating mixed anhydride *in situ* did not give ideal results, isolated mixed anhydrides **56** were next tested. Three mixed anhydrides **60 a-c** were synthesised using trimethylacetyl chloride **61** and the corresponding parent carboxylic acids of the best performing homoanhydrides (**53, 56p and 56r**) (Scheme 19). The mixed anhydride was obtained as the only product when using diphenylacetic acid **59a**, however, when using isobutyric acid **59b** and cyclohexanecarboxylic acid **59c**, mixtures of anhydrides were confirmed by ^{1}H NMR spectroscopy. Chromatographic separation was not possible therefore **62b** and **62c** were used without any further purification.



Scheme 19: Synthesis and mixed anhydrides

The three mixed anhydrides **62 a-c** were tested in the KR of BINOL (±)-**6** in chloroform (Table 9 entries 1-4). 2,2-Diphenylacetic pivalic anhydride **62a** proved to be the best candidate, giving *S*=54 at c=51% (Table 9, entry 1), with both mixed anhydrides **62b** and **62c** also showing good selectivity and reactivity (S = 32 and 37 respectively). The reproducibility of the optimised procedure using anhydride **62a** was confirmed by 2 repeat reactions with *S*=54±1 at 50% conversion.



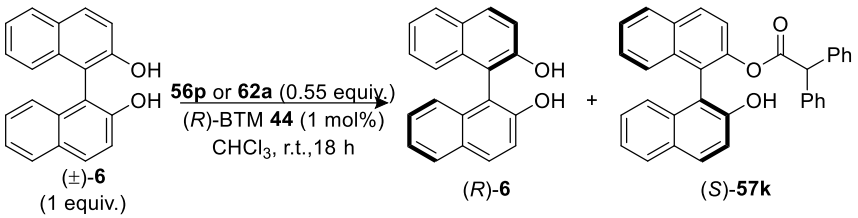
Entry	R	*ee*%**6** [a]	% **6** [b]	*ee*% **57**[a]	% **57**[b]	c (%)[a]	*S* [a]
1	-$CHPh_2$ **62a**	90	38	89	36	50	55
2	-$CHPh_2$ **62a**	94	38	88	40	51	54
3	-$CHiPr_2$ **62b**	99	30	71	34	58	32
4	-C_6H_{11} **62c**	60	40	90	31	40	37

a)*ee*, c and *S* determined by HPLC; b)all isolated yields

Table 9. KR using mixed anhydrides **62 a-c**

2.4 Catalyst loading

The effect of catalyst loading upon selectivity was next investigated. Interestingly, when the catalyst loading was raised to 5 mol% using mixed anhydride **62a** to resolve BINOL (±)-**6**, a large decrease in selectivity (*S* =33) was observed (Table 6, entries 1 & 2). To confirm this trend, different catalyst loadings were tested in the KR of BINOL (±)-**6** using homoanhydride **56p**. By raising the catalyst loading from 1 mol% to 10 mol%, the *S* factor dropped successively from 43 to 25 (Table 10, entries 3-5). As no diacylation was observed in these reactions, an explanation for this decrease in selectivity is not immediately apparent, although this presumably reflects a higher proportion of a racemic acylation pathway resulting in overall lower selectivity. Although no definite reason could be proposed in this case, this trend observed did confirm that low catalyst loading is favoured in this KR procedure.



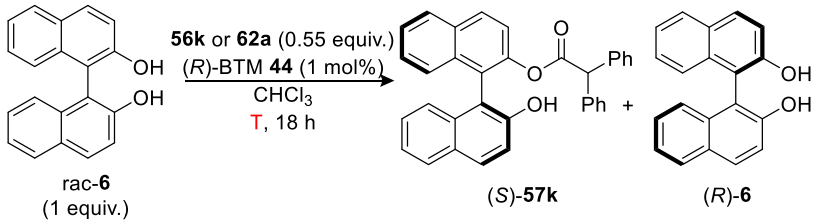
Entry	anhydride	**44** (mol%)	*ee*% **6** [a]	% **6** [b]	*ee*% **57k**[a]	% **57k**[b]	c (%)[a]	*S* [a]
1	**62a**	1	90	38	89	36	50	54
2	**62a**	5	88	25	85	34	51	33
3	**56P**	1	93	26	85	34	52	43
4	**56P**	5	86	41	74	38	51	31
5	**56P**	10	84	44	80	41	51	25

a)*ee*, c and *S* determined by HPLC; b)all isolated yields

Table 10. Catalyst loading effects on the selectivity of KR

2.5 Temperature dependence

The effect of reaction temperature on the KR was the final variable to be investigated. The reactions were performed at 4 different temperatures (45˚C, rt, 0˚C and -40˚C) in $CHCl_3$ using the mixed anhydride **62a** and the homoanhydride **56p** in parallel reactions using BTM (1 mol%). For anhydride **62a**, the *S* factor raised from 38 to 55 by going from 45 °C to room temperature. Further dropping the temperature to 0 °C and −40 °C gave *S* < 40 (Table 11, entries 1-4). Similar trend was given by anhydride **56p** with the highest *S* factor (*S* = 43) also obtained at room temperature (Table 11, 5-8). Interestingly, no diacylation was observed in all cases. The substrate scope was hence carried on at room temperature.

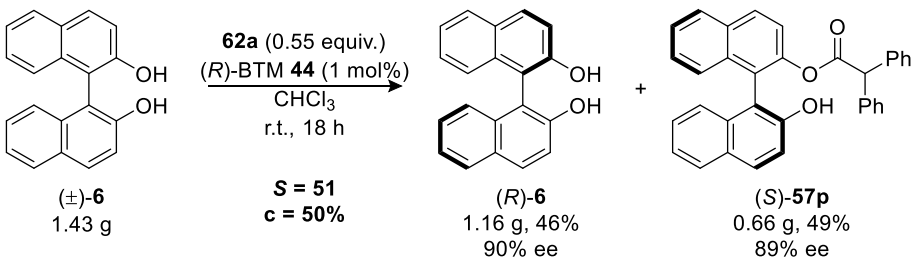


Entry	Anhydride	T/ °C	*ee*% **6**[a]	% **6**[b]	*ee*% **57k**[a]	% **57k**[b]	c (%)[a]	*S* [a]
1	**62a**	45	91	24	85	26	52	38
2	**62a**	r.t.	90	38	89	36	50	55
3	**62a**	0	88	35	82	21	52	30
4	**62a**	-40	42	35	92	14	31	35
5	**57k**	45	87	28	85	45	52	34
6	**57k**	r.t.	93	26	85	34	52	43
7	**57k**	0	92	48	86	39	52	42
8	**57k**	-40	83	30	86	30	49	31

a)*ee*, c and *S* determined by HPLC analysis; b)all isolated yields

Table 11. Investigation on temperature dependence

Following these studies, the optimal conditions for the KR of (±)-BINOL using 0.55 equivalents of mixed anhydride **62a** and (*R*)-BTM **44** (1 mol%) in chloroform for 18 hours at room temperature. To further showcase the robustness of this procedure, a gram-scale of the KR of BINOL (±)-**6** was then performed, giving *S* = 51 at c= 50%, with both recovered BINOL (*R*)-**6** and monoester recovered in excellent overall yield and in good enantiopurity (Scheme 20).



Scheme 20. Gram-scale KR of BINOL (±)-**6**

Chapter 3: Substrate scope

Overview

Having demonstrated an effective KR of (±)-BINOL (±)-**6** using the isothiourea BTM **44** (1 mol%) and mixed anhydride **62a**, this chapter demonstrates the scope and limitations of this procedure when applied to a range of (±)-biaryl diols**.**

3.1 BINOL derivatives

Having successfully optimised the isothiourea-catalysed KR of (±)-BINOL (±)-**6**, the synthesis of a range of biaryl diols was next targeted in order to probe the scope and limitations of this KR methodology. Substitution on rings B and B' (positions 5/5' to 8/8') of (±)-BINOL (±)-**6** were first synthesised and investigated, followed by substitution on rings A and A' (positions 3/3' & 4/4') (Figure 18).

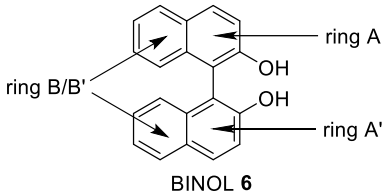
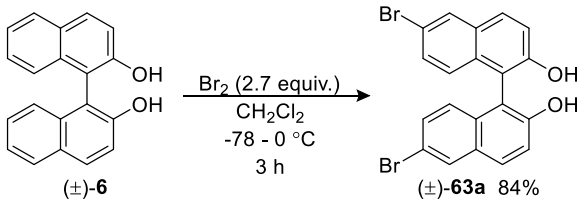


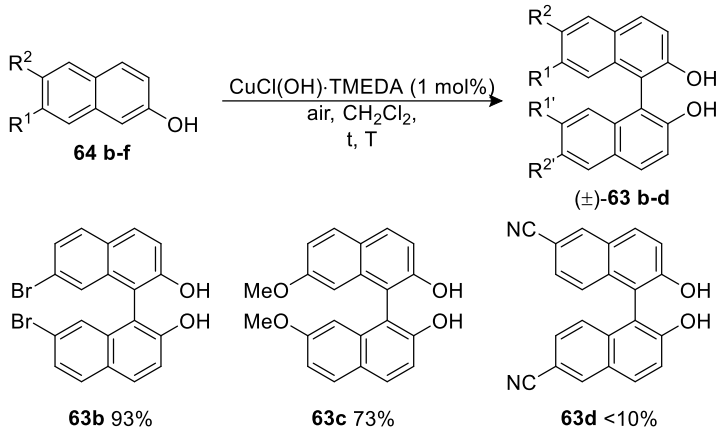
Figure 18. Ring A and ring B of BINOL

Direct modification of BINOL **6** was first attempted. 6,6'-Dibromo-[1,1'-binaphthalene]-2,2'-diol (±)-**63a** was isolated in high yield through direct bromination of BINOL (±)-**6**, with products from bromination at other positions not observed (Scheme 21).



Scheme 21. Synthesis of 6,6'-Dibromo-[1,1'-binaphthalene]-2,2'-diol (±)-**63a**

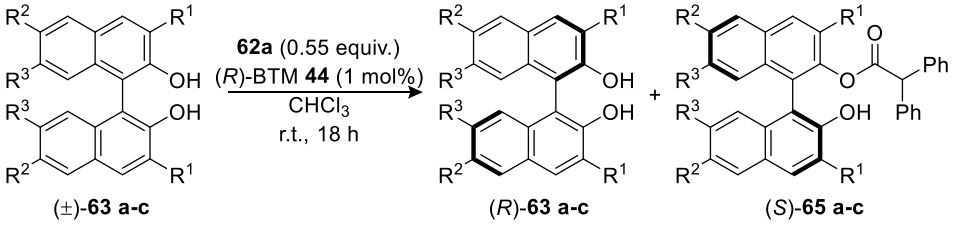
To prepare a number of other derivatives, the methodology reported by Koga and co-workers for the aerobic oxidative coupling of 2-naphthol derivatives using a CuCl-TMEDA complex was applied. 7,7'-Dibromo-[1,1'-binaphthalene]-2,2'-diol (±)-**63b** and 7,7'-dimethoxy-[1,1'-binaphthalene]-2,2'-diol (±)-**63c** were isolated in high yields after chromatographic purification through a silica plug. However 2,2'-dihydroxy-[1,1'-binaphthalene]-6,6'-dicarbonitrile (±)-**63d** was obtained in extremely low yield (around 10%) after multiple attempts, with competitive polymerisation suspected as the cause for this. Unfortunately, due to the low isolated yield, insufficient quantity of (±)-**63d** was isolated for use in a KR (Scheme 22).

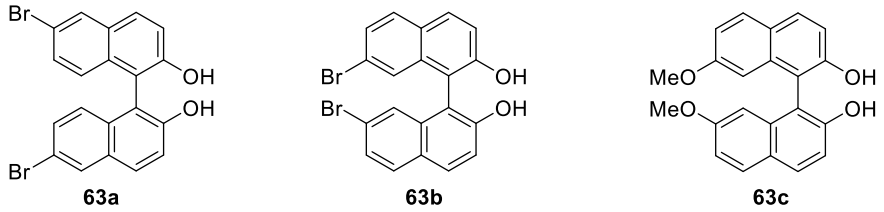


Scheme 22. Synthesis of racemic binaphthol derivatives **63 b-d**

The 3 BINOL derivatives **63 a-c** were then tested under the previously developed KR conditions to assess the generality of the procedure (0.55 equivalent of 2,2-diphenylacetic pivalic anhydride **62a**, (*R*)-BTM **44** (1 mol%), chloroform, r.t., 18 h). All examples were repeated until *S* = n±1, and no diester product was observed with any of the diols tested.

6,6'-Dibromo-BINOL (±)-**63a** gave an *S* factor of 25 with full conversion (55%), and the alcohol **65a** was recovered with 92% *ee* and good yield (43%) (Table 12, entry 1). Interestingly, by moving the bromo groups to the 7/7' positions, an *S* factor of only 10 was observed at 54% of conversion. Both recovered (*R*)-diol **63b** and (*S*)-monoester **65b** were isolated in good yields but moderate *ee* (Table 12, entry 2). However, with methoxy groups on the 7/7' positions, 7,7'-dimethoxy-BINOL (±)-**63c** was resolved with high selectivity *S* = 56 at c=52%, with the recovered alcohol obtained in high *ee* (96%) (Table 12, entry 3). Although the reason behind the differences in the selectivity is not immediately apparent, this presumably reflects a combination of electronic effects and/or steric effects of the substituents.



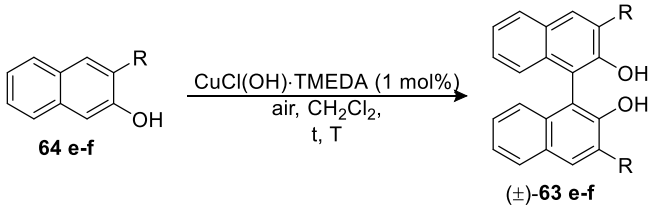


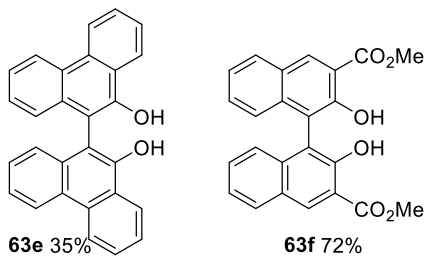
Entry	Diol	T/°C	Cat.	*i*Pr$_2$NEt	*ee*% **63**[a]	%**63**[b]	*ee*% **65**[a]	%**65**[b]	c (%)[a]	*S*[a]
1	**63a**	r.t.	1% **44**	-	92	43	77	49	55	25
2	**63b**	r.t.	1% **44**	-	77	50	64	47	54	10
3	**63c**	r.t.	1% **44**	-	97	52	87	44	52	56

a)*ee*, c and *S* determined by HPLC analysis; b)all isolated yields;

Table 12. KR of BINOL derivatives

Substitution on ring A of (±)-BINOL (±)-**6** were next investigated (Figure 18). Using commercially available 2-naphthol derivatives **64 e-f** with substitution at 3-position and the same aerobic oxidative coupling method as before,[68] dimethyl 2,2'-dihydroxy-[1,1'-binaphthalene]-3,3'-dicarboxylatediol (±)-**63f** was isolated in high yields after chromatographic purification through a silica plug. However, [9,9'-biphenanthrene]-10,10'-diol (±)-**63e** was obtained in low yield, but enough sample was successfully isolated for KR tests (Scheme 23).

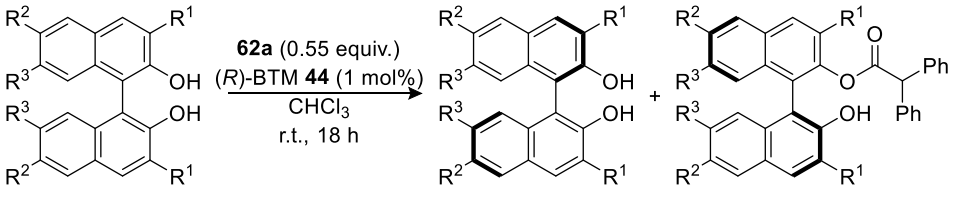


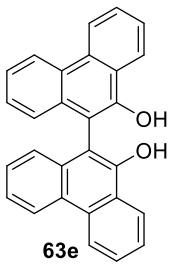


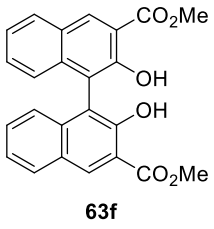
Scheme 23. Synthesis of racemic binaphthol derivatives **63 e-f**

[9,9'-Biphenanthrene]-10,10'-diol (±)-**63e** was first tested, with ^{1}H NMR spectroscopy confirming that the reaction only proceeded to less than 10% conversion after 18 hours under the developed conditions (Table 13, entry 1). Leaving the reaction for a further 24 hours showed no change in the conversion. The reaction did proceed to 27% of conversion after 18 hours by raising the catalyst loading to 10 mol%, however, the selectivity was very low in this case (*S* = 6) (Table 13, entry 2).

The derivative with ester groups at the 3/3'- positions (**63f**) was then investigated. The racemic sample of monoester **65f** was successfully isolated using DMAP catalysis. However, dimethyl 2,2'-dihydroxy-[1,1'-binaphthalene]-3,3'-dicarboxylatediol (±)-**63f** did not show any conversion under the optimal condition (Table 13, entry 3). No trace of the monoester **65f** was observed after catalyst loading was raised to up to 10 mol%, temperature raised up to 65 °C, with the addition of *i*Pr$_2$NEt (Table 8, entries 7). Further investigations including changing the catalyst to HyperBTM **48** at high catalyst loading and high temperature, raising the amount of anhydride **62a** to 1.5 equivalent, as well as switching to less bulky isobutyric anhydride **53** also showed no improvement in conversion. These observations suggest that substitution at the 3/3'-position creates a steric barrier to acylation that disfavours reaction with the acylated catalyst. Substitution at this position also leads to low enantioselectivity, potentially disrupting a key element of stereocontrol compared to the parent (±)-BINOL.







Entry	Diol	T/°C	Cat.	*i*Pr$_2$NEt	*ee*% **63**[a]	%**63**[b]	*ee*% **65**[a]	%**65**[b]	c (%)[a]	*S*[a]
1	**63e**	r.t.	1% **44**	-	-	-	-	-	<10[c]	-
2	**63e**	r.t.	10% **44**	-	23	45	65	25	27	6
3	**63f**	r.t.	1% **44**	-	-	-	-	-	0	-
4	**63f**	65	10% **44** or **48**	0.6	-	-	-	-	0	-

a)*ee*, c and *S* determined by HPLC analysis; b)all isolated yields;

Table 13. KR of BINOL derivatives

3.2 Biphenyl derivatives

With the data obtained from the BINOL derivatives **63** in hand, biphenyl derivatives **66** were next investigated. Biphenyl derivatives **66** with substitution in the 6/6' positions are expected to exhibit restricted rotation resulting in axial chirality (Figure 19).

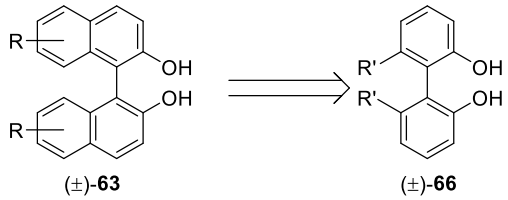
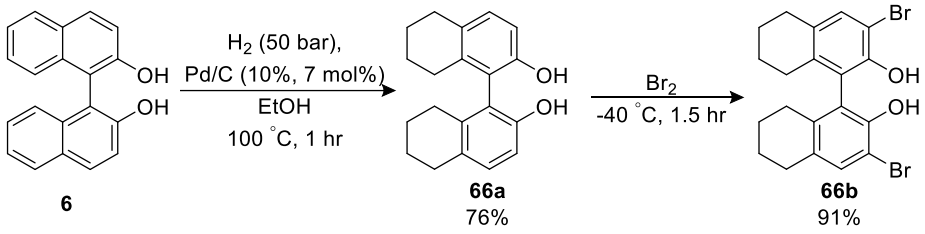


Figure 19. General structures of **63** and **66**

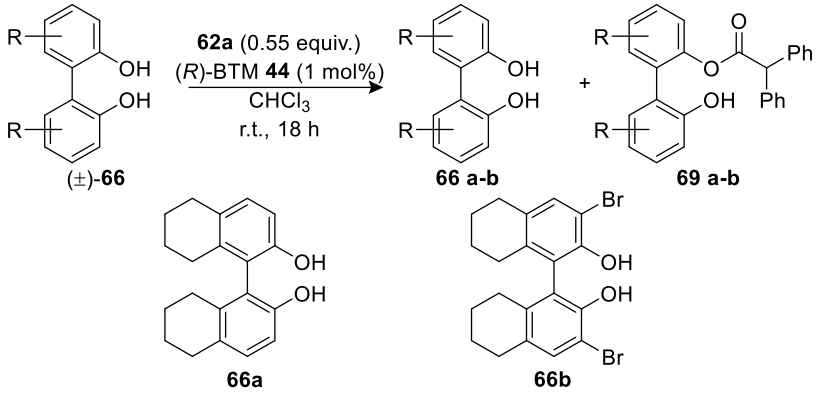
Derivatives of (±)-BINOL (±)-**6** with saturated ring B were first synthesised and investigated. Hydrogenation of BINOL **6** gave 5,5',6,6',7,7',8,8'-octahydro-1,1'-bi-2-naphthol (H8-BINOL) **66a** in good yield (76%),[69] which was further treated with bromine to give 3,3'-dibromo-5,5',6,6',7,7',8,8'-octahydro-[1,1'-binaphthalene]-2,2'-diol **66b** in 91% yield (Scheme 24).[70]



Scheme 24. Synthesis of **66a** and **66b** from BINOL **6**

H8-BINOL **66a** was first tested in the KR. Interestingly, with 1 mol% of BTM **44**, no conversion was observed (Table 14, entry 1). By raising the catalyst loading to 5 mol%, the reaction proceeded to 45% of conversion but with very low selectivity (*S* = 3); further raising the catalyst loading to 10 mol% showed no improvement in either conversion or selectivity (Table 14, entries 2 & 3). HyperBTM **48** was then tested in this case. Interestingly, the reaction proceeded to 41% conversion with improved selectivity of *S* = 10 with only 1 mol% of HyperBTM **48**. By raising the catalyst loading to 5 mol%, improvements in conversion was observed while the selectivity remained the same (Table 14, entries 4 & 5). In order to have a direct comparison, the HyperBTM **48** catalysed KR of BINOL **6** was also performed. As expected from initial screening (Table 1), very poor selectivity of *S* = 3 was observed (Table 14, entry 6). No diester product was observed in this case.

3,3'-Dibromo-5,5',6,6',7,7',8,8'-octahydro-[1,1'-binaphthalene]-2,2'-diol **66b** was next tested. The racemic sample of monoester **69b** was successfully isolated using DMAP catalysis, however, under the developed conditions of KR, no conversion was observed following changing the catalyst loading, catalyst, temperature or by adding base (Table 14, entries 7 & 8). Replacement of the bulky mixed anhydride **62a** with acetic anhydride **56a** also did not show any reactivity with various catalyst loadings. This observation further confirms that this newly developed KR procedure is not suitable for resolving biaryl structures with substituents on 3/3'-positions.

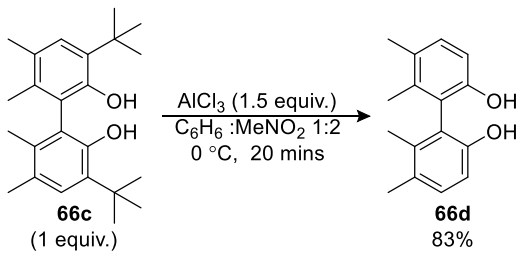


Entry	Diol	T/°C	Cat.	*i*Pr$_2$NEt	*ee*% **66**[a]	%**66**[b]	*ee*% **69**[a]	%**69**[b]	c (%)[a]	*S*[a]
1	**66a**	r.t.	1% **44**	-	-	-	-	-	0	-
2	**66a**	r.t.	5% **44**	-	30	23	37	13	45	3
3	**66a**	r.t.	10% **44**	-	34	43	38	44	47	3
4	**66a**	r.t.	1% **48**	-	51	50	72	40	41	10
5	**66a**	r.t.	5% **48**	-	74	50	66	17	53	11
6	**6**	r.t.	1% **48**	-	43	43	39	38	53	3
7	**66b**	r.t.	1% **44**	-	-	-	-	-	0	-
8	**66b**	65	10% **44**/**48**	0.6	-	-	-	-	0	-

a)*ee*, c and *S* determined by HPLC analysis; b)all isolated yields

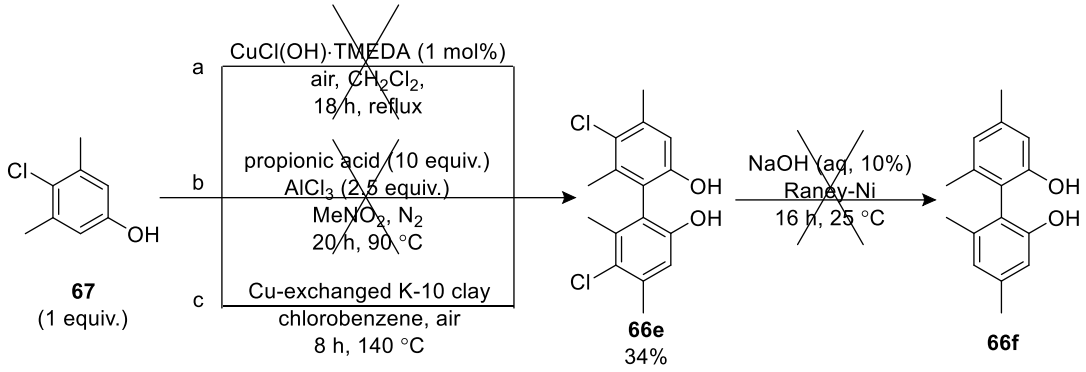
Table 14. KR of biphenol derivatives

Next, biphenol derivatives with acyclic substitutions were synthesised and investigated. 5,5',6,6'-Tetramethyl-[1,1'-biphenyl]-2,2'-diol **66d** was obtained in high yield (83%) from cheap and commercially available 3,3'-di-*tert*-butyl-5,5',6,6'-tetramethyl-[1,1'-biphenyl]-2,2'-diol **66c** through a dealkylation reaction (Scheme 25).[71]



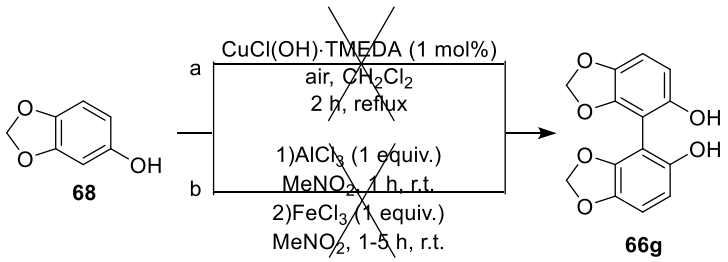
Scheme 25. Synthesis of 5,5',6,6'-tetramethyl-[1,1'-biphenyl]-2,2'-diol **66d**

The synthesis of 5,5'-dichloro-4,4',6,6'-tetramethyl-[1,1'-biphenyl]-2,2'-diol **66e** was attempted using commercially available 4-chloro-3,5-dimethylphenol **67**. The aerobic oxidative coupling method used to synthesise BINOL derivatives **63** was first tested,[68] however, no conversion was observed in this case (Scheme 26a). Another method employing $AlCl_3$ and excessive propionic acid was tested at different temperatures[72], however, no sign of the desired product was observed by ^1H NMR spectroscopy (Scheme 26b). A third method was tested using Cu-exchanged K-10 clay synthesised in house[73], with this method affording the desired product in a moderate yield of 34% (Scheme 26c).[74] Subsequent removal of the chlorine substituents from **66e** by using Raney-Nickel however was unsuccessful.[75]



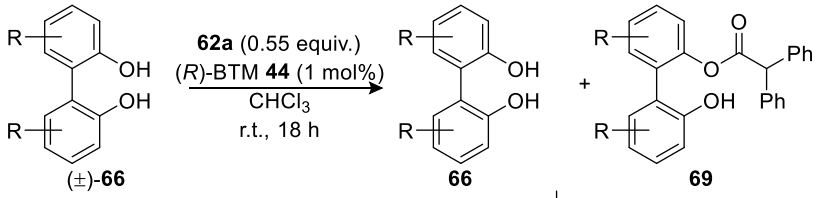
Scheme 26. Synthesis of 5,5'-dichloro-4,4',6,6'-tetramethyl-[1,1'-biphenyl]-2,2'-diol **66e**

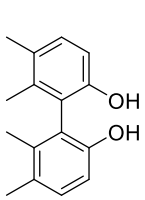
The synthesis of dimethyl 2,2'-dihydroxy-[1,1'-binaphthalene]-3,3'-dicarboxylatediol **66g** from cheap commercially available natural product sesamol **68** was attempted using aerobic oxidative coupling with CuCl-amine complex (Scheme 26a).[68] However, no product was observed with polymerisation postulated. Another reported oxidative coupling method was next tested using $AlCl_3$ and $FeCl_3$ (Scheme 26b).[76] Unfortunately, none of the desired product was observed.

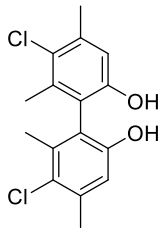


Scheme 26. Failed attempts to synthesise **66g**

5,5',6,6'-Tetramethyl-[1,1'-biphenyl]-2,2'-diol **66d** was then resolved to give good selectivity with *S* = 37 at c=48%, with both the recovered alcohol **66d** and monoester **69d** obtained with high *ee* (Table 15, entry 1). The KR of 5,5'-dichloro-4,4',6,6'-tetramethyl-[1,1'-biphenyl]-2,2'-diol **66e** also proceeded to high conversion (48%), however a diminished *S* factor of 14 was obtained using BTM **44** (Table 15, entry 2). The high conversion suggests that substitution on the 4/4'-positions does not affect the reactivity of the reaction. The relatively low selectivity of this case might be due to the steric effects or electronic effects of the chorine groups on 5/5' positions. Interestingly, by switching the catalyst to HyperBTM **48**, reduced selectivity (*S* < 5) was observed (Table 15. Entry 3).







Entry	Diol	T/°C	Cat.	*i*Pr$_2$NEt	*ee*% **66**[a]	%**66**[b]	*ee*% **69**[a]	%**69**[b]	c (%)[a]	*S*[a]
1	**66d**	r.t.	1% **44**	-	81	44	87	40	48	37
2	**66e**	r.t.	1% **44**	-	69	48	74	40	48	14
3	**66e**	r.t.	1% **48**	-	56	44	46	54	55	5

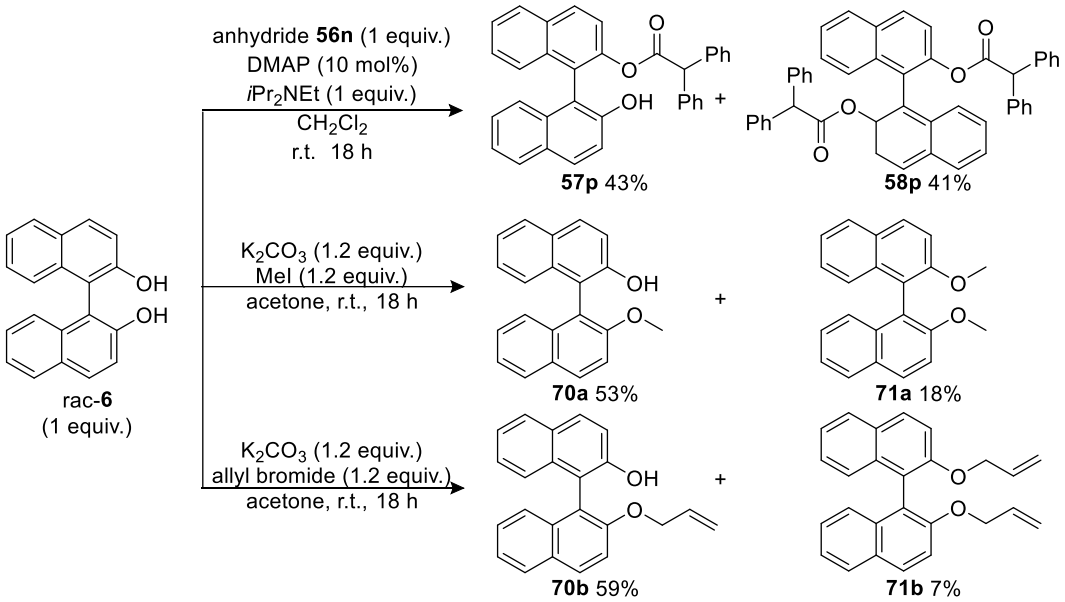
a)*ee*, c and *S* determined by HPLC analysis; b)all isolated yields

Table 15. KR of biphenol derivatives

3.3 Mono-protected biaryl diols and NOBIN derivatives

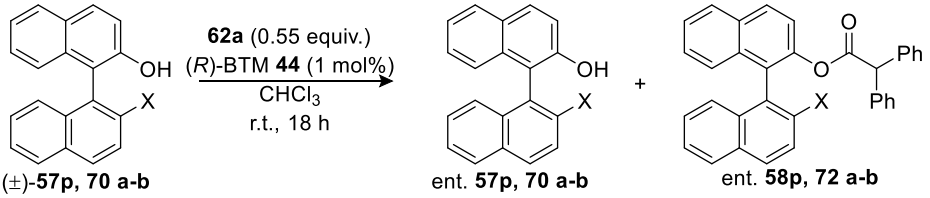
As the KR of monoester (±)-**54** did not proceed with high selectivity (Scheme 15), the reason behind this was next investigated. Multiple computational studies of Lewis base catalysed acylation processes have suggested the carboxylate generated *in situ* from reaction of an anhydride could act as a H-bond acceptor in the TS of acylation/KR of alcohols.[65,77] As monoester (±)-**54** could not be resolved with good selectivity, it was suspected that both of the hydroxy groups within the biaryl diol structure might be involved in the transition state through H-bonding, or the bulkiness of the mono-protecting ester group changed the conformation of the TS. To investigate these hypothesis, i) mono-protected biaryl diols were synthesised and tested to verify the reason for the lack of selectivity with only one hydroxy group available on the diol, and ii) *N*-protected NOBIN derivatives were synthesised and tested to investigate if two hydrogen donors on the biaryls are needed for good selectivity.

A racemic sample of monoester **57p** was prepared in moderate yield (43%) using DMAP catalysis, with methyl and allyl protected BINOL derivatives also synthesised by alkylation of (±)-BINOL (±)-**6** in moderate yields (53% and 59% respectively) (Scheme 27). In all cases the difunctionalised product was observed.



Scheme 27. Synthesis of mono-protected BINOL derivatives

The KR of mono-protected diols was then performed under the previously developed conditions (Table 16). KR of monoester **57p** gave only low selectivity (*S* = 1) and conversion (10%), consistent with previous observation (Table 16, entry 1; Scheme 15). Methylated BINOL **70a** was tested next. Interestingly, with less bulky alkyl *O*-substituent, the selectivity of the KR was still low (*S* < 2). Raising the catalyst loading resulted in improved yield but no change was observed in selectivity (Table 16, entries 2-4). Although racemic sample was isolated by DMAP catalysis, the more bulky *O*-allyl-BINOL **70b** showed no conversion at various catalyst loadings in the KR procedure (Table 16, entry 5).



(±)-**57p, 70 a-b** ent. **57p, 70 a-b** ent. **58p, 72 a-b**

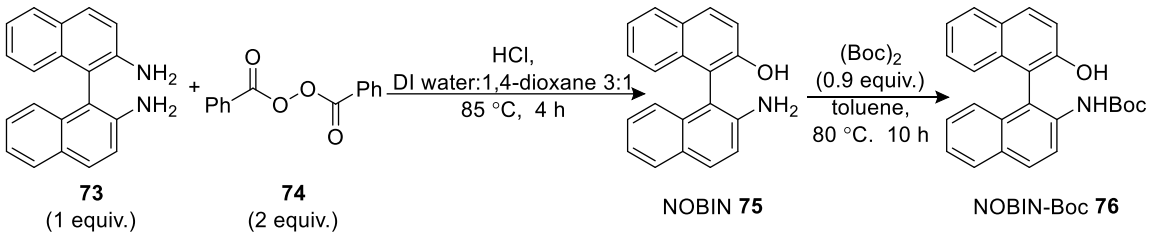
57k **70a** **70b**

Entry	alcohol	Cat.	$ee_{alcohol}$[a]	%alcohol[b]	ee_{ester}[a]	%ester[b]	c (%)[a]	*S* [a]
1	**57p**	1% **44**	0.3	5*	3.2	14	10	1.1
2	**70a**	1% **44**	1.1	87	28	3	4	1.8
3	**70a**	5% **44**	6	78	25	19	20	1.8
4	**70a**	10% **44**	8	61	24	23	25	1.8
5	**70b**	10% **44**	-	-	-	-	0	-

a)*ee*, c and *S* determined by HPLC analysis; b)all isolated yields ; *diester

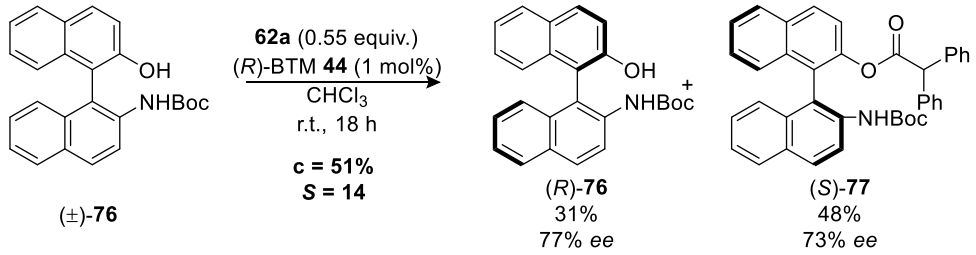
Table 16. KR of mono-protected BINOL derivatives

As the KR of mono-protected BINOL derivatives has proven ineffective, the synthesis of NOBIN **75** and an *N*-protected NOBIN derivative was next investigated. Commercially available BINAM **73** was converted to NOBIN **75** in moderate yield using benzoyl peroxide **73**.[78] Boc-protected NOBIN **76** was also isolated in moderate yield[79] (Scheme 28). However, the purification of both **75** and **76** through column chromatography and recrystallisation proved to be challenging. The potential KR of N-Boc-NOBIN **76** therefore used material isolated without further purification.



Scheme 28. Synthesis of NOBIN **75** and NOBIN-Boc **76**

The KR of NOBIN-Boc **76** was then performed under the previously developed conditions (Scheme 29). The KR proceeded with high conversion (51%) and good selectivity (*S* = 14), with both recovered (*R*)-NOBIN-Boc **76** and ester (*S*)-**77** isolated in good yield and enantiopurity. The effect of impurities in **76** on the selectivity of the KR is not clear at this stage.



Scheme 29. KR of NOBIN-Boc **76**

Taken together, these results indicate that biaryl diols containing only one H-bond donor were resolved with poor selectivity and reactivity, while NOBIN-Boc **76** could be resolved with reasonable levels of selectivity (*S* = 14) at high conversion. These results suggest that the biaryl needs to carry two H-bond donors in order to obtain good selectivity and reactivity in this KR procedure.

Chapter 4: Mechanism insights

4.1 Proposed catalytic cycle

Based on previous experiments and computational work the following mechanism can be proposed.[65] Reversible *N*-acylation of the catalyst **44** by mixed anhydride **62a** gives acyl ammonium intermediate **78**. The carbonyl group is postulated to lie in the same plane as the S and N atoms of the catalyst due to a non-bonding S---O interaction.[64a] The phenyl group is forced to adopt a pseudoaxial orientation to avoid 1,2 strain, providing enough steric hindrance to effectively block the "bottom" face (*Re*) of the acylated catalyst.[64b] Selective nucleophilic attack of BINOL (±)-**6** proceeds *anti*-to the stereodirecting phenyl unit, giving enantioenriched (*R*)-BINOL (*R*)-**6** and (*S*)-monoester (*S*)-**57p** upon deprotonation and regeneration of the catalyst (*R*)-BTM **44**. As the KR is performed in the absence of base, the carboxylate generated *in situ* is expected to act as the deprotonating species in the catalytic cycle. The selectivity of the KR is determined by the difference in the energies of the diastereomeric transition states (TSs) for acylation of the two enantiomers of BINOL **6**.

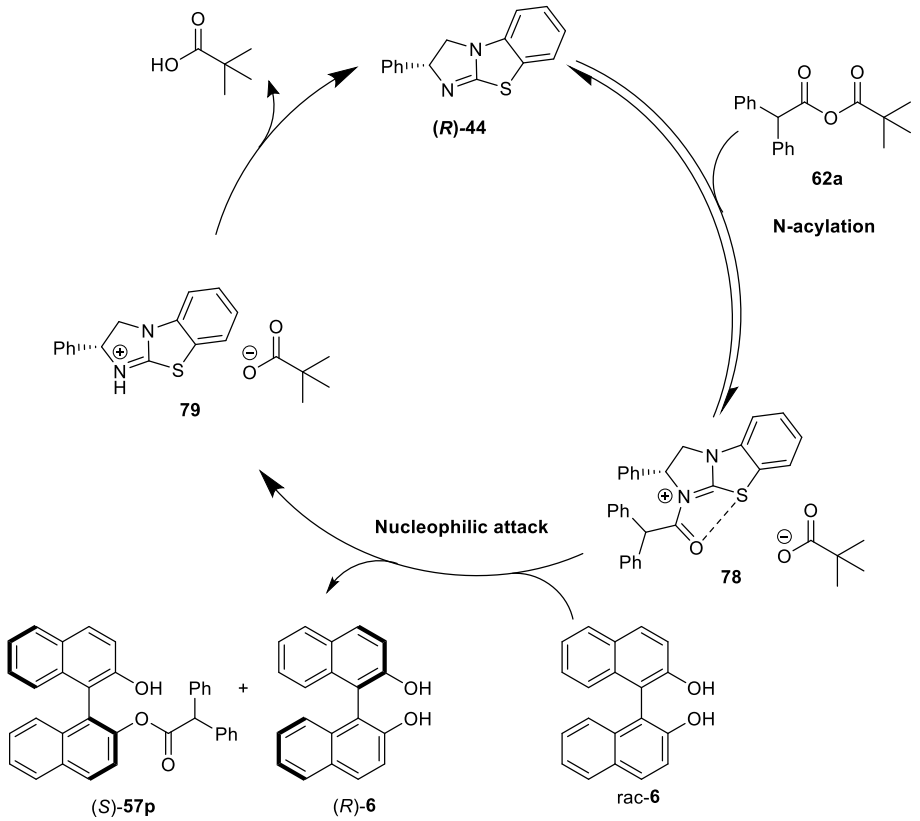


Figure 20. Proposed catalytic cycle for the KR of BINOL **6** using (*R*)-BTM **44**

4.2 Proposed acylation transition states

Three major observations from the substrate scope are as follows:

1) The biaryl must contain two H-bond donors (2 × OH or 1 OH + 1 NH) in order to obtain good selectivity and reactivity in this KR procedure.

2) Saturation of B/B' ring (H8-BINOL) leads to significantly reduced selectivity in the KR;

3) Biaryl structures with substituents at the 3/3'-positions gave very low or no conversion in this KR procedure.

Based upon these observations a simple stereochemical model for the acylation TS can be proposed.

Multiple computational studies have suggested the non-innocent role of the carboxylate counterion generated *in situ* in the acylation/KR of alcohols.[65,76] The H-bond acceptor ability of carboxylates has been proposed to stabilise the acylation TS though two-point H-bonding to both the alcohol substrate and acylated catalyst in the KR of tertiary alcohol substrates (Figure 21 left). Based on the necessity for two H-bond donors in the substrate in the current methodology, it is suspected that the carboxylate binds with the two H-bond donors of the substrate through two-point binding to stabilise the acylation TS and promote reactivity (Figure 21 right). This two-point coordination is not possible for the KR of mono-protected diols and hence results in less efficient acylation. The lack of this stabilising coordination also appears to result in a smaller energy difference between the diastereomeric TSs for acylation of the two enantiomers of the substrate, due to the lower selectivity factors obtained. In contrast, the requisite dual H-bond donating ability of the substrate is still present in mono *N*-protected NOBIN derivative **77**, explaining its effective KR under standard conditions (*S* = 14 and c > 50%).

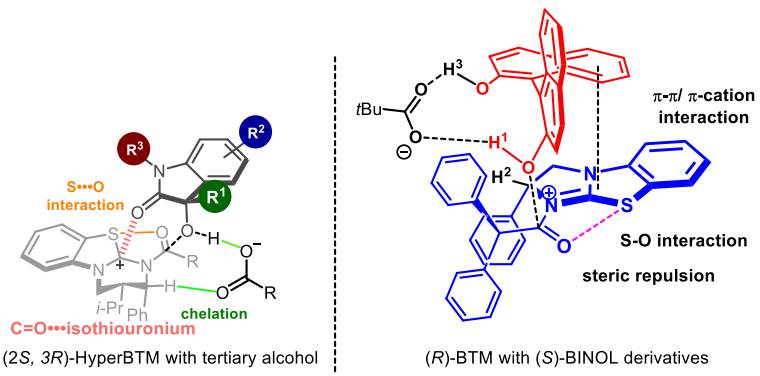


Figure 21. Proposed two-point binding between the carboxylate counterion and the alcohol substrate in isothiourea-catalysed KR of alcohols

Assuming the necessity of this two-point carboxylate binding with the substrate in both diastereomeric acylation TS, the selectivity of the developed KR procedure can then be rationalised (Figure 22). For the KR using (*R*)-BTM **44**, (*S*)-BINOL (*S*)-**6** is the faster reacting enantiomer of (±)-BINOL **6**, providing enantioenriched (*R*)-BINOL (*R*)-**6** and (*S*)-monoester (*S*)-**57p** after the KR procedure. In the acylation TS for the fast reacting (*S*)-BINOL, π-π and/or π-cation interactions between the extended naphthylene π-system of BINOL **6** and the cationic *N*-acylated isothiouronium could serve to stabilise this TS (Figure 22 left). For the acylation of (*R*)-BINOL, these additional stabilising π-π and/or π-cation interactions are not present (Figure 22 right).

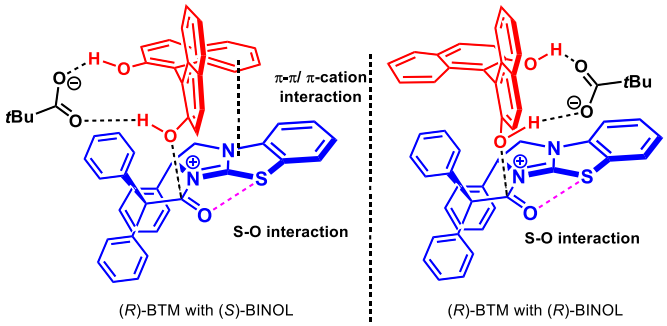


Figure 22. Interactions between (*R*)-BTM and two enantiomers of BINOL

Incorporation of substituents at the 6/6' and 7/7' positions of BINOL **6** leads to perturbation of the steric and electronic nature of the naphthylene unit, thus modulating the magnitude of these stabilising π-π and/or π-cation interactions and leading to changes in the selectivity of these KR processes. Semisaturation of the naphthalene unit to give H8-BINOL **66a** would result in a loss of these stabilising π-π and/or π-cation interactions, consistent with the reduced selectivity observed in the KR (*S* = 3). Substitution at the 3/3' positions leads to reduced reactivity, which can be rationalised as the 3-substituent would provide a steric barrier to reaction of the alcohol with the carbonyl group of the acylated catalyst, thus preventing attack of the hydroxy group to the carbonyl at the optimal angle (Figure 23).

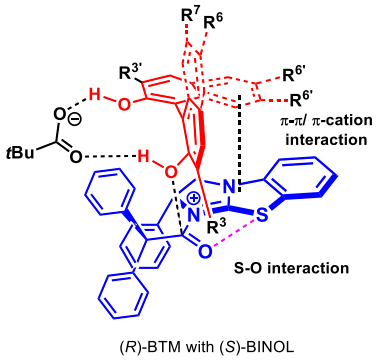
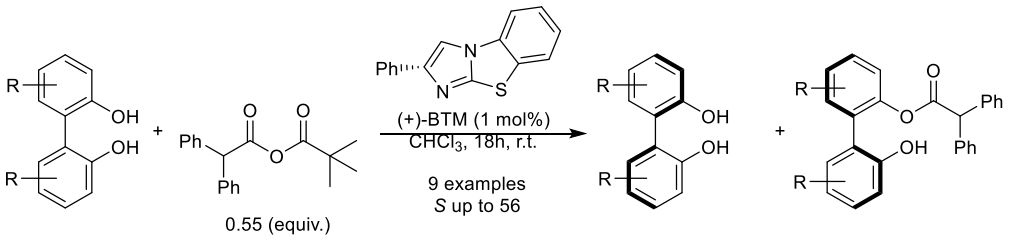


Figure 23. (*R*)-BTM and BINOL derivatives

Chapter 5: Conclusions

5.1 Conclusions

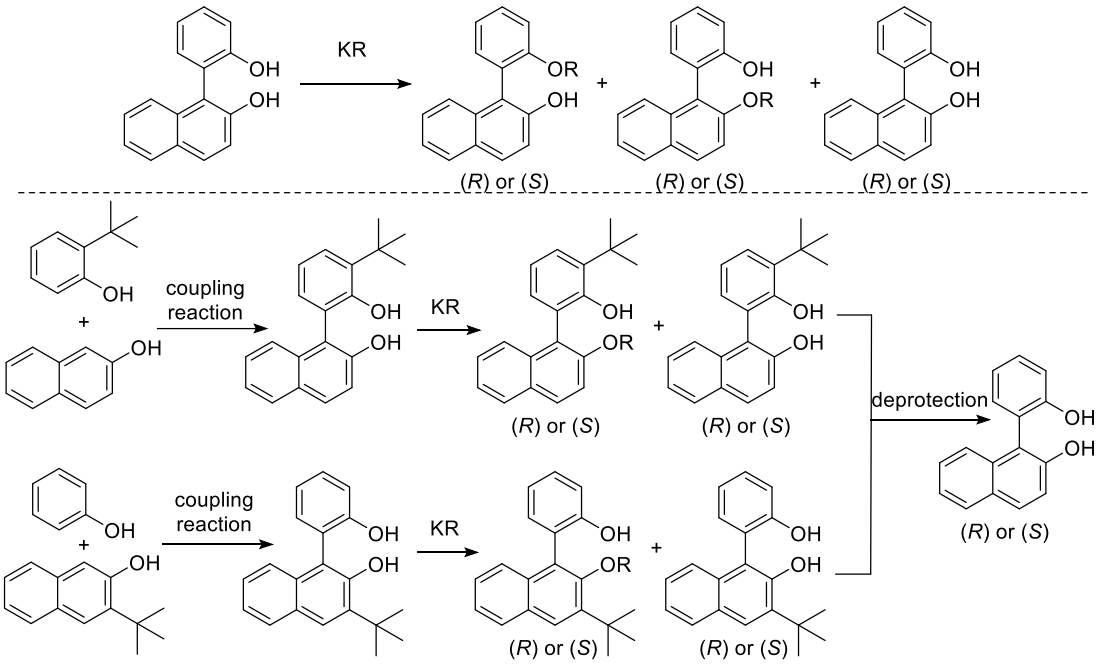
In conclusion, this work describes the first method of isothiourea-catalyzed acylative KR of biaryl diols. In the model system, of the 3 isothioureas tested, (R)-BTM was found to be the optimal catalyst for the KR of (±)-BINOL. Of the 10 common solvents tested, chloroform was found to be the optimal solvent. Although the choice of the solvent has an effect on the monoester:diester product ratio in the KR, the generation of diesters does not have a significant effect on the selectivity of the KR as shown by control experiments. After testing 18 homoanhydrides and 3 mixed anhydrides (generated *in situ* or isolated), 2,2-diphenylacetic pivalic anhydride was found to be the best performing anhydride for enantioselective acylation, giving *S* = 55 at c = 50%. It was also found that higher selectivity was observed with the lower catalyst loading (1 mol%), while previous publications on acylative KR of biaryls reported the necessary use of ≥ 10 mol% Lewis base catalyst. It was also found that the KR shows better selectivity without the use of base. A total of 13 BINOL, biphenol and NOBIN derivatives were tested in the KR process, showing moderate to good selectivity (*S* up to 56). Substitution on the 3/3'-positions of the symmetrical biaryl diols was found to be not suitable to this newly established procedure, however this feature could be utilized to benefit future work on KR of asymmetrical biaryl diols (see section 5.2 Future work). Interestingly to obtain good reactivity and selectivity two H-bond donor groups are required within the starting material. Mono-methylated BINOL gave low selectivity (*S* = 1.8) at 25% conversion with 10 mol% catalyst loading and no reactivity observed with mono-allylated BINOL under various conditions, while Boc-protected NOBIN could be resolved with *S* =14 at c > 50%.



Scheme 30. BTM-catalyzed acylative KR of biaryl diols

5.2 Future work

This work has shown that symmetrical biaryl diols bearing 3/3'-substituents are not suitable for this newly established KR procedure, however, this feature could be utilized in the KR of asymmetric biaryl diols in order to avoid the generation of diastereoisomers (Scheme 31). As the 2-hydroxy group will be effectively blocked by the adjacent 3-substitution, only one ester product can be obtained from the KR. The substitution could be incorporated on either aromatic moiety before the coupling reaction to afford the biaryl, based on the availability and cost of the starting material. The substitution on the 3/3'- position can be selected so that it can be easily removed after the KR procedure.



Scheme 31. KR of asymmetric biaryl diols

Kinetic resolution is a popular method for obtaining enantioenriched products. Despite the high selectivity of the results obtained in this project, it is limited by the nature of racemates and the inherent disadvantage of KR, where the theoretical maximum yield of one enantiomer is only 50%. This limitation can be overcome through employing a dynamic kinetic resolution (DKR), in which constant *in situ* racemization of the diol will be coupled with a KR to allow quantitative product yields under optimal conditions. In order to obtain one single enantiomer with high enantiopurity after the DKR, the rate constant *k*' of interconversion needs to be bigger than the rate constant of KR of the slower reacting enantiomer k_{slow} (Figure 24).

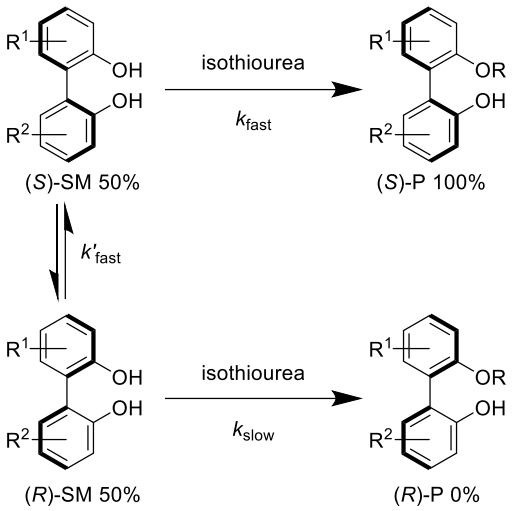


Figure 24. DKR of biaryl alcohols using BTM

Although most biaryl alcohols are configurationally stable to heating, there are known cases where racemization of atropisomers can be promoted by either photochemical irradiation[79] or acid catalysis.[80] Future studies on this subject will focus on finding reaction conditions for an efficient DKR of biaryl alcohols. Upon optimisation of the reaction conditions, the scope and limitations of these DKR processes could be developed. Kinetic and mechanistic studies could be carried out and applications in target biaryl-natural product synthesis could be explored.

Chapter 6: Experimental

6.1 General Information

Moisture sensitive reactions were carried out under a nitrogen (N_2) atmosphere using standard vacuum line techniques and anhydrous solvents. All glassware used were flame-dried and allowed to cool to room temperature under vacuum before use. Anhydrous solvents (THF and CH_2Cl_2) were obtained after passing through an alumina column (Mbraun SPS-800). All other solvents and commercial reagents were used as supplied without further purification.

Room temperature (r.t.) refers to 20-25 °C. Temperatures of 0 °C were obtained using ice/water bath while −78 °C obtained using CO_2(s)/acetone baths. *In vacuo* refers to the use of a Büchi Rotavapor R-2000 or a Heidolph Laborota 4001 rotary evaporator with a vacuum controller.

Analytical thin layer chromatography was performed on pre-coated aluminium plates (Kieselgel 60 F254 silica). TLC visualisation was carried out with ultraviolet light (254 nm), followed by staining with a 1% aqueous $KMnO_4$ solution. Automated chromatography was performed on a Biotage Isolera Four running Biotage OS578 with a UV/Vis detector using the method stated and cartridges filled with Kieselgel 60 silica.

Melting points were recorded on an Electrothermal 9100 melting point apparatus and are uncorrected. Infrared spectra (ν_{max} /cm^{-1}) were recorded on a Shimadzu IRAffinity-1 using a Pike attenuated total reflectance (ATR) accessory. Only the characteristic peaks are quoted.

^1H and ^{13}C {^1H} nuclear magnetic resonance (NMR) spectra were acquired on a Bruker Avance II 400 (500 MHz, ^1H, 127 MHz ^{13}C) spectrometer at room temperature in $CDCl_3$ (solvent reference peak for $CDCl_3$ in the ^1H NMR = 7.26 ppm, and in $^{13}C\{^1H\}$ NMR = 77). All chemical shifts are quoted in parts per million (ppm) relative to the residual solvent as the internal standard. All coupling constants, *J*, are quoted in Hertz (Hz). Multiplicities are indicated by: s (singlet), d (doublet), t (triplet), dd (doublet of doublets), ddd (doublet of doublet of doublets), ddt (doublet of doublet of triplets), dt (doublet of triplets), tt (triplet of triplets) and m (multiplet). The abbreviation Ar is used to denote aromatic, br to denote broad and app to denote apparent. NMR peak assignments were confirmed using 2D ^1H correlated spectroscopy (COSY), 2D ^1H–^{13}C heteronuclear multiple-bond correlation

spectroscopy (HMBC), and 2D $^{1}H–^{13}C$ heteronuclear single quantum coherence spectroscopy (HSQC) where necessary.

HPLC traces of enantiomerically enriched compounds were compared with authentic racemic spectra. HPLC analyses were obtained operated on a Shimadzu HPLC instrument consisting of a DGU20A5 degasser, LC-20AT liquid chromatograph, SIL-20AHT autosampler, CMB-20A communications bus module, SPD-M20A diode array detector and a CTO-20A column oven which allowed the temperature to be set from 25-40 °C. Separation was achieved using either a DAICEL CHIRALCEL OD-H and OJ-H column or DAICEL CHIRALPAK AD-H, AS-H and IB columns using the method stated.

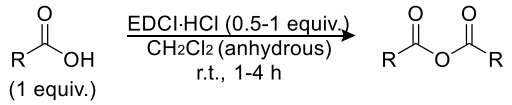
Mass spectrometry (m/z) data were acquired by atmospheric solids analysis probe (ASAP) or nanospray ionisation (NSI) either at the EPSRC UK National Mass Spectrometry Facility at Swansea University ($[A]^{+}$ quoted).

Optical rotations were measured on a Perkin Elmer Precisely/Model-341 polarimeter operating at the sodium D line with a 100 mm path cell at room temperature in $CHCl_3$.

6.2 General Procedures

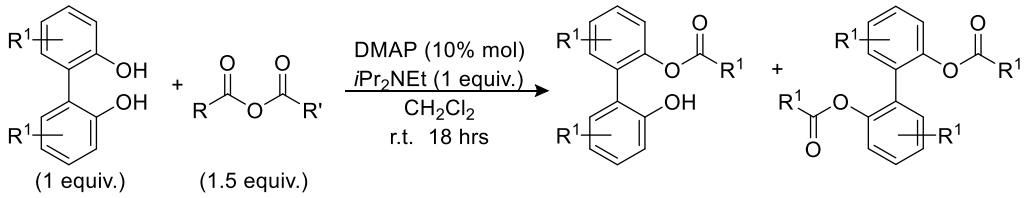
General Procedure A: Preparation of homoanhydrides using EDCI·HCl

Carboxylic acid (1 equiv.) was dissolved in CH_2Cl_2 (0.8 M) and EDCI·HCl (0.5-1 equiv.) was then added. The resulting mixture was stirred for 3 hours at room temperature. The solution was diluted with CH_2Cl_2 and washed with distilled water and subsequently with saturated aqueous solution of $NaHCO_3$. The organic layer was dried over $MgSO_4$, filtered and concentrated *in vacuo* to give desired homoanhydride.



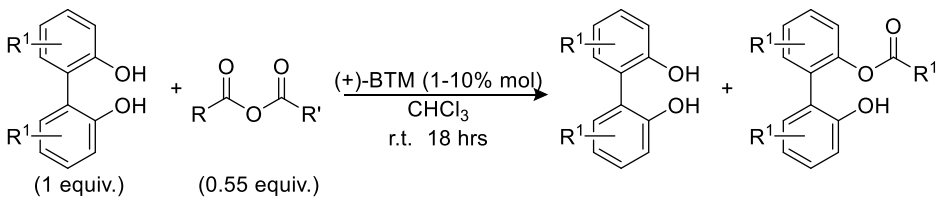
General Procedure B: DMAP-catalyzed acylation for racemic samples

Alcohol (1 equiv.) and DMAP (10 mol%) were added into CH_2Cl_2 (0.05 M) at room temperature. Homoanhydride (1.5 equiv.) and *i*Pr_2NEt (1 equiv.) were added to the previous solution. The resulting solution was left stirring for 18 hours at room temperature. The reaction mixture was concentrated *in vacuo* and purified as specified.



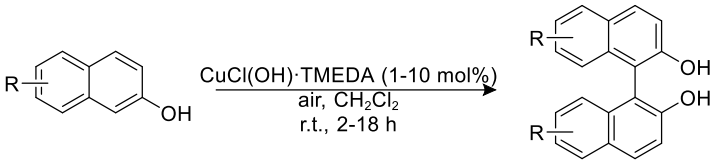
General Procedure C: Isothiourea-catalyzed acylation for enantioenriched samples

Alcohol (1 equiv.) and isothiourea (1-10 mol%) were added into solvent (0.05 M) at stated temperature. Stated anhydride (0.55 equiv.) was added to the previous solution. The resulted solution was left stirring for 18 hours at room temperature. The reaction mixture was concentrated *in vacuo* and purified as specified.



General Procedure D: Aerobic cross coupling to synthesis symmetrical biaryl compounds

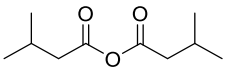
Naphthol derivative (1 equiv.) was dissolved in MeOH (0.1 M) at room temperature. Cu-TMEDA catalyst (1-10 mol %) was added and the solution was stirred for the stated time under the stated temperature. The mixture was purified as specified.



6.3 Experimental

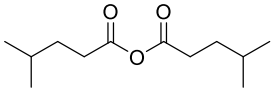
Preparation of anhydrides:

Isovaleric anhydride 56d



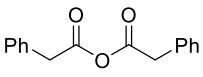
Following general procedure A: EDCI·HCl (479 mg, 2.5 mmol) and isovaleric acid (511 mg, 5.0 mmol) were added to CH_2Cl_2 (6 mL, 0.83 M) to give a clear solution, which was stirred for 4 hours at room temperature. The solution was diluted with CH_2Cl_2 (50 mL) was and the washed with distilled water (2 × 50 mL) then saturated aqueous solution of $NaHCO_3$ (50 mL). The organic layer was dried ($MgSO_4$), filtered and removed *in vacuo* to give isovaleric anhydride as a pale yellow oil (0.15 g, 32%). ν_{max} (ATR): 2961 (C-H), 1815 (C=O), 1024 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 2.31 (d, *J* 7.2, 4H, 2 × C*H*$_2$), 2.14 (septet, *J* 6.8, 2H, 2 × -C*H*), 0.99 (d, *J* 6.7, 12H, 4 × -C*H*$_3$); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 169.0 (2 × C=O), 44.3 (2 × -*C*H_2), 25.4 (2 × -*C*H), 22.4 (4 × -*C*H_3)

4-Methylpentanoic anhydride 56e



Following general procedure A: 4-Methylpentanoic acid (581 mg, 5.0 mmol) was added to CH_2Cl_2 (6 mL, 0.8 M), giving a cloudy solution. EDCI·HCl (959 mg, 5.0 mmol) was then added to give a clear solution, which was stirred for 3 hours at room temperature. CH_2Cl_2 (50 mL) was added and the solution was washed with distilled water (2 × 50 mL) then saturated aqueous solution of $NaHCO_3$ (50 mL). The organic layer was dried ($MgSO_4$), filtered and removed *in vacuo* to give 4-methylpentanoic anhydride as colorless liquid (0.408 g, 1.5 mmol, 60%). ν_{max} (ATR): 2957 (C-H), 1817 (C=O), 1034 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 2.43 (t, *J* 7.5, 2H, -CO-C*H*$_2$-), 1.64-1.51 (m, 3H, -CH_2C*H*$_2$CH-, -CH_2C*H*-), 0.89 (d, *J* 6.5, 6H, -C*H*$_3$); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 170.0 (2 × C=O), 33.5 (2 × -CO-*C*H_2-), 33.0 (2 × -CH_2*C*H_2CH-), 27.6 (2 × -*C*H-), 22.3 (2 × -*C*H_3)

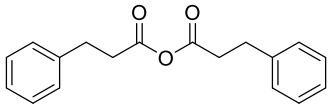
Phenylacetic anhydride 56f



Following general procedure A: EDCI·HCl (959 mg, 5.0 mmol) and phenylacetic acid (681 mg, 5.0 mmol) were added to CH_2Cl_2 (6 mL, 0.83 M) to give a clear solution, which was stirred for

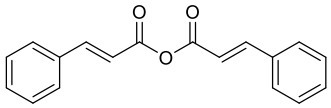
5 hours at room temperature. The solution was diluted with CH_2Cl_2 (50 mL) was and the washed with distilled water (2 × 50 mL) then saturated aqueous solution of $NaHCO_3$ (50 mL). The organic layer was dried ($MgSO_4$), filtered and removed *in vacuo* to give phenylacetic anhydride as white crystals (0.40 g, 1.56 mmol, 62%); ^{1}H NMR (500 MHz, $CDCl_3$) δ_H: 7.35-7.30 (m, 6H, Ar*H*), 7.22-7.19 (m, 4H, Ar*H*), 3.76 (s, 4H, 2 × -C*H*$_2$-). Data in agreement with literature.[82]

3-Phenylpropanoic anhydride 56g



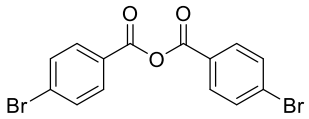
Following general procedure A: Phenylpropanoic acid (751 mg, 5.0 mmol) was added to CH_2Cl_2 (6 mL, 0.8 M), giving a cloudy solution. EDCI·HCl (959 mg, 5.0 mmol) was then added to give a clear solution, which was stirred for 3 hours at room temperature. CH_2Cl_2 (50 mL) was added and the solution was washed with distilled water (2 × 50 mL) then saturated aqueous solution of $NaHCO_3$ (50 mL). The organic layer was dried ($MgSO_4$), filtered and removed *in vacuo* to give 3-phenylpropanoic anhydride as colorless liquid (0.388 g, 55%). ν_{max} (ATR): 3028 (C-H), 1815 (C=O), 1454 (C=C), 1028 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 7.36-7.32 (m, 4H, Ar*H*), 7.28-7.23 (m, 6H, Ar*H*), 7.58-7.60 (m, 4H, Ar*H*), 3.00 (t, *J* 7.9, 2H, -C*H*$_2$-), 2.78 (t, *J* 8.0, 2H, -C*H*$_2$-). Data in agreement with literature.[83]

(*E*)-Cinnamic anhydride 56h



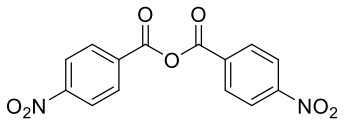
Following general procedure A: (*E*)-Cinnamic acid (741 mg, 5.0 mmol) was added to anhydrous CH_2Cl_2 (6 mL, 0.8 M), giving a cloudy solution. EDCI·HCl (959 mg, 5.0 mmol) was then added to give a clear solution, which was stirred for 2 hours at room temperature. CH_2Cl_2 (50 mL) was added and the solution was washed with distilled water (2 x 50 mL) then saturated aqueous solution of $NaHCO_3$ (50 mL). The organic layer was dried ($MgSO_4$), filtered and removed *in vacuo* to give (*E*)-Cinnamic anhydride as colorless solid (0.41 g, 1.7 mmol, 29%), **mp** 132-133 °C [lit[68] 135-136 °C]; **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 6.54 (2H, d, *J* 15.9, ArCH=C*H*), 7.41-7.47 (6H, m, Ar*H*), 7.58-7.60 (4H, m, Ar*H*) 7.87 (2H, d, *J* 15.9, ArC*H*=CH). Data in agreement with literature.[84]

4-Bromobenzoic anhydride 56j



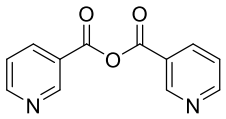
Following general procedure A: EDCI·HCl (959 mg, 5.0 mmol) and 4-bromobenzoic acid (1005 mg, 5.0 mmol) were added to CH_2Cl_2 (6 mL, 0.83 M) to give a cloudy solution, which was stirred for 3 hours at room temperature. The solution was diluted with CH_2Cl_2 (50 mL) was and the washed with distilled water (2 × 50 mL) then saturated aqueous solution of $NaHCO_3$ (50 mL). The organic layer was dried ($MgSO_4$), filtered and removed *in vacuo*, the pale yellow residue was recrystallized in EtOAc to give 4-bromobezoic anhydride as yellow crystals (0.50 g, 1.3 mmol, 52%); ν_{max} (ATR): 3100 (C-H), 1782 (C=O), 1585 (C=C), 1067 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 8.90 (d, *J* 8.6, 4H), 7.68 (d, *J* 8.6, 4H). Data in agreement with literature.[85]

4-Nitrobezoic anhydride 56k



Following general procedure A: EDCI·HCl (959 mg, 5.0 mmol) and 4-nitrobenzoic acid (836 mg, 5.0 mmol) were added to CH_2Cl_2 (6 mL, 0.83 M) to give a cloudy solution, which was stirred for 3 hours at room temperature. The solution was diluted with CH_2Cl_2 (50 mL) was and the washed with distilled water (2 × 50 mL) then saturated aqueous solution of $NaHCO_3$ (50 mL). The organic layer was dried ($MgSO_4$), filtered and removed *in vacuo* to give 4-nitrobezoic anhydride as white solids (0.44 g, 1.4 mmol, 56%), ν_{max} (ATR): 3080 (C-H), 1790 (C=O), 1607 (C=C), 1525 (N-O), 1346 (N-O), 1059 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 8.41 (m, d, *J* 8.9, 4H), 8.35 (m, d, *J* 8.9, 1H). Data in agreement with literature.[86]

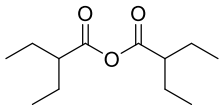
Nicotinic anhydride 56m



Following general procedure A: EDCI·HCl (959 mg, 5.0 mmol) and nicotinic acid (616 mg, 5.0 mmol) were added to CH_2Cl_2 (6 mL, 0.83 M) to give a clear solution, which was stirred for 5 hours at room temperature. The solution was diluted with CH_2Cl_2 (50 mL) was and the washed with distilled water (2 × 50 mL) then saturated aqueous solution of $NaHCO_3$ (50 mL). The organic layer was dried ($MgSO_4$), filtered and removed *in vacuo* to give nicotinic

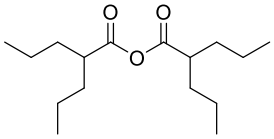
anhydride as white solids (0.25 g, 1.1 mmol, 44%); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 9.36 (dd, *J* 2.3, 0.8, 2H), 8.92 (dd, *J* 4.9, 1.7, 2H), 8.43 (ddd, *J* 8.0, 1.8, 1.8, 2H), 7.53 (ddd, *J* 8.0, 4.9, 0.9, 2H). Data in agreement with literature.[87]

2-Ethylbutanoic anhydride 56n



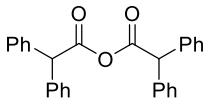
Following general procedure A: EDCI·HCl (479 mg, 2.5 mmol) and 2-ethylbutanoic acid (581 mg, 5.0 mmol) were added to CH_2Cl_2 (6 mL, 0.83 M) to give a clear solution, which was stirred for 18 hours at room temperature. The solution was diluted with CH_2Cl_2 (50 mL) was and the washed with brine (3 × 50 mL), saturated aqueous solution of $NaHCO_3$ (2 × 50 mL), then brine (50 mL). The organic layer was dried ($MgSO_4$), filtered and removed *in vacuo* to give 2-ethylbutanoic anhydride as a colorless liquid (0.42 g, 1.95 mmol, 78%). ν_{max} (ATR): 2967 (C-H), 1807 (C=O), 1001 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 2.33-2.28 (m, 2H, 2 × -C*H*-), 1.74-1.65 (m, 4H, 2 × -CH_2-), 1.62-1.54 (m, 4H, 2 × -CH_2-), 0.96 (t, *J* 7.4, 12H, 4 × -CH_3). Data in agreement with literature.[88]

2-Propylpentanoic anhydride 56o



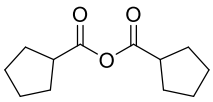
Following general procedure A: EDCI·HCl (479 mg, 2.5 mmol) and 2-propylpentanoic acid (721 mg, 5.0 mmol) were added to CH_2Cl_2 (6 mL, 0.83 M) to give a clear solution, which was stirred for 18 hours at room temperature. The solution was diluted with CH_2Cl_2 (50 mL) was and the washed with brine (3 × 50 mL), saturated aqueous solution of $NaHCO_3$ (2 × 50 mL), then brine (50 mL). The organic layer was dried ($MgSO_4$), filtered and removed *in vacuo* to give 2-propylpentanoic anhydride as a colorless liquid (0.55 g, 2.05 mmol, 82%). ν_{max} (ATR): 2959 (C-H), 1809 (C=O), 1018 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 2.44 (tt, *J* 8.7, 5.4, 2H, 2 × -C(2)*H*), 1.68-1.61 (m, 4H, 2 × -C(3)H_2), 1.50-1.44 (m, 4H, 2 × -C(3)H_2), 1.42-1.29 (m, 8H, 4 × -C(4)H_2), 0.92 (t, *J* 7.3, 12H, 4 × -CH_3); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 172.1 (2 × C=O), 46.4 (2 × -*C*(2)H), 34.1 (4 × -*C*H_2-), 20.6 (4 × -*C*H_2-), 14.11 (4 × -*C*(5)H_3)

Diphenylacetic anhydride 56p



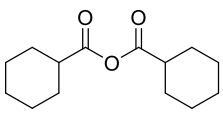
DCC (412 mg, 2 mmol) was added to CH_2Cl_2 (20 mL, 0.5 M) under N_2, followed by the addition of diphenylacetic anhydride (848 mg, 4.0 mmol) to give a cloudy mixture, which was stirred for 2 hours at room temperature. CH_2Cl_2 was removed *in vacuo* and the residue was dissolved in a mixture of EtOAc:petrol (3:7, 100 mL). The mixture was filtered and the resulting clear solution was washed saturated aqueous solution of $NaHCO_3$ (3 × 100 mL) and brine (100 mL). The organic layer was dried ($MgSO_4$), filtered and removed *in vacuo* to give diphenylacetic anhydride as colorless crystals (0.601 g, 1.5 mmol, 59%), mp 89-90 °C [lit[1] 90-93 °C]. ν_{max} (ATR): 2930 (C-H), 1800 (C=O), 1454 (C=C), 1059 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 7.34-7.26 (m, 12H, Ar*H*), 7.19-7.15 (m, 8H, Ar*H*), 5.02 (s, 1H, -C*H*Ph_2). Data in agreement with literature.[89]

Cyclopentanecarboxylic anhydride 56q



Following general procedure A: EDCI·HCl (479 mg, 2.5 mmol) and cyclopentanecarboxylic acid (641 mg, 5.0 mmol) were added to CH_2Cl_2 (6 mL, 0.83 M) to give a clear solution, which was stirred for 18 hours at room temperature. The solution was diluted with CH_2Cl_2 (50 mL) was and the washed with HCl (1M, 2 × 50 mL), saturated aqueous solution of $NaHCO_3$ (2 × 50 mL) then brine (2 × 50 mL). The organic layer was dried ($MgSO_4$), filtered and removed *in vacuo* to give cyclopentanecarboxylic anhydride as a colorless liquid (0.31 g, 1.45 mmol, 58%). ν_{max} (ATR): 2955 (C-H), 1807 (C=O), 1022 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 2.85 (quintet, *J* 8.0, 2H), 1.96-1.84 (m, 8H, C(3)H_2), 1.76-1.68 (m, 4H, C(2)H_2), 1.64-1.56 (m, 4H, C(2)H_2); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 172.6 (2 × C=O), 44.8 (2 × *C*(1)H), 29.6 (4 × *C*(3)H_2), 25.9 (4 × *C*(2)H_2)

Cyclohexanecarboxylic anhydride 56r

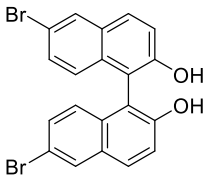


Following general procedure A: EDCI·HCl (479 mg, 2.5 mmol) and cyclohexanecarboxylic acid (641 mg, 5.0 mmol) were added to CH_2Cl_2 (6 mL, 0.83 M) to give a clear solution, which was

stirred for 18 hours at room temperature. The solution was diluted with CH_2Cl_2 (50 mL) was and the washed with HCl (1M, 2 × 50 mL), saturated aqueous solution of $NaHCO_3$ (2 × 50 mL) then brine (2 × 50 mL). The organic layer was dried ($MgSO_4$), filtered and removed *in vacuo* to give cyclohexanecarboxylic anhydride as a yellow oil (0.15 g, 0.8 mmol, 32%). ν_{max} (ATR): 2930 (C-H), 1805 (C=O), 984 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 2.40 (tt, *J* 11.2, 3.7, 2 H), 1.98–1.94 (m, 4H), 1.81–1.76 (m, 4H), 1.67–1.62 (m, 2H), 1.52–1.44 (m, 4H), 1.34–1.22 (m, 6H). Data in agreement with literature.[90]

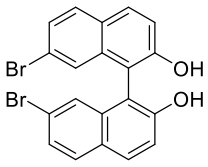
Preparation of biaryls alcohols:

6,6'-Dibromo-[1,1'-binaphthalene]-2,2'-diol 63a



BINOL (859 mg, 3 mmol) was dissolved in CH_2Cl_2 (17 mL, 0.18 M) and cooled to -78 °C. Br_2 (0.43 mL, 1.29 g, 8.1 equiv.) was added dropwise over 10 mins at -78 °C while stirring. The solution was left stirring for 3 hours while gradually warm to room temperature. Saturated $NaHSO_3$ solution (20 mL) was added in to the previous solution and layers separated. Organic layer was washed with brine (3 × 20 mL) and dried over $MgSO_4$. The solvent was removed *in vacuo* to give 6,6'-dibromo-[1,1'-binaphthalene]-2,2'-diol (1.12 g, 84%) as white solids. mp 193-195 °C [lit[2] 197-198 °C]; **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 8.05 (d, *J* 2.0, 2H, Ar*H*), 7.89 (d, *J* 9.0, 2H, Ar*H*), 7.39 (d, *J* 9.0, 2H, Ar*H*), 7.36 (dd, *J* 9.0, 2.0, 2H, Ar*H*), 6.95 (d, *J* 8.9, 2H, Ar*H*), 5.01 (s, 2H, 2 × -O*H*). Data in agreement with literature.[91]

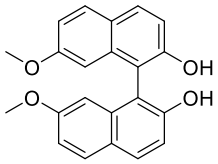
7,7'-Dibromo-[1,1'-binaphthalene]-2,2'-diol 63b



Following general procedure D: 7-Bromo-2-naphthol (669.21 mg, 3 mmol) was dissolved in CH_2Cl_2 (30 mL, 0.1 M) at room temperature. Cu-TMEDA catalyst (14 mg, 0.03 mmol) was added and the solution was stirred for 18 hours. The mixture was filtered through silica plug and concentrated *in vacuo* to 7,7'-dibromo-[1,1'-binaphthalene]-2,2'-diol (613 mg, 92%) as yellow solids, mp 200-201 °C [lit[2] 197-198 °C]; 7.96 (d, *J* 9.0, 2H, Ar*H*), 7.77 (d, *J* 8.7, 2H, Ar*H*),

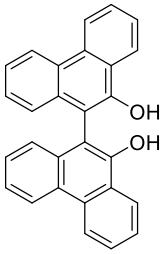
7.47 (dd, *J* 8.7, 1.9, 2H, Ar*H*), 7.39 (*J* 9.0, 2H, Ar*H*), 7.23 (d, *J* 1.9, 2H, Ar*H*), 5.03 (s, 2H, 2 × -O*H*). Data in agreement with literature.[92]

7,7'-Dimethoxy-[1,1'-binaphthalene]-2,2'-diol 63c



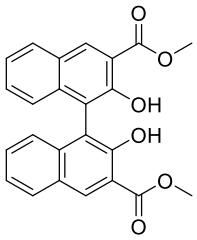
Following general procedure D: 7-Methoxy-2-naphthol (523 mg, 3 mmol) was dissolved in CH_2Cl_2 (30 mL 0.1 M) at room temperature. Cu-TMEDA catalyst (14 mg, 0.03 mmol) was added and the solution was stirred for 2 hours. The mixture was filtered and concentrated *in vacuo* to give a brown oil, which was purified by column chromatography (Isolera 4, Et_2O in petrol, 0% -> 50% over 40 CV), giving 7,7'-dimethoxy-[1,1'-binaphthalene]-2,2'-diol (380 mg, 73%) as pale yellow solids. mp 147-148 °C [lit[2] 144-146 °C]; **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 7.88 (d, *J* 8.9, 2H, Ar*H*), 7.79 (d, *J* 8.2, 2H, Ar*H*), 7.23 (d, *J* 8.9, 2H, Ar*H*), 7.04 (dd, *J* 9.0, 2.5, 2H, Ar*H*),6.48 (d, *J* 2.5, 2H, Ar*H*), 5.04 (s, 2H, -OH), 3.58 (s, 6H, 2 × -C*H*$_3$). Data in agreement with literature.[68,93]

[9,9'-Biphenanthrene]-10,10'-diol 63e



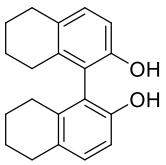
Following general procedure D: 9-Phenanthrol (456 mg, 2.5 mmol) was dissolved in CH_2Cl_2 (25 mL, 0.1 M) at room temperature. Cu-TMEDA catalyst (11.6 mg, 0.025 mol) was added and the solution was stirred for 2 hours. The mixture was filtered and concentrated *in vacuo* to give a pale brown oil, which was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 20% over 20 CV), giving [9,9'-biphenanthrene]-10,10'-diol (168 mg, 0.43 mmol, 35%) as yellow crystals, mp 218-220 °C [lit[2] 231-233 °C]; **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 8.81 (d, *J* 8.4, 2H, Ar*H*), 8.75 (d, *J* 8.3, 2H, Ar*H*), 8.48 (dd, *J* 8.2, 1.0, 2H, Ar*H*), 7.85-7.82 (m, 2H, Ar*H*), 7.75-7.72 (m, 2H, Ar*H*), 7.56-7.53 (m, 2H, Ar*H*), 7.38-7.35 (m, 2H, Ar*H*), 8.27 (dd, *J* 8.2, 1.0, 2H, Ar*H*), 5.56 (s, 2H, 2 × -O*H*). Data in agreement with literature.[68, 94]

2,2'-Dihydroxy-[1,1'-binaphthalene]-3,3'-dicarboxylatediol 63f



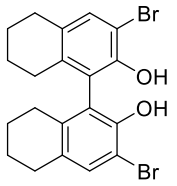
Following general procedure D: Methyl 3-hydroxy-2-naphthoate (607 mg, 3 mmol) was dissolved in MeOH (30 mL, 0.1 M) at room temperature. Cu-TMEDA catalyst (14 mg, 0.03 mmol) was added and the solution was stirred for 144 hours under reflux. The mixture was filtered and concentrated *in vacuo* to give dimethyl 2,2'-dihydroxy-[1,1'-binaphthalene]-3,3'-dicarboxylatediol (58.6 mg, 97%) as bright yellow solids, mp 270-272 °C [lit[2] 285-287 °C]; **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 10.72 (s, 2 × -OH), 8.69 (s, 2 H, Ar*H*), 7.94-7.90 (m, 2 H, Ar*H*), 7.36-7.32 (m, 4 H, Ar*H*), 7.17-7.14 (m, 2 H, Ar*H*), 4.06 (s, 6H, 2 × -C*H*$_3$). Data in agreement with literature.[68, 95]

5,5',6,6',7,7',8,8'-Octahydro-1,1'-bi-2-naphthol 66a



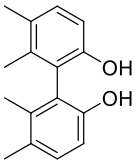
BINOL (1.72 g, 6 mmol) and Pd/C (10% wt, 447 mg, 0.42 mmol) and ethanol (30 mL, 0.2 M) were placed into a 150 mL autoclave and stirred under 50 bar H_2 at 100 °C for 1 hour. The reaction mixture was cooled to room temperature, the metal catalyst was filtered off and washed with CH_2Cl_2 (3 × 10 mL). The combined filtrates were concentrated in *vacuo* and the residue was purified by column chromatography (0% -> 20% EtOAc in hexane over 30 CV) to give 5,5',6,6',7,7',8,8'-Octahydro-1,1'-bi-2-naphthol (1.34 g, 76%) as white solids. mp 132-134 °C [lit[2] 156-157 °C]; **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 7.07 (d, *J* 8.3, 2H, Ar*H*), 6.83 (d, *J* 8.3, 2H, Ar*H*), 4.54 (s, 2H, 2 × -O*H*), 2.75 (t, *J* 6.2, 4H, -C*H*$_2$-), 2.29 (dt, *J* 17.6, 6.2, 2H, -C*H*$_2$-), 2.16 (dt, *J* 17.5, 6.5, 2H, -C*H*$_2$-), 1.76–1.72 (m, 4H, -C*H*$_2$-), 1.70–1.65 (m, 4H, -C*H*$_2$-). Data in agreement with literature.[69,96]

3,3'-Dibromo-5,5',6,6',7,7',8,8'-octahydro-[1,1'-binaphthalene]-2,2'-diol 66b



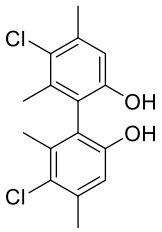
5,5',6,6',7,7',8,8'-Octahydro-1,1'-bi-2-naphthol (736 mg, 2.5 mol) was dissolved in CH_2Cl_2 (25 mL, 0.1 M) at -40 °C. Bromine (800 mg, 5 mol) was added and the solution was stirred for 1.5 hour. Saturated $NaHSO_3$ solution (20 mL) was added to the solution and the resulted mixture was warmed up to room temperature. The organic phase was washed with $NaHCO_3$ (sat. 3 × 20 mL) and cold H_2O (3 × 20 mL), dried over $MgSO_4$, filtered and concentrated *in vacuo* to give 3,3'-dibromo-5,5',6,6',7,7',8,8'-octahydro-[1,1'-binaphthalene]-2,2'-diol (926 mg, 91%) as white solid. mp 159-160 °C [lit[2] 166.5-170 °C]; **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 7.28 (s, 2H, C(4)*H,* C(4')*H,* -Ar*H*), 5.10 (s, 2H, 2 × -O*H*), 2.78-2.69 (m, 4H, 2 × -CH_2-), 2.31-2.25 (m, 2H, 2 × -CH_{2a}-), 2.12-2.05 (m, 2H, 2 × -CH_{2b}-), 1.83-1.60 (m, 8H, 4 × -CH_2-). Data in agreement with literature.[70,97]

5,5',6,6'-Tetramethyl-[1,1'-biphenyl]-2,2'-diol 66d



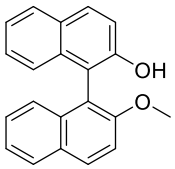
3,3'-di-tert-butyl-5,5',6,6'-tetramethyl-[1,1'-biphenyl]-2,2'-diol (355 mg, 1 mmol) dissolved in benzene (5 mL) at 0 °C. $AlCl_3$ (200 mg, 1.5 mmol) in benzene (1 mL) and $MeNO_2$ (2 mL) was added dropwise. The mixture was quenched by water after left stirring for 20 mins. The aqueous layer was extracted with Et_2O (3 × 10 mL). The combined organic layer washed with brine (3 × 10 mL), filtered and concentrated *in vacuo* to give the crude, which was purified by column chromatography (0% -> 10% EtOAc in petrol over 50 CV) to give 5,5',6,6'-tetramethyl-[1,1'-biphenyl]-2,2'-diol (200.4 mg, 83.7%), mp 191-193 °C [lit[2] 198.5-200 °C]; **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 7.13 (d, *J* 8.2, 2H, Ar*H*), 6.81 (d, *J* 8.3, 2H, Ar*H*), 4.51 (s, 2H, 2 × -O*H*), 2.26 (s, 6H, 2 × -CH_3), 1.90 (s, 6H, 2 × -CH_3). Data in agreement with literature.[71]

5,5'-Dichloro-4,4',6,6'-tetramethyl-[1,1'-biphenyl]-2,2'-diol 66e



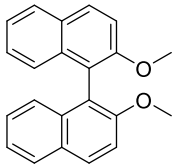
4-Chloro-3,5,-dimethylphenol (470 mg, 3 mmol) and Cu-exchanged clay (1.5 g, 7) were stirred vigorously in chlorobenzene (30 mL, 0.1 M), the resulted mixture was stirred at 140 °C for 6 hours with air bubbled through. The mixture was filtered and the catalyst washed by CH_2Cl_2 (2 × 30 mL), followed by acetone (2 × 30 mL), the combined filtrate was concentrated *in vacuo* and the resulting crude was purified by column chromatography (0%-20% EtOAc in petrol over 40 CV) to give 5,5'-dichloro-4,4',6,6'-tetramethyl-[1,1'-biphenyl]-2,2'-diol (124.9 mg, 27%) as yellow solids, mp 215-217 °C [lit[2] 233-235 °C], R_f = 0.29 (20% EtOAc in petroleum ether); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 6,84 (s, 2 H, Ar*H*), 4.57 (s, 2 H), 2.41 (s, 6H, 2 × -C*H*$_3$), 2.05 (s, 6H, 2 × -C*H*$_3$). Data in agreement with literature.[72,74,98]

2'-Methoxy-[1,1'-binaphthalen]-2-ol 70a



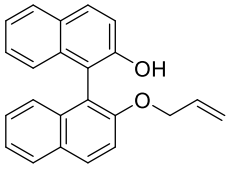
BINOL (1.43 g, 5 mmol) and K_2CO_3 (829 mg, 6 mmol) were stirred in acetone (6 mL, 0.83 M) for 1 hour at room temperature under N_2. Methyl iodide (851 mg, 0.37 mL, 6 mmol) was added and the resulted mixed was stirred overnight. The mixture was filtered and solid washed with acetone. Filtrate was concentrated *in vacuo* and the residue was purified by column chromatography (0% -> 10% EtOAc in petrol over 50 CV) to give 2'-methoxy-[1,1'-binaphthalen]-2-ol (0.80 g, 53%) as white solids. mp 152-154 °C [lit[2] 152-153 °C]; **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 8.05 (d, *J* 9.1, 1H, Ar*H*), 7.91 (d, *J* 8.9, 1H, Ar*H*), 7.90 (d, *J* 8.3, 1H, Ar*H*), 7.87 (d, *J* 8.1, 1H, Ar*H*), 7.48 (d, *J* 9.0, 1H, Ar*H*), 7.40-7.36 (m, 1H, Ar*H*), 7.36 (d, *J* 8.9, 1H, Ar*H*), 7.34-7.29 (m, 2H, Ar*H*), 7.25-7.22 (m, 1H, Ar*H*), 7.18 (d, *J* 8.5, 1H, Ar*H*), 7.18 (d, *J* 8.5, 1H, Ar*H*), 4.94 (s, 1H, -OH), 3.81 (s, 3H, -C*H*$_3$). Data in agreement with literature.[32,99]

2,2'-Dimethoxy-1,1'-binaphthalene 71a



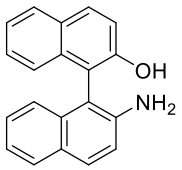
BINOL (1.43 g, 5 mmol) and K_2CO_3 (829 mg, 6 mmol) were stirred in acetone (6 mL, 0.83 M) for 1 hour at room temperature under N_2. Methyl iodide (851 mg, 0.37 mL, 6 mmol) was added and the resulted mixed was stirred overnight. The mixture was filtered and solid washed with acetone. Filtrate was concentrated *in vacuo* and the residue was purified by column chromatography (0% -> 10% EtOAc in petrol over 50 CV) to give 2,2'-dimethoxy-1,1'-binaphthalene (277.3 mg, 17.6%) as white solids. **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 7.99 (d, *J* 9.1, 2H, Ar*H*), 7.89 (d, *J* 8.3, 2H, Ar*H*), 7.47 (d, *J* 9.1, 2H, Ar*H*), 7.36-7.33 (m, 2H, Ar*H*), 7.26-7.22 (m, 2H, Ar*H*), 7.14 (d, *J* 8.5, 2H, Ar*H*), 3.79 (s, 6H, 2 × -C*H*$_3$). Data in agreement with literature.[32,99]

2'-(Allyloxy)-[1,1'-binaphthalen]-2-ol 70b



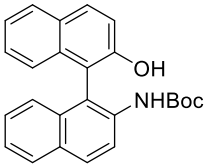
BINOL (1.43 g, 5 mmol) and K_2CO_3 (829 mg, 6 mmol) were stirred in acetone (6 mL, 0.83 M) for 1 hour at room temperature under N_2. Allyl bromide (736 mg, 6 mmol) was added and the resulted mixed was stirred overnight. The mixture was filtered and solid washed with acetone. Filtrate was concentrated *in vacuo*, dissolved in CH_2Cl_2 (20 mL) and filtered. The filtrate was concentrated *in vacuo* and the residue was purified by column chromatography (0% -> 10% EtOAc in hexane over 50 CV) to give 2'-(allyloxy)-[1,1'-binaphthalen]-2-ol (0.96 g, 59%) as white solids. mp 105-107 °C [lit[2] 109.5-111 °C]; **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 8.01 (d, *J* 9.0, 1H, Ar*H*), 7.95 (d, *J* 8.9, 1H, Ar*H*), 7.94-7.90 (m, 2H, Ar*H*), 7.44 (d, *J* 9.0, 1H, Ar*H*), 7.41 (d, *J* 8.9, 1H, Ar*H*), 7.44-7.40 (m, 1H, Ar*H*), 7.39-7.35 (m, 1H, Ar*H*), 7.34-7.30 (m, 1H, Ar*H*), 7.29-7.25 (m, 2H, Ar*H*), 7.15 (d, *J* 8.5, 1H, Ar*H*), 5.83-5.76 (m, 1H, Ar*H*), 5.12-5.09 (m, 1H, Ar*H*), 5.09-5.07 (m, 1H, Ar*H*), 5.06 (s, 1H, -OH), 4.62-4.54 (m, 2H, -C*H*$_2$-). Data in agreement with literature.[32,99]

2'-Amino-[1,1'-binaphthalen]-2-ol 75



BINAM (427 mg, 1.5 mmol), benzoyl peroxide (727 mg, 3 mmol), HCl (12 M, 21 mL) 1,4-dioxane (42 mL) and deionised water (126 mL) were mixed and stirred at 85 °C for 4 hours then cooled to room temperature. The pH was brought to 8 using sat. $NaHCO_3$ solution. All solvents were removed. The crude was dissolved in EtOAc: DI water (1:1) and extracted by EtOAc. The combined organic phases were concentrated in *vacuo* and the residue was purified by column chromatography (0% -> 30% EtOAc in hexane over 45 CV) to give crude NOBIN (276 mg, 65%) as black solids. **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 7.92 (d, *J* = 8.8 Hz, 1H), 7.89-7.85 (m, 2H), 7.82-7.80 (m, 1H), 7.37 (d, *J* = 8.9 Hz, 1H), 7.37-7.33 (m, 1H), 7.30-7.21 (m, 3H), 7.19-7.15 (m, 2H), 7.06-7.04 (m, 1H), 5.11 (br, s, 1H, -O*H*), 3.74 (br, s, 2H, -NH_2). Data in agreement with literature.[32,100]

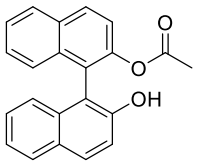
***Tert*-butyl (2'-hydroxy-[1,1'-binaphthalen]-2-yl)carbamate 76**



NOBIN (645 mg, 2.26 mmol) and $(BOC)_2O$ (493 mg, 2.26 mmol) were dissolved in benzene (6.4 mL) and stirred at 80 °C for 24 hrs then cooled to room temperature. Solvents were removed *in vacuo* and the crude was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 20% over 25 CV), the crude product was recrystallized from hexane to give NOBIN-BOC (381 mg, 52%) as black solids; **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 8.49 (d, *J* 9.2, 1H, Ar*H*), 8.04 (d, *J* 9.1, 1H, Ar*H*), 7.98 (d, *J* 8.9, 1H, Ar*H*), 7.92-7.88 (m, 2H, Ar*H*), 7.42-7.36 (m, 3H, Ar*H*), 7.29-7.25 (m, 2H, Ar*H*), 7.06 (d, *J* 8.5, 1H, Ar*H*), 7.01 (d, *J* 8.4, 1H, Ar*H*), 6.25 (s, 1H, -N*H*Boc), 5.03 (s, 1H, -O*H*), 1.39 (s, 9H, 3 × -CH_3). Data in agreement with literature.[79]

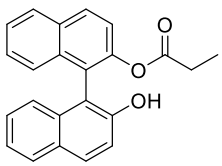
Preparation of Monoesters:

2'-Hydroxy-[1,1'-binaphthalen]-2-yl acetate 57a



Following general procedure B: BINOL (57.3 mg, 0.2 mmol) and DMAP (2.5 mg, 0.02 mmol) were added into CH_2Cl_2 (4 mL, 0.05 M) at room temperature, giving a clear solution. Acetic anhydride (30.6 mg, 28 µL, 0.3 mmol) and *i*Pr_2NEt (27.9 mg, 35 µL, 0.2 mmol) were added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The solution was diluted with EtOAc (10 mL), washed with HCl (1 M. 2 × 10 mL), $NaHCO_3$ (sat., 2 × 10 mL) and brine (10 mL). The organic layer was dried over $MgSO_4$, filtered and concentrated *in vacuo*, to give pale brown oil, which was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 20% over 20 CV) to give 2'-hydroxy-[1,1'-binaphthalen]-2-yl acetate as (16.8 mg, 26%) white solids; R_f = 0.23 (20% EtOAc in petroleum ether); mp 121-122 °C [lit[1] 125-127 °C]; ν_{max} (ATR): 3455 (O-H, br), 1757 (C=O), 1550 (C=C), 1201 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 8.08 (d, *J* 8.9, 1H, C(4)*H*), 7.97 (d, *J* 8.4, 1H, C(5)*H*), 7.91 (d, *J* 8.8, 1H, C(4')*H*), 7.86 (d, *J* 8.2, 1H, C(5')*H*), 7.53-7.49 (m, 1H, C(6)*H*), 7.40 (d, *J* 8.3, 1H, C(3)*H*), 7.6-7.32 (m, 3H, C(7)*H,* C(3')*H,* C(6')*H*), 7.27-7.23 (m, 2H, C(8)*H,* C(7')*H*), 7.03 (d, *J* 8.5, 1H, C(8')*H*), 5.19 (s, 1H, -O*H*), 1.87 (s, 3H -C*H*$_3$); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 170.6 (*C*=O), 151.8 (*C*(2')), 148.2 (*C*(2)), 133.6 (*C*(8a)), 133.6 (*C*(8a')), 132.4 (*C*(4a)), 131.0 (*C*(4)), 130.5 (*C*(4'), 129.1 (*C*(4a')), 128.4 (*C*(5)), 128.1 (*C*(5')), 127.6 (*C*(7)), 126.9 (*C*(7')), 126.5 (*C*(6)), 125.9 (*C*(8)), 124.7 (*C*(8')), 123.7 (*C*(6')), 123.2 (*C*(1)), 121.9 (*C*(3)), 118.4 (*C*(3')), 114.1 (*C*(1')), 20.6 (-*C*H_3); HRMS (NSI$^+$) $C_{22}H_{16}O_3$ $[M+H]^+$ found 329.1176, requires 329.1172 (+1.2 ppm). Data in agreement with literature.[101]

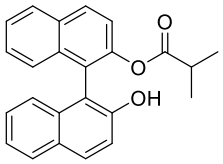
2'-Hydroxy-[1,1'-binaphthalen]-2-yl propionate 57b



Following general procedure C: BINOL (57.3 mg, 0.2 mmol) and (+)-BTM (0.5 mg, 0.002 mmol) were added into tert-Amyl alcohol (4 mL, 0.05 M) at room temperature, giving a clear solution. Propionic anhydride (14.3 mg, 14.1 µL, 0.11 mmol) was added to the previous

solution. The resulted clear solution was left stirring for18 hours at room temperature. The solution was diluted with EtOAc (10 mL), washed with HCl (1 M. 2 × 10 mL), $NaHCO_3$ (sat., 2 × 10 mL) and brine (10 mL). The organic layer was dried over $MgSO_4$, filtered and concentrated *in vacuo* to give a pale brown oil, which was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 20% over 30 CV) to give 2'-hydroxy-[1,1'-binaphthalen]-2-yl propionate (15.3 mg, 22%) as white solids; R_f = 0.16 (20% EtOAc in petroleum ether); mp 146-147 °C [lit[1] 140-142 °C]; $[\alpha]_D^{20}$ −76.3 (c = 0.1 in $CHCl_3$); **Chiral HPLC analysis**: ChiralCel OJ-H (10% *i*PrOH:hexane, flow rate 1.0 mL min^{-1}, 211 nm, 30 °C), t_R major: 16.4 min, t_R minor: 24.0 min, 83.5:16.5 er; ν_{max} (ATR): 3408 (O-H), 2936 (C-H), 1726 (C=O), 1506 (C=C), 1180 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 8.08 (d, *J* 8.9, 1H, C(4)*H*), 7.98 (d, *J* 8.3, 1H, C(5)*H*), 7.90 (d, *J* 8.8, 1H, C(4')*H*), 7.84 (d, *J* 8.1, 1H, C(5')*H*), 7.53-7.50 (m, 1H, C(6)*H*), 7.40 (d, *J* 8.9, 1H, C(3)*H*), 7.37-7.31 (m, 3H, C(7)*H,* C(3')*H,* C(6')*H*), 7.29 (d, *J* 8.4, 1H, C(8)*H*), 7.27-7.23 (m, 1H, C(7')*H*), 7.04 (d, *J* 8.5, 1H, C(8')*H*), 5.17 (s, 1H, -O*H*), 2.20-2.04 (m, 2H, -C*H*$_2$CH$_3$), 0.70 (t, *J* 7.6, 3H, -CH$_2$C*H*$_3$); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 174.1 (*C*=O), 151.9 (*C*(2')), 146.9 (*C*(2)), 133.6 (*C*(8a), *C*(8a')), 132.4 (*C*(4a)), 130.7 (*C*(4)), 130.5 (*C*(4'), 129.1 (*C*(4a')), 128.5 (*C*(5)), 128.1 (*C*(5')), 127.6 (*C*(7)), 126.8 (*C*(7')), 126.4 (*C*(6)), 125.8 (*C*(8)), 124.7 (*C*(8')), 123.7 (*C*(6')), 123.1 (*C*(1)), 122.0 (*C*(3)), 118.4 (*C*(3')), 114.2 (*C*(1')), 27.6 (-*C*H$_2$-), 8.9 (-*C*H$_3$); HRMS (NSI$^+$) $C_{23}H_{18}O_3$ $[M+H]^+$ found 343.1333, requires 333.1329 (+1.3 ppm). Data in agreement with literature.[101]

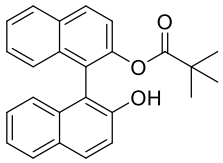
2'-Hydroxy-[1,1'-binaphthalen]-2-yl isobutyrate 54



Following general procedure C: BINOL (57.3 mg, 0.2 mmol) and (+)-BTM (0.5 mg, 0.002 mmol) were added into CH_2Cl_2 (4 mL, 0.05 M) at room temperature, giving a clear solution. Isobutyric anhydride (47.5 mg, 49.7 µL, 0.3 mmol) and *i*Pr$_2$NEt (27.9 mg, 35 µL, 0.2 mmol) were added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The solution was diluted with EtOAc (10 mL), washed with HCl (1 M, 2 × 10 mL), $NaHCO_3$ (sat., 2 × 10 mL) and brine (10 mL). The organic layer was dried over $MgSO_4$, filtered and concentrated *in vacuo*, to give pale brown oil, which was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 20% over 20 CV) to give 2'-hydroxy-[1,1'-binaphthalen]-2-yl isobutyrate (26.0 mg, 37%); R_f = 0.39 (20% EtOAc in

petroleum ether); mp 147-149 °C [lit[1] 147-148 °C]; $[\alpha]_D^{20}$ −97.5 (c = 0.1 in $CHCl_3$); **Chiral HPLC analysis**: ChiralCel OJ-H (20% *i*PrOH:hexane, flow rate 1.0 mL min^{-1}, 211 nm, 30 °C), t_R major: 8.3 min, t_R minor: 13.1 min, 95:5 er; ν_{max} (ATR): 3389 (O-H), 2890 (C-H), 1717 (C=O), 1504 (C=C), 1207 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 8.08 (d, *J* 8.8, 1H, Ar*H*), 7.98 (dt, *J* 8.2, 0.9, 1H, Ar*H*), 7.89 (d, *J* 8.9, 1H, Ar*H*), 7.84 (d, *J* 8.1, 1H, Ar*H*), 7.53-7.50 (m, 1H, Ar*H*), 7.40 (d, *J* 8.9, 1H, Ar*H*), 7.38-7.31 (m, 4H, Ar*H*), 7.27-7.24 (m, 1H, Ar*H*), 7.05 (d, *J* 8.5, 1H, Ar*H*), 5.04 (s, 1H, -O*H*), 2.39 (sept, *J* 6.9, 1H), 0.78 (d, *J* 7.1, 3H), 0.60 (d, *J* 7.1, 3H); HRMS (ASAP$^+$) $C_{24}H_{20}O_3$ $[M+H]^+$ found 357.1492, requires 357.1491 (+0.3 ppm). Data in agreement with literature.[51]

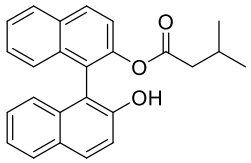
2'-Hydroxy-[1,1'-binaphthalen]-2-yl pivalate 57c



Following general procedure C: BINOL (57.3 mg, 0.2 mmol) and (+)-BTM (0.5 mg, 0.002 mmol) were added into tert-Amyl alcohol (4 mL, 0.05 M) at room temperature, giving a clear solution. Trimethylacetic anhydride (20.5 mg, 0.11 mmol) was added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The solution was diluted with EtOAc (10 mL), washed with HCl (1 M. 2 × 10 mL), $NaHCO_3$ (sat., 2 × 10 mL) and brine (10 mL). The organic layer was dried over $MgSO_4$, filtered and concentrated *in vacuo*, to give pale brown oil, which was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 20% over 20 CV) to give 2'-hydroxy-[1,1'-binaphthalen]-2-yl pivalate (27.1 mg, 37%) as colorless crystals; R_f = 0.43 (20% EtOAc in petroleum ether); mp 123.5-125 °C; $[\alpha]_D^{20}$ −70.1 (c = 0.1 in $CHCl_3$); **Chiral HPLC analysis**: ChiralPak AD-H (10% *i*PrOH:hexane, flow rate 1.0 mL min^{-1}, 211 nm, 30 °C), t_R major: 6.2 min, t_R minor: 8.2 min, 90:10 er; ν_{max} (ATR): 3391 (O-H), 2900 (C-H), 1717 (C=O), 1506 (C=C), 1142 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 8.08 (d, *J* 8.8, 1H, C(4)*H*), 7.98 (d, *J* 8.2, 1H, C(5)*H*), 7.88 (d, *J* 8.9, 1H, C(4')*H*), 7.83 (d, *J* 8.2, 1H, C(5')*H*), 7.53-7.50 (m, 1H, C(6)*H*), 7.39-7.30 (m, 5H, C(3)*H,* C(7)*H,* C(8)*H*, C(6')*H,* C(3')*H*), 7.47-7.24 (m, 1H, C(7')*H*), 7.06 (d, *J* 8.5, 1H, C(9')*H*), 5.17 (s, 1H, -O*H*), 0.78 (s, 9H, -(*CH*$_3$)$_3$); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 178.3 (*C*=O), 151.9 (*C*(2')), 148.2 (*C*(2)), 133.7 (*C*(8a')), 133.6 (*C*(8a)), 132.4 (*C*(4a)), 130.9 (*C*(4)), 130.4 (*C*(4'), 129.1 (*C*(4a')), 128.5 (*C*(5)), 128.0 (*C*(5')), 127.6 (*C*(7)), 126.8 (*C*(7')), 126.4 (*C*(6)), 125.7 (*C*(8)), 124.7 (*C*(8')), 123.7 (*C*(6')), 123.1 (*C*(1)), 121.9 (*C*(3)), 118.4 (*C*(3')), 114.4 (*C*(1')), 38.8 (-*C*(CH_3)$_3$), 26.6 (-*C*H_3);

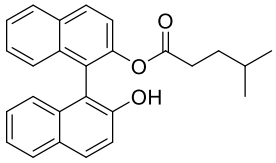
HRMS (ASAP$^+$) $C_{25}H_{22}O_3$ $[M+H]^+$ found 371.1647, requires 371.1647 (0 ppm). Data in agreement with literature.[102]

2'-Hydroxy-[1,1'-binaphthalen]-2-yl 3-methylbutanoate 57d



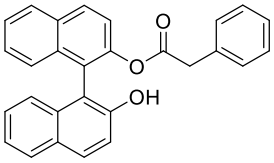
Following general procedure C: BINOL (57.3 mg, 0.2 mmol) and (+)-BTM (0.5 mg, 0.002 mmol) were added into chloroform (4 mL, 0.05 M) at room temperature, giving a clear solution. 3-Methylbutanoic anhydride (22 mg, 0.12 mmol) was added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The solution was diluted with EtOAc (10 mL), washed with HCl (1 M. 2 × 10 mL), $NaHCO_3$ (sat., 2 × 10 mL) and brine (10 mL). The organic layer was dried over $MgSO_4$, filtered and concentrated *in vacuo* to give a pale brown oil, which was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 20% over 20 CV) to give 2'-hydroxy-[1,1'-binaphthalen]-2-yl 3-methylbutanoate (29.7 mg, 41%) as white solid; mp 250.5-251.5 °C; R_f = 0.44 (20% EtOAc in petroleum ether); $[\alpha]_D^{20}$ −63.2 (c = 0.1 in $CHCl_3$); **Chiral HPLC analysis**: ChiralPak AD-H 2% *i*PrOH:hexane, flow rate 1.0 mL min^{-1}, 211 nm, 30 °C), t_R major: 23.7 min, t_R minor: 48.4 min, 82:18 er; ν_{max} (ATR): 3430 (O-H), 2959 (C-H), 1748 (C=O), 1508 (C=C), 1150 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 8.07 (d, *J* 8.9, 1H, C(4)*H*), 7.97 (d, *J* 8.3, 1H, C(5)*H*), 7.89 (d, *J* 8.9, 1H, C(4')*H*), 7.84 (d, *J* 8.0, 1H, C(5')*H*), 7.52-7.49 (m, 1H, C(6)*H*), 7.38 (d, *J* 8.9, 1H, C(3)*H*), 7.36-7.31 (m, 3H, C(7)*H,* C(6')*H,* C(3')*H*), 7.27-7.23 (m, 2H, C(8)*H,* C(7')*H*), 7.03(d, *J* 8.4, 1H, C(8')*H*), 5.25 (s, 1H, -O*H*), 2.09-1.98 (m, 2H, -C*H*$_2$-), 1.68 (sept, *J* 6.8, 1H, -C*H*-), 0.60 (d, *J* 6.6, 3H, -C*H*$_3$), 0.58 (d, *J* 6.6, 3H, -C*H*$_3$); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 172.7 (*C*=O), 151.9 (*C*(2')), 148.2 (*C*(2)), 133.6 (*C*(8a'), *C*(8a)), 132.3 (*C*(4a)), 131.0 (*C*(4)), 130.5 (*C*(4'), 129.2 (*C*(4a')), 128.4 (*C*(5)), 128.1 (*C*(5')), 127.6 (*C*(7)), 126.8 (*C*(7')), 126.4 (*C*(6)), 125.9 (*C*(8)), 124.7 (*C*(8')), 123.6 (*C*(6')), 123.3 (*C*(1)), 122.0 (*C*(3)), 118.5 (*C*(3')), 114.3 (*C*(1')), 43.0 (-*C*H$_2$-), 25.6 (-*C*H-), 22.0 (-*C*H$_3$), 22.0 (-*C*H$_3$); HRMS (ASAP$^+$) $C_{25}H_{22}O_3$ $[M+H]^+$ found 371.1652, requires 371.1647 (+1.3 ppm). Data in agreement with literature.[51]

2'-Hydroxy-[1,1'-binaphthalen]-2-yl 4-methylpentanoate 57e



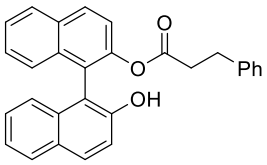
Following general procedure C: BINOL (57.3 mg, 0.2 mmol) and (+)-BTM (0.5 mg, 0.002 mmol) were added into CH_2Cl_2 (4 mL, 0.05 M) at room temperature, giving a clear solution. 4-methylpentanoic anhydride (64.3 mg, 0.3 mmol) and *i*Pr_2NEt (27.9 mg, 35 µL, 0.2 mmol) were added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The solution was diluted with EtOAc (10 mL), washed with HCl (1 M. 2 × 10 mL), $NaHCO_3$ (sat., 2 × 10 mL) and brine (10 mL). The organic layer was dried over $MgSO_4$, filtered and concentrated *in vacuo*, to give pale brown oil, which was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 20% over 20 CV) to give 2'-hydroxy-[1,1'-binaphthalen]-2-yl 4-methylpentanoate (33.1 mg, 43%) as cloudy gum; R_f = 0.47 (20% EtOAc in petroleum ether); $[\alpha]_D^{20}$ −77.6 (c = 0.1 in $CHCl_3$); **Chiral HPLC analysis**: ChiralCel OD-H (1% *i*PrOH:hexane, flow rate 1.0 mL min^{-1}, 211 nm, 30 °C), t_R major: 15.0 min, t_R minor: 18.5 min, 90:10 er; ν_{max} (ATR): 3440 (O-H), 2955 (C-H), 1746 (C=O), 1508 (C=C), 1206 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 8.08 (d, *J* 8.9, 1H, C(4)*H*), 7.98 (d, *J* 8.3, 1H, C(5)*H*), 7.90 (d, *J* 8.9, 1H, C(4')*H*), 7.85 (d, *J* 8.0, 1H, C(5')*H*), 7.53-7.49 (m, 1H, C(6)*H*), 7.39 (d, *J* 8.9, 1H, C(3)*H*), 7.37-7.31 (m, 3H, C(7)*H*, C(6')*H,* C(3')*H*), 7.30 (d, *J* 8.4, 1H, C(8)*H*), 7.29-7.24 (m, 1H, C(7')*H*), 7.05 (d, *J* 8.4, 1H, C(8')*H*), 5.21 (s, 1H, -O*H*), 2.18-2.08 (m, 2H, -OC-CH_2-CH_2-), 1.05 (sept, *J* 6.6, 1H, -C*H*$(CH_3)_2$), 0.99-0.88 (m, 2H, -CH_2-CH$(CH_3)_2$), 0.62 (d, *J* 6.5, 3H, -CH_3), 0.56 (d, *J* 6.5, 3H, -CH_3); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 173.6 (*C*=O), 151.9 (*C*(2')), 148.2 (*C*(2)), 133.6 (*C*(8a')), 133.6 (*C*(8a)), 132.4 (*C*(4a)), 131.0 (*C*(4)), 130.5 (*C*(4'), 129.2 (*C*(4a')), 128.4 (*C*(5)), 128.1 (*C*(5')), 127.6 (*C*(7)), 126.9 (*C*(7')), 126.4 (*C*(6)), 125.8 (*C*(8)), 124.6 (*C*(8')), 123.7 (*C*(6')), 123.3 (*C*(1)), 121.9 (*C*(3)), 118.4 (*C*(3')), 114.3 (*C*(1')), 33.5 (-*C*H_2-CH-), 32.3 (-CO-*C*H_2-), 27.2 (-*C*H-), 22.1 (-*C*H_3), 22.0 (-*C*H_3); HRMS (ASAP$^+$) $C_{26}H_{24}O_3$ $[M+H]^+$ found 385.1800, requires 385.1804 (−1.0 ppm)

2'-Hydroxy-[1,1'-binaphthalen]-2-yl 2-phenylacetate 57f



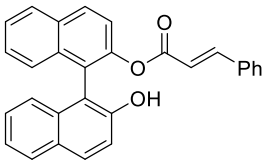
Following general procedure C: BINOL (57.3 mg, 0.2 mmol) and (+)-BTM (0.5 mg, 0.002 mmol) were added into chloroform (4 mL, 0.05 M) at room temperature, giving a clear solution. Phenylacetic anhydride (28.0 mg, 0.11 mmol) was added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The solution was diluted with EtOAc (10 mL), washed with HCl (1 M. 2 × 10 mL), $NaHCO_3$ (sat., 2 × 10 mL) and brine (10 mL). The organic layer was dried over $MgSO_4$, filtered and concentrated *in vacuo* to give a pale brown oil, which was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 20% over 40 CV) to give 2'-hydroxy-[1,1'-binaphthalen]-2-yl 2-phenylacetate (23.2 mg, 29%) as white solid; R_f = 0.28 (20% EtOAc in petroleum ether); mp 127-128 °C [lit[1] 104.5-105.5 °C]; $[\alpha]_D^{20}$ −60.8 (c = 0.1 in $CHCl_3$); **Chiral HPLC analysis**: ChiralPak AD-H (10% *i*PrOH:hexane, flow rate 1.0 mL min^{-1}, 211 nm, 30 °C), t_R major: 16.2 min, t_R minor: 21.4 min, 92:8 er; ν_{max} (ATR): 3451 (O-H), 2890 (C-H), 1746 (C=O), 1597 (C=C), 1117 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 8.05 (d, *J* 8.9, 1H, C(4)*H*), 7.96 (d, *J* 8.2, 1H, C(5)*H*), 7.86 (d, *J* 8.9, 1H, C(4')*H*), 7.84 (d, *J* 8.0, 1H, C(5')*H*), 7.52-7.48 (m, 1H, C(6)*H*), 7.37 (d, *J* 8.9, 1H, C(3)*H*), 7.36-7.31 (m, 2H, C(7)*H,* C(6')*H*), 7.24 (d, *J* 8.9, 1H, C(8)*H*), 7.27-7.20 (m, 2H, C(3')*H,* C(7')*H*), 7.14-7.10 (m, 1H, *p*-ArC*H*), 7.07-7.03 (m, 2H, 2 × *m*-ArC*H*), 7.01-6.98 (m, 1H, C(8')*H*), 6.76-6.73 (m, 2H, 2 × *o*-ArC*H*), 5.12 (s, 1H, -O*H*), 3.42 (s, 2H, -CH_2-); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 170.9 (*C*=O), 151.8 (*C*(2')), 148.2 (*C*(2)), 133.6 (*C*(8a), *C*(8a')), 132.7 (*i*-Ar*C*H), 132.4 (*C*(4a)), 131.0 (*C*(4)), 130.6 (*C*(4'), 129.2 (*C*(4a')), 129.0 (2× *o*-Ar*C*H), 128.5 (2 × *m*-Ar*C*H), 128.4 (*C*(5)), 128.2 (*C*(5')), 127.6 (*C*(7)), 127.1 (*p*-Ar*C*H), 126.8 (*C*(7')), 126.5 (*C*(6)), 125.8 (*C*(8)), 124.6 (*C*(8')), 123.7 (*C*(6')), 123.3 (*C*(1)), 121.7 (*C*(3)), 118.4 (*C*(3')), 114.0 (*C*(1')), 41.0 (-*C*H_2-); HRMS (ASAP$^+$) $C_{28}H_{20}O_3$ $[M+H]^+$ found 405.1486, requires 405.1491 (−1.2 ppm). Data in agreement with literature.[103]

2'-Hydroxy-[1,1'-binaphthalen]-2-yl 3-phenylpropanoate 57g



Following general procedure C: BINOL (57.3 mg, 0.2 mmol) and (+)-BTM (0.5 mg, 0.002 mmol) were added into chloroform (4 mL, 0.05 M) at room temperature, giving a clear solution. 3-Phenylpentanoic anhydride (31.1 mg, 0.11 mmol) was added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The solution was diluted with EtOAc (10 mL), washed with HCl (1 M. 2 × 10 mL), $NaHCO_3$ (sat., 2 × 10 mL) and brine (10 mL). The organic layer was dried over $MgSO_4$, filtered and concentrated *in vacuo* to give 2'-hydroxy-[1,1'-binaphthalen]-2-yl 3-phenylpropanoate (23.9 mg, 29%) as white solids; R_f = 0.32 (20% EtOAc in petroleum ether); mp 127-128 °C; $[\alpha]_D^{20}$ −57.5 (c = 0.1 in $CHCl_3$); **Chiral HPLC analysis**: Chiral HPLC analysis, ChiralPak IB (2% *i*PrOH:hexane, flow rate 1.0 mL min^{-1}, 211 nm, 30 °C), t_R major: 15.4 min, t_R minor: 23.2 min, 87.5:12.5 er; ν_{max} (ATR): 3400 (O-H, br), 2885 (C-H), 1713 (C=O), 1508 (C=C), 1157 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 8.08 (d, *J* 8.8, 1H, C(4)*H*), 7.98 (d, *J* 8.4, 1H. C(5)*H*), 7.90 (d, *J* 9.0, 1H, C(4')*H*), 7.85 (d, *J* 8.0, 1H, C(5')*H*), 7.54-7.50 (m, 1H, C(6)*H*), 7.38-7.30 (m, 5H, C(7)*H,* C(3)*H,* C(6')*H,* C(3')*H,* C(8)*H*), 7.28-7.25 (m, 1H, C(7')*H*), 7.23-7.20 (m, 2H, 2 × *m*-ArC*H*), 7.18-7.14 (m, 1H, *p*-ArC*H*), 7.06 (d, *J* 8.5, 1H, C(8')*H*), 6.95-6.93 (m, 2H, 2 × *o*-ArC*H*) 5.17 (s, 1H, -O*H*), 2.50-2.33 (m, 4H, 2 × -CH_2-); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 172.4 (*C*=O), 151.9 (*C*(2')), 148.1 (*C*(2)), 140.0 (*i*-Ar*C*H), 133.6 (*C*(8a), *C*(8a')), 132.4 (*C*(4a)), 131.0 (*C*(4)), 130.6 (*C*(4'), 129.1 (*C*(4a')), 128.6 (2 × *m*-Ar*C*H), 128.5 (*C*(5)), 128.2 (2 × *o*-Ar*C*H), 128.2 (*C*(5')), 127.7 (*C*(7)), 126.9 (*C*(7')), 126.5 (*C*(6)), 126.4 (*p*-Ar*C*H), 125.8 (*C*(8)), 124.7 (*C*(8')), 123.7 (*C*(6')), 123.1 (*C*(1)), 121.9 (*C*(3)), 118.4 (*C*(3')), 114.2 (*C*(1')), 35.6 (-CO-*C*H_2-), 30.5 (-*C*H_2-Ph); HRMS (ASAP$^+$) $C_{29}H_{22}O_3$ $[M+H]^+$ found 419.1653, requires 419.1647 (+1.4 ppm)

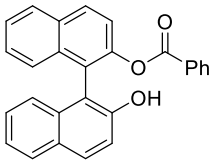
2'-Hydroxy-[1,1'-binaphthalen]-2-yl cinnamate 57h



Following general procedure C: BINOL (57.3 mg, 0.2 mmol) and (+)-BTM (0.5 mg, 0.002 mmol) were added into tert-Amyl alcohol (4 mL, 0.05 M) at room temperature, giving a clear solution. Cinnamic anhydride (30.6 mg, 0.11 mmol) was added to the previous solution. The

resulted clear solution was left stirring for 18 hours at room temperature. The solution was diluted with EtOAc (10 mL), washed with HCl (1 M. 2 × 10 mL), $NaHCO_3$ (sat., 2 × 10 mL) and brine (10 mL). The organic layer was dried over $MgSO_4$, filtered and concentrated *in vacuo* to give a pale brown oil, which was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 20% over 50 CV) to give 2'-hydroxy-[1,1'-binaphthalen]-2-yl 2,2-diphenylacetate (23.6 mg, 28%) as white solid; R_f = 0.35 (20% EtOAc in petroleum ether); mp 150-152 °C [lit[1] 134-135 °C]; $[\alpha]_D^{20}$ −93 (c = 0.1 in $CHCl_3$); **Chiral HPLC analysis**: ChiralPak AD-H (20% *i*PrOH:hexane, flow rate 1.0 mL min^{-1}, 211 nm, 30 °C), t_R major: 11.6 min, t_R minor: 16.6 min, 74.5:25.5 er; ν_{max} (ATR): 3400 (O-H, br), 2924 (C-H), 1717 (C=O), 1634 (C=C), 1550 (C=C, aromatic), 1138 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 8.11 (d, *J* 8.9, 1H, C(4)*H*), 7.99 (d, *J* 8.2, 1H, C(5)*H*), 7.85 (d, *J* 8.9, 1H, C(4')*H*), 7.82 (d, *J* 8.1, 1H, C(5')*H*), 7.54-7.50 (m, 1H, C(6)*H*), 7.49 (d, *J* 8.9, 1H, C(3)*H*), 7.40 (d, *J* 16.0, 1H, -CH=C*H*-Ph), 7.37-7.26 (m, 10H, Ar*H*), 7.10 (d, *J* 8.1, 1H, C(8)*H*), 6.24 (d, *J* 16.0, 1H, -CO-C*H*=), 5.37 (s, 1H, -O*H*); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 166.5 (*C*=O), 152.0 (*C*(2')), 149.0 (*C*(2)), 147.2 (-CH=*C*H-Ph), 134.0 (*i*-Ar*C*H), 133.6 (*C*(8a), *C*(8a')), 132.4 (*C*(4a)), 131.0 (*p*-Ar*C*H), 131.0 (*C*(4)), 130.5 (*C*(4'), 129.2 (*C*(4a')), 129.0 (2 × Ar*C*H), 128.4 (*C*(5), 2 × Ar*C*H), 128.2 (*C*(5')), 127.6, 126.8, 126.4 (*C*(6)), 125.9, 124.7 (*C*(8)), 123.6, 123.5 (*C*(1)), 122.0 (*C*(3)), 118.5 (*C*(3')), 114.2 (*C*(1')); HRMS (ASAP$^+$) $C_{29}H_{20}O_3$ $[M+H]^+$ found 417.1497, requires 417.1391 (+1.4 ppm). Data in agreement with literature.[103]

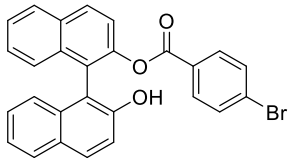
2'-Hydroxy-[1,1'-binaphthalen]-2-yl benzoate 57i



Following general procedure C: BINOL (57.3 mg, 0.2 mmol) and (+)-BTM (0.5 mg, 0.002 mmol) were added into tert-Amyl alcohol (4 mL, 0.05 M) at room temperature. Benzoic anhydride (24.9 mg, 0.11 mmol) was added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The crude product was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 20% over 25 CV) giving 2'-hydroxy-[1,1'-binaphthalen]-2-yl benzoate (32 mg, 41%) as white solids; R_f = 0.24 (20% EtOAc in petroleum ether); mp 214-216 °C; $[\alpha]_D^{20}$ −133.4 (c = 0.1 in $CHCl_3$); **Chiral HPLC analysis**: ChiralPak AS-H (1% *i*PrOH:hexane, flow rate 1.0 mL min^{-1}, 211 nm, 30 °C), t_R major: 18.0 min, t_R minor: 34.7 min, 88.5:11.5 er; ν_{max} (ATR): 3424 (O-H), 2963 (C-H), 1703 (C=O), 1508 (C=C), 1256 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 8.13 (d, *J* 8.8, 1H, C(4)*H*), 8.01 (d, *J* 8.2, 1H, C(5)*H*), 7.81-7.78 (m,

2H, C(4')*H,* C(5')*H*), 7.68-7.66 (m, 2H, 2 × *o*-ArC*H*), 7.55 (d, *J* 8.2, 1H, C(3)*H*), 7.55-7.52 (m, 1H, d, C(6)*H*), 7.47-7.44 (m, 1H, *p*-ArC*H*), 7.39-7.36 (m, 1H, C(7)*H*), 7.33- 7.28 (m, 3H, C(8)*H,* C(6')*H,* C(7')*H*), 7.27-7.23 (m, 3H, 2 × *m*-ArC*H*, C(3')*H*), 7.17-7.15 (m, 1H, C(8')*H*), 5.32 (s, 1H, -O*H*); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 166.1 (*C*=O), 151.9 (*C*(2')), 148.4 (*C*(2)), 133.7 (*C*(8a), *C*(8a')), 133.6 (*p*-Ar*C*H), 132.4 (*C*(4a)), 131.0 (*C*(4)), 130.5 (*C*(4'), 130.1 (2 × *o*-Ar*C*H), 129.1 (*C*(4a')), 128.9 (*i*-Ar*C*H), 128.5 (*C*(5)), 128.4 (2 × *m*-Ar*C*H), 128.1 (*C*(5')), 127.7 (*C*(7)), 126.8 (*C*(7')), 126.5 (*C*(6)), 125.9 (*C*(8)), 124.7 (*C*(8')), 123.6 (*C*(6')), 123.3 (*C*(1)), 122.0 (*C*(3)), 118.3 (*C*(3')), 114.0 (*C*(1')); HRMS (NSI$^+$) $C_{27}H_{18}O_3$ $[M+H]^+$ found 391.1329, requires 391.1329 (+0.1 ppm)

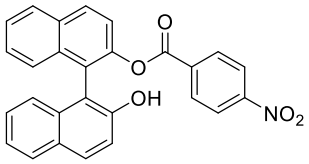
2'-hydroxy-[1,1'-binaphthalen]-2-yl 4-bromobenzoate 57j



Following general procedure C: BINOL (57.3 mg, 0.2 mmol) and (+)-BTM (0.5 mg, 0.002 mmol) were added into chloroform (4 mL, 0.05 M) at room temperature, giving a clear solution. 4-Bromobezoic anhydride (31.1 mg, 0.11 mmol) was added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The solution was diluted with EtOAc (10 mL), washed with HCl (1 M. 2 × 10 mL), $NaHCO_3$ (sat., 2 × 10 mL) and brine (10 mL). The organic layer was dried over $MgSO_4$, filtered and concentrated *in vacuo* to give a pale brown oil, which was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 20% over 40 CV) to give 2'-hydroxy-[1,1'-binaphthalen]-2-yl 4-bromobenzoate (40.9 mg, 44%) as white solids; R_f = 0.30 (20% EtOAc in petroleum ether); mp 161-162 °C; $[\alpha]_D^{20}$ −123.3 (c = 0.1 in $CHCl_3$); **Chiral HPLC analysis**: ChiralPak AD-H (20% *i*PrOH:hexane, flow rate 1.0 mL min^{-1}, 211 nm, 30 °C), t_R major: 9.3 min, t_R minor: 14.7 min, 86:14 er; ν_{max} (ATR) 3455 (O-H), 2890 (C-H), 1721 (C=O), 1587 (C=C), 1198 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 8.13 (d, *J* 8.9, 1H, C(4)*H*), 8.01 (d, *J* 8.4, 1H, C(5)*H*), 7.80 (d, *J* 8.9, 1H, C(4')*H*), 7.80-7.78 (m, 1H, C(5')*H*), 7.55 (d, *J* 8.9, 1H, C(3)*H*), 7.56-7.53 (m, 1H, C(6)*H*), 7.49-7.46 (m, 2H, 2 × ArC*H*), 7.40-7.36 (m, 3H, C(7)*H,* 2 × ArC*H*), 7.36-7.34 (m, 1H, C(8)*H*), 7.34-7.27 (m, 2H, C(6')*H,* C(7')*H*), 7.24 (d, *J* 8.9, 1H, C(3')*H*), 7.24 (m, 1H, C(8')*H*), 5.21 (s, 1H, -O*H*); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 165.2 (*C*=O), 151.8 (*C*(2')), 148.2 (*C*(2)), 133.6 (*C*(8a), *C*(8a')), 132.5 (*C*(4a)), 131.1 (*C*(4)), 131.8 (2 × *o/m*-Ar*C*H), 131.5 (2 × *o/m*-Ar*C*H), 130.6 (*C*(4'), 129.1 (*C*(4a')), 128.9 (*p/i*-Ar*C*H), 128.6 (*C*(5)), 128.2 (*C*(5')), 127.8 (*C*(7)), 127.7 (*p/i*-Ar*C*H), 126.9 (*C*(7')), 126.6 (*C*(6)),

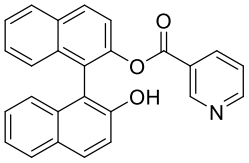
125.9 (*C*(8)), 124.6 (*C*(8')), 123.6 (*C*(6')), 123.1 (*C*(1)), 121.8 (*C*(3)), 118.2 (*C*(3')), 113.8 (*C*(1')); HRMS (ASAP$^+$) $C_{27}H_{17}BrO_3$ $[M+H]^+$ found 469.0444, requires 469.0439 (+1.1 ppm)

2'-Hydroxy-[1,1'-binaphthalen]-2-yl 4-nitrobenzoate 57k



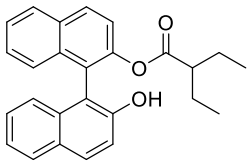
Following general procedure C: BINOL (57.3 mg, 0.2 mmol) and (+)-BTM (0.5 mg, 0.002 mmol) were added into chloroform (4 mL, 0.05 M) at room temperature, giving a clear solution. 4-Nitrobenzoic anhydride (31.1 mg, 0.11 mmol) was added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The solution was diluted with EtOAc (10 mL), washed with HCl (1 M. 2 × 10 mL), $NaHCO_3$ (sat., 2 × 10 mL) and brine (10 mL). The organic layer was dried over $MgSO_4$, filtered and concentrated *in vacuo* to give a pale brown oil, which was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 20% over 40 CV) to give 2'-hydroxy-[1,1'-binaphthalen]-2-yl 4-nitrobenzoate (24.6 mg, 29%) as yellow gum; R_f = 0.14 (20% EtOAc in petroleum ether); $[\alpha]_D^{20}$ −100.9 (c = 0.1 in $CHCl_3$); **Chiral HPLC analysis**: ChiralPak IB (5% *i*PrOH:hexane, flow rate 1.0 mL min^{-1}, 211 nm, 30 °C), t_R major: 27.8 min, t_R minor: 35.4 min, 86.5:13.5 er; ν_{max} (ATR): 3454 (O-H), 3050 (C-H), 1738 (C=O), 1526 (N-O), 1346 (N-O), 1207 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 8.16 (d, *J* 8.9, 1H, C(4)*H*), 8.07-8.03(m, 3H, 2 × *m*-ArC*H,* C(5)*H*), 7.80 (d, *J* 8.9, 1H, C(4')*H*), 7.80-7.78 (m, 1H, C(5')*H*), 7.72 (m, 2H, 2 × *o*-ArC*H*), 7.59 (d, *J* 8.9, 1H, C(3)*H*), 7.59-7.55 (m, 1H, C(6)*H*), 7.44-7.39 (m, 2H, C(7)*H,* C(8)*H*), 7.35-7.29 (m, 2H, C(6')*H,* C(7')*H*), 7.23 (d, *J* 8.9, 1H, C(3')*H*), 7.18-7.15 (m, 1H, C(8')*H*), 5.11 (s, 1H, -O*H*); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 163.9 (*C*=O), 151.7 (*C*(2')), 150.8 (*p*-Ar*C*H), 148.0 (*C*(2)), 134.2 (*i*-Ar*C*H), 133.5 (*C*(8a)), 133.4 (*C*(8a')), 132.6 (*C*(4a)), 131.2 (*C*(4)), 131.0 (2 × *o*-Ar*C*H), 130.8 (*C*(4'), 129.1 (*C*(4a')), 128.6 (*C*(5)), 128.3 (*C*(5')), 127.9 (*C*(7)), 127.1 (*C*(7')), 126.8 (*C*(6)), 125.9 (*C*(8)), 124.5 (*C*(8')), 123.8 (*C*(6')), 123.5 (2 × *m*-Ar*C*H), 123.0 (*C*(1)), 121.5 (*C*(3)), 118.1 (*C*(3')), 113.5 (*C*(1')); HRMS (ASAP$^+$) $C_{27}H_{17}NO_5$ $[M+H]^+$ found 436.1187, requires 436.1185 (+0.5 ppm)

2'-Hydroxy-[1,1'-binaphthalen]-2-yl nicotinate 57m



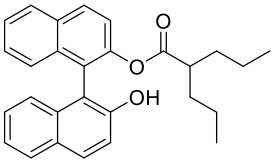
Following general procedure C: BINOL (57.3 mg, 0.2 mmol) and (+)-BTM (0.5 mg, 0.002 mmol) were added into chloroform (4 mL, 0.05 M) at room temperature, giving a clear solution. Nicotinic anhydride (25.0 mg, 0.11 mmol) was added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The solution was diluted with EtOAc (10 mL), washed with HCl (1 M. 2 × 10 mL), $NaHCO_3$ (sat., 2 × 10 mL) and brine (10 mL). The organic layer was dried over $MgSO_4$, filtered and concentrated *in vacuo* to give a pale brown oil, which was purified by column chromatography (Isolera 4, MeOH in CH_2Cl_2, 0% -> 2% over 20 CV, then 2% over 10 CV) to give 2'-hydroxy-[1,1'-binaphthalen]-2-yl nicotinate (43.1 mg, 44%) as white solid; R_f = 0.17 (2% MeOH in CH_2Cl_2), mp 250.5-251.5 °C; $[\alpha]_D^{20}$ −101.7 (c = 0.1 in $CHCl_3$); **Chiral HPLC analysis**: ChiralPak AD-H (10% *i*PrOH:hexane, flow rate 1.0 mL min^{-1}, 211 nm, 30 °C), t_R major: 24.4 min, t_R minor: 38.4 min, 89.5:10.5 er; ν_{max} (ATR): 3052 (O-H), 2644 (C-H), 1742 (C=O), 1504 (C=C) 1279 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 8.77 (d, *J* 1.4, 1H, hetero-Ar*H*(2)), 8.64 (dd, *J* 5.0, 1.7, 1H, hetero-Ar*H*(6)), 8.13 (d, *J* 8.9, 1H, C(4)*H*), 8.01 (d, *J* 8.2, 1H, C(5)*H*), 7.86 (dt, *J* 8.0, 2.0, 1H, hetero-Ar*H*(4)), 7.81-7.77 (m, 2H, C(4')*H,* C(5')*H*), 7.56 (d, *J* 8.9, 1H, C(3)*H*), 7.57-7.53 (m, 1H, C(6)*H*), 7.42-7.36 (m, 2H, C(7)*H,* C(8)*H*), 7.33-7.27 (m, 2H, C(6')*H,* C(7')*H*), 7.24 (d, *J* 8.9, 1H, C(3')*H*), 7.19 (dd, *J* 8.0, 5.0, 1H, hetero-Ar*H*(5)), 7.16-7.14 (m, 1H, C(8')*H*), 5.30 (s, 1H, -O*H*); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 164.5 (*C*=O), 154.0 (hetero-Ar*C*H(6)), 151.8 (*C*(2')), 151.1 (hetero-Ar*C*H(2)), 147.8 (*C*(2)), 137.4 (hetero-Ar*C*H(4)), 133.5 (*C*(8a), *C*(8a')), 132.5 (*C*(4a)), 131.1 (*C*(4)), 130.7 (*C*(4'), 129.1 (*C*(4a')), 128.6 (*C*(5)), 128.2 (*C*(5')), 127.8 (*C*(7)), 127.0 (*C*(7')), 126.7 (*C*(6)), 125.9 (*C*(8)), 124.9 (hetero-Ar*C*H(3)), 124.6 (*C*(8')), 123.7 (*C*(6')), 123.3 (hetero-Ar*C*H(5)), 123.2 (*C*(1)), 121.7 (*C*(3)), 118.1 (*C*(3')), 113.6 (*C*(1')); HRMS (NSI$^+$) $C_{26}H_{17}NO_3$ $[M+H]^+$ found 392.1281, requires 392.1281 (−0.1 ppm)

2'-Hydroxy-[1,1'-binaphthalen]-2-yl 2-ethylbutanoate 57n



Following general procedure C: BINOL (57.3 mg, 0.2 mmol) and (+)-BTM (0.5 mg, 0.002 mmol) were added into tert-Amyl alcohol (4 mL, 0.05 M) at room temperature, giving a clear solution. 2-Ethylbutanoic anhydride (22 mg, 0.12 mmol) was added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The solution was diluted with EtOAc (10 mL), washed with HCl (1 M. 2 × 10 mL), $NaHCO_3$ (sat., 2 × 10 mL) and brine (10 mL). The organic layer was dried over $MgSO_4$, filtered and concentrated *in vacuo* to give a pale brown oil, which was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 20% over 20 CV) to give 2'-hydroxy-[1,1'-binaphthalen]-2-yl 2-ethylbutanoate (29.0 mg, 38%) as white solids; R_f = 0.44 (20% EtOAc in petroleum ether); mp 72-74 °C; $[\alpha]_D^{20}$ −61.9 (c = 0.1 in $CHCl_3$); **Chiral HPLC analysis**: ChiralPak AD-H (2% *i*PrOH:hexane, flow rate 1.0 mL min^{-1}, 211 nm, 30 °C), t_R major: 19.1 min, t_R minor: 26.4 min, 92:8 er; ν_{max} (ATR): 3450 (O-H), 1744 (C=O), 1508 (C=C), 1204 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 8.07 (d, *J* 8.9, 1H, C(4)*H*), 7.97 (d, *J* 8.1, 1H, C(5)*H*), 7.88 (d, *J* 8.9, 1H, C(4')*H*), 7.83 (d, *J* 8.1, 1H, C(5')*H*), 7.53-7.49 (m, 1H, C(6)*H*), 7.36 (d, *J* 8.9, 1H, C(3)*H*), 7.36-7.29 (m, 3H, C(7)*H,* C(3')*H,* C(6')*H*), 7.28 (d, *J* 8.4, 1H, C(8)*H*), 7.26-7.23 (m, 1H, C(7')*H*), 7.05 (d, *J* 8.4, 1H, C(8')*H*), 5.29 (s, 1H, -O*H*), 2.08 (tt, *J* 8.6, 5.4, 1H, -C*H*$(CH_3)_2$), 1.33-1.14 (m, 4H, 2× -CH_2-), 0.58 (t, *J* 7.5, 3H, -CH_3), 0.50 (t, *J* 7.5, 3H, -CH_3); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 175.7 (*C*=O), 151.9 (*C*(2')), 148.2 (*C*(2)), 133.7 (*C*(8a')), 133.7 (*C*(8a)), 132.3 (*C*(4a)), 131.0 (*C*(4)), 130.5 (*C*(4'), 129.2 (*C*(4a')), 128.4 (*C*(5)), 128.0 (*C*(5')), 127.6 (*C*(7)), 126.8 (*C*(7')), 126.4 (*C*(6)), 125.8 (*C*(8)), 124.7 (*C*(8')), 123.6 (*C*(6')), 123.4 (*C*(1)), 122.0 (*C*(3)), 118.5 (*C*(3')), 114.4 (*C*(1')), 48.7 (-*C*H-), 24.8 (-*C*H_2-), 24.7 (-*C*H_2-), 11.5 (-*C*H_3), 11.2 (-*C*H_3); HRMS (ASAP$^+$) $C_{26}H_{24}O_3$ $[M+H]^+$ found 385.1798, requires 385.1804 (−1.6 ppm)

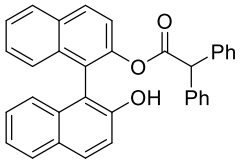
2'-Hydroxy-[1,1'-binaphthalen]-2-yl 2-propylpentanoate 57o



Following general procedure C: BINOL (57.3 mg, 0.2 mmol) and (+)-BTM (0.5 mg, 0.002 mmol) were added into tert-Amyl alcohol (4 mL, 0.05 M) at room temperature, giving a clear

solution. 2-Propylpentanoic anhydride (29.7 mg, 0.12 mmol) was added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The solution was diluted with EtOAc (10 mL), washed with HCl (1 M. 2 × 10 mL), $NaHCO_3$ (sat., 2 × 10 mL) and brine (10 mL). The organic layer was dried over $MgSO_4$, filtered and concentrated *in vacuo* to give a pale brown oil, which was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 20% over 30 CV) to give 2'-hydroxy-[1,1'-binaphthalen]-2-yl 2-propylpentanoate (24.1 mg, 29%) as white solids; R_f = 0.47 (20% EtOAc in petroleum ether); mp 99-100 °C; $[\alpha]_D^{20}$ −77.8 (c = 0.1 in $CHCl_3$); **Chiral HPLC analysis**: ChiralPak AD-H (10% *i*PrOH:hexane, flow rate 1.0 mL min^{-1}, 211 nm, 30 °C), t_R major: 17.1 min, t_R minor: 22.7 min, 92:8 er; ν_{max} (ATR): 3450 (O-H), 2957 (C-H), 1740 (C=O), 1508 (C=C), 1204 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 8.07 (d, *J* 8.9, 1H, C(4)*H*), 7.97 (d, *J* 8.2, 1H, C(5)*H*), 7.89 (d, *J* 8.9, 1H, C(4')*H*), 7.83 (d, *J* 8.3, 1H, C(5')*H*), 7.52-7.49 (m, 1H, C(6)*H*), 7.36-7.30 (m, 4H, C(3)*H*, C(7)*H,* C(6')*H,* C(3')*H*), 7.28-7.23 (m, 2H, C(8)*H,* C(7')*H*), 7.06(d, *J* 8.4, 1H, C(8')*H*), 5.30 (s, 1H, -O*H*), 2.27-2.21 (m, 1H, -C*H*-), 1.27-1.19 (m, 2H, -CH_2-), 1.14-1.06 (m, 2H, -CH_2-), 1.03-0.80 (m, 4H, 2 × -CH_2-), 0.65 (t, *J* 7.3, 3H, -CH_3), 0.60 (t, *J* 7.3, 3H, -CH_3); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 176.0 (*C*=O), 152.0 (*C*(2')), 148.2 (*C*(2)), 133.7 (*C*(8a')), 133.7 (*C*(8a)), 132.3 (*C*(4a)), 131.0 (*C*(4)), 130.5 (*C*(4'), 129.3 (*C*(4a')), 128.4 (*C*(5)), 128.1 (*C*(5')), 127.6 (*C*(7)), 126.8 (*C*(7')), 126.4 (*C*(6)), 125.8 (*C*(8)), 124.6 (*C*(8')), 123.6 (*C*(6')), 123.5 (*C*(1)), 121.9 (*C*(3)), 118.5 (*C*(3')), 114.5 (*C*(1')), 45.3 (-*C*H-), 34.4 (-*C*H_2-), 34.3 (-*C*H_2-), 20.5 (-*C*H_2-), 20.2 (-*C*H_2-), 14.1 (-*C*H_3), 13.9 (-*C*H_3); HRMS (ASAP$^+$) $C_{28}H_{28}O_3$ $[M+H]^+$ found 413.2114, requires 413.2117 (−0.7 ppm)

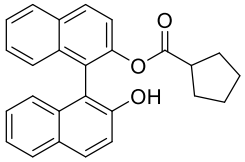
2'-Hydroxy-[1,1'-binaphthalen]-2-yl 2,2-diphenylacetate 57p



Following general procedure C: BINOL (57.3 mg, 0.2 mmol) and (+)-BTM (0.5 mg, 0.002 mmol) were added into tert-Amyl alcohol (4 mL, 0.05 M) at room temperature, giving a clear solution. Diphenylacetic anhydride (44.7 mg, 0.11 mmol) was added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The solution was diluted with EtOAc (10 mL), washed with HCl (1 M. 2 × 10 mL), $NaHCO_3$ (sat., 2 × 10 mL) and brine (10 mL). The organic layer was dried over $MgSO_4$, filtered and concentrated *in vacuo* to give a pale brown oil, which was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 20% over 40 CV) to give 2'-hydroxy-[1,1'-binaphthalen]-2-yl 2,2-

diphenylacetate (36.1 mg, 38%) as white solid; R_f = 0.22 (20% EtOAc in petroleum ether);); mp 133-134 °C; $[\alpha]_D^{20}$ −57.3 (c = 0.1 in $CHCl_3$); **Chiral HPLC analysis**: ChiralPak AD-H (10% *i*PrOH:hexane, flow rate 1.0 mL min^{-1}, 211 nm, 30 °C), t_R major: 9.6 min, t_R minor: 12.0 min, 92.5:7.5 er; ν_{max} (ATR): 3455 (O-H), 3050 (C-H), 1736 (C=O), 1452 (C=C), 1202 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H 8.04 (d, *J* 8.9, 1H, C(4)*H*), 7.96 (d, *J* 8.0, 1H, C(5)*H*), 7.87 (d, *J* 8.9, 1H, C(4')*H*), 7.85 (d, *J* 8.1, 1H, C(5')*H*), 7.52-7.49 (m, 1H, C(6)*H*), 7.35-7.32 (m, 2H, C(7)*H,* C(6')*H*), 7.32 (d, *J* 8.9, 1H, C(3)*H*), 7.27-7.24 (m, 2H, C(8)*H,* C(3')*H*), 7.23-7.19 (m, 1H, C(7')*H*), 7.17-7.13 (m, 2H, *p*-ArC*H, p'*-ArC*H*), 7.12-7.08 (m, 4H, 2 × *m*-ArC*H,* 2 × *m'*-ArC*H*), 7.02-6.99 (m, 1H, C(8')*H*), 6.93-6.90 (m, 2H, 2 × *o*-ArC*H*), 6.83-6.80 (m, 2H, 2 × *o'*-ArC*H*), 5.20 (s, 1H, -O*H*), 4.87 (s, 1H, -C*H*Ph_2); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 172.1 (*C*=O), 151.9 (*C*(2')), 148.1 (*C*(2)), 137.7 (*i*-Ar*C*H), 137.5 (*i'*-Ar*C*H), 133.6 (*C*(8a), *C*(8a')), 132.4 (*C*(4a)), 131.0 (*C*(4)), 130.6 (*C*(4'), 129.2 (*C*(4a')), 128.6 (2 × *m*-Ar*C*H), 128.6 (2 × *m'*-Ar*C*H), 128.5 (2 × *o*-Ar*C*H), 128.4 (2 × *o'*-Ar*C*H), *C*(5)), 128.1 (*C*(5')), 127.6 (*C*(7)), 127.3 (*p*-Ar*C*H), 127.3 (*p'*-Ar*C*H), 126.9 (*C*(7')), 126.5 (*C*(6)), 125.9 (*C*(8)), 124.7 (*C*(8')), 123.7 (*C*(6')), 123.4 (*C*(1)), 121.6 (*C*(3)), 118.5 (*C*(3')), 114.1 (*C*(1')), 56.8 (-*C*H-); HRMS (ASAP$^+$) $C_{34}H_{24}O_3$ $[M+H]^+$ found 481.1802, requires 481.1804 (−0.4 ppm)

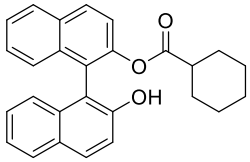
2'-Hydroxy-[1,1'-binaphthalen]-2-yl cyclopentanecarboxylate 57q



Following general procedure C: BINOL (57.3 mg, 0.2 mmol) and (+)-BTM (0.5 mg, 0.002 mmol) were added into tert-Amyl alcohol (4 mL, 0.05 M) at room temperature, giving a clear solution. Cyclopetanecarboxylic anhydride (23.1 mg, 0.12 mmol) was added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The solution was diluted with EtOAc (10 mL), washed with HCl (1 M., 2 × 10 mL), $NaHCO_3$ (sat., 2 × 10 mL) and brine (10 mL). The organic layer was dried over $MgSO_4$, filtered and concentrated *in vacuo* to give a pale brown oil, which was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 20% over 20 CV) to give 2'-hydroxy-[1,1'-binaphthalen]-2-yl cyclopentanecarboxylate (26.4 mg, 35%) as white solids; R_f = 0.38 (20% EtOAc in petroleum ether); mp 99-100 °C; $[\alpha]_D^{20}$ −64 (c = 0.1 in $CHCl_3$); **Chiral HPLC analysis**: ChiralPak AD-H (10% *i*PrOH:hexane, flow rate 1.0 mL min^{-1}, 211 nm, 30 °C), t_R major: 9.3 min, t_R minor: 12.6 min, 89.5:10.5 er; ν_{max} (ATR): 3364 (O-H), 2963 (C-H), 1708 (C=O), 1504 (C=C),

1206 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 8.08 (d, *J* 8.9, 1H, C(4)*H*), 7.98 (d, *J* 8.2, 1H, C(5)*H*), 7.90 (d, *J* 8.9, 1H, C(4')*H*), 7.84 (d, *J* 8.0, 1H, C(5')*H*), 7.53-7.49 (m, 1H, C(6)*H*), 7.40 (d, *J* 8.9, 1H, C(3)*H*), 7.37-7.30 (m, 4H, C(7)*H,* C(6')*H,* C(3')*H,* C(8)*H*), 7.27-7.23 (m, 1H, C(7')*H*), 7.04 (d, *J* 8.4, 1H, C(8')*H*), 5.19 (s, 1H, -O*H*), 2.61-2.56 (m, 1H, C(1'')*H*), 1.58-1.02 (m, 8H, 4 × -CH_2-); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 176.4 (*C*=O), 151.9 (*C*(2')), 148.3 (*C*(2)), 133.6 (*C*(8a')), 133.6 (*C*(8a)), 132.3 (*C*(4a)), 131.0 (*C*(4)), 130.5 (*C*(4'), 129.1 (*C*(4a')), 128.4 (*C*(5)), 128.1 (*C*(5')), 127.6 (*C*(7)), 126.8 (*C*(7')), 126.4 (*C*(6)), 125.8 (*C*(8)), 124.7 (*C*(8')), 123.7 (*C*(6')), 123.2 (*C*(1)), 122.0 (*C*(3)), 118.5 (*C*(3')), 114.4 (*C*(1')), 43.4 (-*C*H-), 29.8 (-*C*H_2-), 29.2 (-*C*H_2-), 25.6 (-*C*H_2-), 25.6 (-*C*H_2-); HRMS (ASAP$^+$) $C_{26}H_{22}O_3$ $[M+H]^+$ found 383.1642, requires 383.1647 (−1.3 ppm)

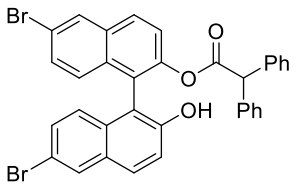
2'-Hydroxy-[1,1'-binaphthalen]-2-yl cyclohexanecarboxylate 57r



Following general procedure C: BINOL (57.3 mg, 0.2 mmol) and (+)-BTM (0.5 mg, 0.002 mmol) were added into chloroform (4 mL, 0.05 M) at room temperature, giving a clear solution. Cyclohexanecarboxylic anhydride (26.2 mg, 0.12 mmol) was added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The solution was diluted with EtOAc (10 mL), washed with HCl (1 M. 2 × 10 mL), $NaHCO_3$ (sat., 2 × 10 mL) and brine (10 mL). The organic layer was dried over $MgSO_4$, filtered and concentrated *in vacuo* to give a pale brown oil, which was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 20% over 20 CV) to give 2'-hydroxy-[1,1'-binaphthalen]-2-yl cyclohexanecarboxylate (23.1 mg, 29%) as white solids; R_f = 0.44 (20% EtOAc in petroleum ether); mp 144-146 °C; $[\alpha]_D^{20}$ −87.9 (c = 0.1 in $CHCl_3$); **Chiral HPLC analysis**: ChiralPak AD-H (10% *i*PrOH:hexane, flow rate 1.0 mL min^{-1}, 211 nm, 30 °C), t_R major: 14.5 min, t_R minor: 26.7 min, 95:5 er; ν_{max} (ATR): 3456 (O-H), 2930 (C-H), 1726 (C=O), 1508 (C=C), 1152 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 8.07 (d, *J* 8.9, 1H, C(4)*H*), 7.97 (d, *J* 8.2, 1H, C(5)*H*), 7.89 (d, *J* 8.9, 1H, C(4')*H*), 7.84 (d, *J* 8.1, 1H, C(5')*H*), 7.52-7.49 (m, 1H, C(6)*H*), 7.38 (d, *J* 8.9, 1H, C(3)*H*), 7.37-7.29 (m, 4H, C(7)*H,* C(6')*H,* C(3')*H,* C(8)*H*), 7.27-7.24 (m, 1H, C(7')*H*), 7.04 (d, *J* 8.4, 1H, C(8')*H*), 5.20 (s, 1H, -O*H*), 2.20-2.14 (m, 1H, C(1'')*H*), 1.53-0.84 (m, 10H, 5 × -CH_2-); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 175.7 (*C*=O), 151.9 (*C*(2')), 148.2 (*C*(2)), 133.7 (*C*(8a')), 133.6 (*C*(8a)), 132.3 (*C*(4a)), 131.0 (*C*(4)), 130.4 (*C*(4'), 129.1 (*C*(4a')), 128.4 (*C*(5)), 128.0 (*C*(5')), 127.6 (*C*(7)), 126.8

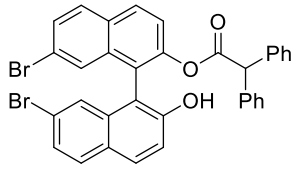
(*C*(7')), 126.4 (*C*(6)), 125.8 (*C*(8)), 124.7 (*C*(8')), 123.6 (*C*(6')), 123.2 (*C*(1)), 122.0 (*C*(3)), 118.4 (*C*(3')), 114.3 (*C*(1')), 42.7 (-*C*H-), 28.4 (-*C*H_2-), 28.2 (-*C*H_2-), 25.6 (-*C*H_2-), 25.1 (-*C*H_2-), 25.0 (-*C*H_2-); HRMS (ASAP$^+$) $C_{27}H_{24}O_3$ $[M+H]^+$ found 397.1794, requires 397.1804 (−2.5 ppm)

6,6'-Dibromo-2'-hydroxy-[1,1'-binaphthalen]-2-yl 2,2-diphenylacetate 65a



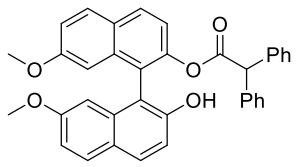
Following general procedure C: 6,6'-dibromo-[1,1'-binaphthalene]-2,2'-diol (88.8 mg, 0.2 mmol) and (+)-BTM (0.5 mg, 0.002 mmol) were added into chloroform (4 mL, 0.05 M) at room temperature, giving a clear solution. 2,2-Diphenylacetic pivalic anhydride (32.6 mg, 0.11 mmol) was added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The solvent was removed *in vacuo* and the residue was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 20% over 30 CV) to give 6,6'-dibromo-2'-hydroxy-[1,1'-binaphthalen]-2-yl 2,2-diphenylacetate (63.6 mg, 49.8%) as white solid. R_f = 0.47 (20% EtOAc in petroleum ether); mp 130-132 °C; $[\alpha]_D^{20}$ +1.9 (c = 0.1 in $CHCl_3$); Chiral HPLC analysis, ChiralPak AD-H (5% *i*PrOH:hexane, flow rate 1.0 mL min^{-1}, 211 nm, 30 °C), t_R major: 46.1 min, t_R minor: 80.6 min, 88:12 er; ν_{max} (ATR): 3408 (O-H), 2922 (C-H), 1722 (C=O), 1493 (C=C), 1150 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H 8.12 (d, *J* 1.9, 1H, C(5)*H*), 7.97 (d, *J* 2.0, 1H, C(5')*H*), 7.97 (d, *J* 9.0, 1H, C(4)*H*), 7.73 (d, *J* 9.0, 1H, C(4')*H*), 7.40 (dd, *J* 9.0, 2.0, 1H, C(7)*H*), 7.35 (d, *J* 8.9, 1H, C(3)*H*), 7.25 (dd, *J* 9.0, 2.1, 1H, C(7')*H*), 7.21 (d, *J* 8.9, 1H, C(3')*H*), 7.19-7.16 (m, 2H, *p*-ArC*H, p'*-ArC*H*), 7.14-7.10 (m, 4H, 2 × *m*-ArC*H,* 2 × *m'*-ArC*H*), 7.05 (d, *J* 9.0, 1H, C(8)*H*), 6.92-6.90 (m, 2H, 2 × *o*-ArC*H*), 6.86-6.84 (m, 2H, 2 × *o'*-ArC*H*), 7.05 (d, *J* 9.0, 1H, C(8')*H*), 5.17 (s, 1H, -O*H*), 4.86 (s, 1H, -C*H*Ph_2); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 171.8 (*C*=O), 152.2 (*C*(2')), 148.3 (*C*(2)), 137.4 (*i*-Ar*C*H/ *i'*-Ar*C*H), 137.2 (*i*-Ar*C*H/ *i'*-Ar*C*H), 133.5 (*C*(4a)), 132.0 (*C*(8a)/ *C*(8a')), 131.9 (*C*(8a)/ *C*(8a')), 131.1 (*C*(7)), 130.5 (*C*(5)), 130.3 (*C*(4a')), 130.2 (*C*(5'), *C*(4)), 130.1 (*C*(7')), 129.9 (*C*(4')), 128.7 (2 × *m/m'*-Ar*C*H), 128.6 (2 × *m/m'*-Ar*C*H), 128.4 (2 × *o/o'*-Ar*C*H), 128.3 (2 × *o/o'*-Ar*C*H), 127.5 (*C*(8)), 127.4 (*p'*-Ar*C*H, *p'*-Ar*C*H), 126.3 (*C*(8')), 123.3 (*C*(1)), 122.8 (*C*(3)), 120.9 (*C*(6)), 119.6 (*C*(3')), 117.6 (*C*(6')), 113.8 (*C*(1')), 56.7 (-*C*H-); HRMS (NSI$^+$) $C_{34}H_{22}Br_2O_3$ $[M+H]^+$ found 637.0010, requires 637.008 (+ 0.2 ppm)

7,7'-Dibromo-2'-hydroxy-[1,1'-binaphthalen]-2-yl 2,2-diphenylacetate 65b



Following general procedure C: 6,6'-dibromo-[1,1'-binaphthalene]-2,2'-diol (88.8 mg, 0.2 mmol) and (+)-BTM (0.5 mg, 0.002 mmol) were added into chloroform (4 mL, 0.05 M) at room temperature, giving a clear solution. 2,2-Diphenylacetic pivalic anhydride (32.6 mg, 0.11 mmol) was added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The solvent was removed *in vacuo* and the residue was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 20% over 30 CV) to give 7,7'-dibromo-2'-hydroxy-[1,1'-binaphthalen]-2-yl 2,2-diphenylacetate (61.4 mg, 48.1%) as yellow solids. R_f = 0.47 (20% EtOAc in petroleum ether); mp 167-169 °C; $[\alpha]_D^{20}$ +10.8 (c = 0.1 in $CHCl_3$); Chiral HPLC analysis, ChiralPak AD-H (10% *i*PrOH:hexane, flow rate 1.0 mL min^{-1}, 211 nm, 30 °C), t_R major: 22.1 min, t_R minor: 29.1 min, 82:18 er; ν_{max} (ATR): 3401 (O-H), 3040 (C-H), 1730 (C=O), 1493 (C=C), 1144 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H 8.01 (d, *J* 8.9, 1H, C(4)*H*), 7.83 (d, *J* 8.7, 1H, C(5)*H*), 7.80 (d, *J* 8.9, 1H, C(4')*H*), 7.69 (d, *J* 8.7, 1H, C(5')*H*), 7.59 (dd, *J* 8.7, 1.9, 1H, C(6)*H*), 7.41 (dd, *J* 8.7, 1.9, 1H, C(6')*H*), 7.34 (d, *J* 8.9, 1H, C(3)*H*), 7.32 (d, *J* 1.9, 1H, C(8)*H*), 7.21 (d, *J* 8.9, 1H, C(3')*H*), 7.19-7.09 (m, 12H, *p*-ArC*H, p'*-ArC*H*, 2 × *m*-ArC*H,* 2 × *m'*-ArC*H*), 7.08 (d, *J* 1.9, 1H, C(8')*H*), 6.98-6.96 (m, 2H, 2 × *o*-ArC*H*), 6.82-6.81 (m, 2H, 2 × *o'*-ArC*H*), 5.22 (s, 1H, -O*H*), 4.87 (s, 1H, -C*H*Ph_2); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 172.0 (*C*=O), 152.8 (*C*(2')), 149.0 (*C*(2)), 137.4 (*i/i'*-Ar*C*H), 137.2 (*i/i'*-Ar*C*H), 134.7 (*C*(8a), *C*(8a')), 131.3 (*C*(4)), 131.0 (*C*(4a)), 130.9 (*C*(4')), 130.3 (*C*(6)), 130.2 (*C*(5)), 130.0 (*C*(5')), 128.6 (2 × *m*-Ar*C*H, 2 × *m'*-Ar*C*H), 128.5 (2× *o/o'*-Ar*C*H), 128.3 (2 × *o/o'*-Ar*C*H), 127.7 (*C*(4a')), 127.6 (*C*(8)), 127.5 (*p'*-Ar*C*H, *p'*-Ar*C*H), 126.4 (*C*(8')), 127.3 (*C*(6')), 126.3 (*C*(8')), 122.6 (*C*(7')), 122.2 (*C*(1)), 122.1 (*C*(3)), 121.7 (*C*(7)), 119.1 (*C*(3')), 112.8 (*C*(1')), 56.7 (-*C*H-); HRMS (ASAP$^+$) $C_{34}H_{22}Br_2O_3$ $[M+H]^+$ found 637.0005, requires 637.0014 (−1.4 ppm)

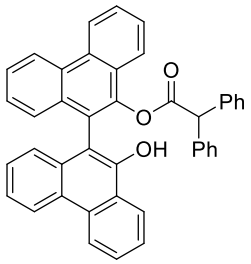
2'-Hydroxy-7,7'-dimethoxy-[1,1'-binaphthalen]-2-yl 2,2-diphenylacetate 65c



Following general procedure C: 7,7'-dimethoxy-[1,1'-binaphthalene]-2,2'-diol (69.3 mg, 0.2 mmol) and (+)-BTM (0.5 mg, 0.002 mmol) were added into chloroform (4 mL, 0.05 M) at

room temperature, giving a clear solution. 2,2-Diphenylacetic pivalic anhydride (32.6 mg, 0.11 mmol) was added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The solution was diluted with EtOAc (10 mL), washed with HCl (1 M. 2 × 10 mL), $NaHCO_3$ (sat., 2 × 10 mL) and brine (10 mL). The organic layer was dried over $MgSO_4$, filtered and concentrated *in vacuo* to give a pale brown oil, which was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 20% over 40 CV) to give 2'-hydroxy-7,7'-dimethoxy-[1,1'-binaphthalen]-2-yl 2,2-diphenylacetate (51.8 mg, 47.9%) as white solids; R_f = 0.25 (20% EtOAc in petroleum ether); mp 142-144 °C; $[\alpha]_D^{20}$ −19.8 (c = 0.1 in $CHCl_3$); **Chiral HPLC analysis**: ChiralCel OD-H (2% *i*PrOH:hexane, flow rate 1.0 mL min^{-1}, 211 nm, 30 °C), t_R major: 37.1 min, t_R minor: 31.0 min, 93.5:6.5 er; ν_{max} (ATR): 3510 (O-H), 1748 (C=O), 1620 (C=C), 1113 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H 7.94 (d, *J* 8.8, 1H, C(4)*H*), 7.85 (d, *J* 8.9, 1H, C(5)*H*), 7.78 (d, *J* 8.9, 1H, C(4')*H*), 7.74 (d, *J* 8.9, 1H, C(5')*H*), 7.18-7.09 (m, 9H, C(3)*H*, C(6)*H, p*-ArC*H, p'*-ArC*H,* 2 × *m*-ArC*H,* 2 × *m'*-ArC*H,* C(3')*H*), 6.99 (dd, *J* 8.9, 2.5, 1H, C(6')*H*), 6.88-6.83 (app. 2 × d, *J* 7.5, 4H, *o*-ArC*H,* 2 × *o'*-ArC*H*), 6.57 (d, *J* 2.4, 1H, C(8)*H*), 6.35 (d, *J* 2.4, 1H, C(8)*H*), 5.09 (s, 1H, -O*H*), 4.85 (s, 1H, -C*H*Ph_2), 3.55 (s, 1H, -OCH_3), 3.49 (s, 1H, -OCH_3); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 172.9 (*C*=O), 159.1 (*C*(7)), 158.5 (*C*(7')), 152.3 (*C*(2')), 148.8 (*C*(2)), 137.8 (*i*-Ar*C*H/ *i'*-Ar*C*H), 137.6 (*i*-Ar*C*H/ *i'*-Ar*C*H), 135.0 (*C*(8a)), 134.9 (*C*(8a')), 130.6 (*C*(4)), 0.3 (*C*(4')), 130.0 (*C*(5)), 130.0 (*C*(5')), 128.6 (2 × *m*-Ar*C*H, 2 × *m'*-Ar*C*H), 128.5 (2 × *o*-Ar*C*H/ 2× *o'*-Ar*C*H), 128.5 (2 × *o*-Ar*C*H/2 × *o'*-Ar*C*H), 127.9 (*C*(1)), 127.3 (*p*-Ar*C*H/ *p'*-Ar*C*H), 127.2 (*p*-Ar*C*H/ *p'*-Ar*C*H), 124.7 (*C*(1')), 121.2 (*C*(4a)), 119.1 (*C*(3)/ *C*(6)), 119.0 (*C*(3)/ *C*(6)), 115.9 (*C*(6')), 115.7 (*C*(3')), 113.4 (*C*(4a)), 104.2 (*C*(8)), 103.7 (*C*(8')), 56.9 (-*C*H-), 55.3 (-O*C*H_3), 55.2 (-O*C*H_3); HRMS (NSI$^+$) $C_{36}H_{28}O_5$ $[M+H]^+$ found 541.2005, requires 541.2010 (−0.8 ppm)

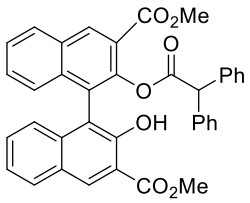
10'-Hydroxy-[9,9'-biphenanthren]-10-yl 2,2-diphenylacetate 65e



Following general procedure C: [9,9'-biphenanthrene]-10,10'-diol (77.3 mg, 0.2 mmol) and (+)-BTM (5 mg, 0.02 mmol) were added into chloroform (4 mL, 0.05 M) at room temperature, giving a clear solution. 2,2-Diphenylacetic pivalic anhydride (32.6 mg, 0.11 mmol) was added to the previous solution. The resulted clear solution was left stirring for 18 hours at room

temperature. The solvent was removed *in vacuo* and the residue was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 10% over 30 CV) to give 10'-hydroxy-[9,9'-biphenanthren]-10-yl 2,2-diphenylacetate (35.0 mg, 45.3%) as yellow solids. R_f = 0.44 (20% EtOAc in petroleum ether); mp 242-244 °C; $[\alpha]_D^{20}$ −19.3 (c = 0.1 in $CHCl_3$); Chiral HPLC analysis, ChiralCel OD-H (5% *i*PrOH:hexane, flow rate 1.0 mL min^{-1}, 211 nm, 30 °C), t_R major: 18.8 min, t_R minor: 23.0 min, 82:18 er; ν_{max} (ATR): 3055 (C-H), 1738 (C=O), 1449 (C=C), 1119 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 8.82 (d, *J* 8.4, 1H, Ar*H*), 8.79 (d, *J* 8.4, 2H, Ar*H*), 8.71 (d, *J* 8.4, 1H, Ar*H*), 8.41 (d, *J* 8.1, 1H, Ar*H*), 7.84-7.80 (m, 1H, Ar*H*), 7.79-7.75 (m, 1H, Ar*H*), 7.74-7.70 (m, 1H, Ar*H*), 7.68-7.65 (m, 1H, Ar*H*), 7.59-7.47 (m, 3H, Ar*H*), 7.41-7.37 (m, 2H, Ar*H*), 7.33-7.30 (m, 1H, Ar*H*), 7.20-6.56 (m, 11H, Ar*H*), 5.85 (s, 1H, -O*H*), 5.01 (s, 1H, -C*H*-); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 137.4, 137.0, 132.1, 131.9, 131.2, 129.8, 128.8, 128.2, 128.0, 127.8, 127.5, 127.4, 127.3, 127.1, 126.8, 126.7, 126.4, 124.5, 123.9, 123.2, 123.1, 122.8, 122.7, 122.3, 56.6 (-*C*H-); HRMS (NSI^+) $C_{42}H_{28}O_3$ $[M+H]^+$ found 581.2112, requires 581.2111 (+0.1 ppm)

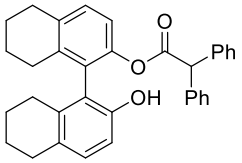
Dimethyl 2-(2,2-diphenylacetoxy)-2'-hydroxy-[1,1'-binaphthalene]-3,3'-dicarboxylate 65f



Following general procedure B: 6,6'-dibromo-[1,1'-binaphthalene]-2,2'-diol (88.8 mg, 0.2 mmol) and DMAP (2.4 mg, 0.02 mmol) were added into CH_2Cl_2 (4 mL, 0.05 M) at room temperature, giving a clear solution. Diphenylacetic anhydride (121.8 mg, 0.3 mmol) and *i*Pr_2NEt (27.9 mg, 35 µL, 0.2 mmol) were added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The concentrated *in vacuo* and the residue was purified by column chromatography (Isolera 4, CH_2Cl_2 in petrol, 0% -> 50%) to give dimethyl 2-(2,2-diphenylacetoxy)-2'-hydroxy-[1,1'-binaphthalene]-3,3'-dicarboxylate (30.1 mg, 25%) as yellow solids. R_f = 0.18 (20% EtOAc in petroleum ether); mp 172-174 °C; ν_{max} (ATR): 3181 (O-H), 2951 (C-H), 1721 (C=O), 1680 (C=O), 1446 (C=C), 1211 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H 10.47 (s, 1H, -O*H*), 8.76 (s, 1H, C(4)*H*), 8.46 (s, 1H, C(4')*H*), 8.02 (d, *J* 8.2, 1H, C(5)*H*), 7.82 (d, *J* 8.2, 1H, C(5')*H*), 7.52-7.48 (m, 1H, C(6)*H*), 7.37-7.28 (m, 3H, C(7)*H,* C(6')*H,* C(7')*H*), 7.15-7.05 (m, 6H, C(8)*H*, *p*-ArC*H,* 2 × *m*-ArC*H,* C(8')*H, p'*-ArC*H*), 7.02 (app. s, br, 2H, 2 × *o*-ArC*H*), 6.06 (t, *J* 7.9, 2H, 2 × *m'*-ArC*H*), 6.72 (app. s, br, 2H, 2 × *o'*-ArC*H*), 4.98 (s,

1H, -C*H*Ph$_2$), 4.06 (s, 1H, -C*H$_3$'*), 3.63 (s, 1H, -C*H$_3$*); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 170.3 (*C*=O), 170.2 (-CO_2Me'), 165.6 (-CO_2Me), 153.4 (*C*(2')), 145.2 (*C*(2)), 138.3 (*i*-Ar*C*H/ *i'*-Ar*C*H), 137.9 (*i*-Ar*C*H/ *i'*-Ar*C*H), 137.0 (*C*(8a')), 135.5 (*C*(8a)), 134.2 (*C*(4)), 133.5 (*C*(4')), 131.1 (*C*(4a)), 129.6 (*C*(5)), 129.5 (*C*(5')), 129.1 (*C*(7)), 128.7 (2 × *o/o'*-Ar*C*H), 128.4 (2 × *m*-Ar*C*H), 128.3 (2 × *m'*-Ar*C*H), 128.2 (2 × *o/o'*-Ar*C*H), 127.0 (*p*-Ar*C*H), 126.9 (*C*(4a')), 126.8 (*C*(3)), 126.8 (*p'*-Ar*C*H), 126.6 (*C*(6)), 125.9 (*C*(8)), 125.2 (*C*(8')), 124.1 (*C*(6')), 122.7 (*C*(1)), 115.5 (*C*(1')), 113.7 (*C*(3')), 56.3 (-*C*H-), 52.8 (-*C*H$_3$'), 52.3 (-*C*H$_3$); HRMS (NSI$^+$) $C_{38}H_{28}O_7$ $[M+H]^+$ found 614.2168, requires 614.2173 (−0.9 ppm)

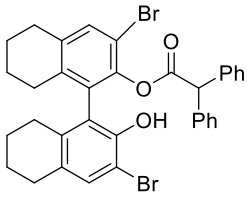
2'-Hydroxy-5,5',6,6',7,7',8,8'-octahydro-[1,1'-binaphthalen]-2-yl 2,2-diphenylacetate 69a



Following general procedure C: 5,5',6,6',7,7',8,8'-Octahydro-1,1'-bi-2-naphthol (58.9 mg, 0.2 mmol) and (+)-BTM (5.0 mg, 0.02 mmol) were added into chloroform (4 mL, 0.05 M) at room temperature, giving a clear solution. 2,2-Diphenylacetic pivalic anhydride (32.6 mg, 0.11 mmol) was added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The solution was diluted with EtOAc (10 mL), washed with HCl (1 M. 2 × 10 mL), $NaHCO_3$ (sat., 2 × 10 mL) and brine (10 mL). The organic layer was dried over $MgSO_4$, filtered and concentrated *in vacuo* to give a pale brown oil, which was purified by column chromatography (Isolera 4, Et_2O in petrol, 0% -> 20% over 40 CV) to give 2'-hydroxy-5,5',6,6',7,7',8,8'-octahydro-[1,1'-binaphthalen]-2-yl 2,2-diphenylacetate (32.6 mg, 33.4%) as white solids; R_f = 0.17 (10% Et_2O in petroleum ether); mp 157-158 °C; $[\alpha]_D^{20}$ −51.6 (c = 0.1 in $CHCl_3$); **Chiral HPLC analysis**; ChiralPak AD-H (5% *i*PrOH:hexane, flow rate 1.0 mL min^{-1}, 211 nm, 30 °C), t_R major: 13.3 min, t_R minor: 18.8 min, 86:14 er; ν_{max} (ATR): 3512 (O-H), 2922 (C-H), 1746 (C=O), 1470 (C=C), 1130 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 7.23-7.17 (m, 6H, *p*-Ar*H*, *p'*-Ar*H*, 2 × *m*-Ar*H,* 2 × *m'*-Ar*H*), 7.12 (d, *J* 8.3, 1H, C(4)*H*), 7.04-7.01 (m, 2H, 2 × *o'*-Ar*H*), 6.98 (d, *J* 8.3, 1H, C(4')*H*), 6.93-6.91 (m, 2H, 2 × *o*-Ar*H*), 6.81 (d, *J* 8.3, 1H, C(3)*H*), 6.76 (d, *J* 8.3, 1H, C(3')*H*), 4.97 (s, 1H, -C*H*-), 4.87 (s, 1H, -O*H*), 2.81-2.78 (m, 2H, C(5)*H$_2$*), 2.75-2.63 (m, 2H, C(5')*H$_2$*), 2.40-2.34 (m, 1H, C(8)*H$_{2a}$*), 2.15-2.05 (m, 2H, C(8)*H$_{2b}$*, C(8')*H$_{2a}$*), 1.94-1.88 (C(8')*H$_{2b}$*), 1.76-1.47 (m, 8H, C(6)*H$_2$*, C(6')*H$_2$*, C(7)*H$_2$*, C(7')*H$_2$*); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 176.4 (*C*=O), 150.8 (*C*(2')), 147.2 (*C*(2)), 138.6 (*C*(8a')), 138.0 (*i*-Ar*C*H), 138.0 (*i'*-Ar*C*H), 136.5 (*C*(4a)), 136.1 (*C*(8a)), 130.5 (*C*(4)), 130.3 (*C*(4')), 129.7 (*C*(1)), 128.7 (2 × *m/m'/o'*-Ar*C*H),

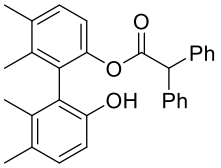
128.7 (2 × *m/m'/o'*-Ar*C*H), 128.6 (2 × *m/m'/o'*-Ar*C*H), 128.5 (2 × *o*-Ar*C*H), 128.4 (*C*(4a')), 127.3 (*p'*-Ar*C*H), 127.2 (*p*-Ar*C*H), 122.5 (*C*(1')), 119.2 (*C*(3)), 114.3 (*C*(3')), 57.1 (-*C*H-), 29.8 (*C*(5)), 29.4 (*C*(5')), 27.3 (*C*(8')), 27.0 (*C*(8)), 23.1 (*C*(6/ 6'/ 7/ 7')), 23.1 (*C*(6/ 6'/ 7/ 7')), 22.9 (*C*(6/ 6'/ 7/ 7')), 22.8 (*C*(6/ 6'/ 7/ 7')); HRMS (NSI$^+$) $C_{34}H_{32}O_3$ $[M+H]^+$ found 489.2424, requires 489.2424 (+0 ppm)

3,3'-Dibromo-2'-hydroxy-5,5',6,6',7,7',8,8'-octahydro-[1,1'-binaphthalen]-2-yl 2,2-diphenylacetate 69b



Following general procedure B: 3,3'-Dibromo-5,5',6,6',7,7',8,8'-octahydro-[1,1'-binaphthalene]-2,2'-diol (90.4 mg, 0.2 mmol) and DMAP (2.4 mg, 0.02 mmol) were added into CH_2Cl_2 (4 mL, 0.05 M) at room temperature, giving a clear solution. Diphenylacetic anhydride (121.8 mg, 0.3 mmol) and *i*Pr_2NEt (27.9 mg, 35 µL, 0.2 mmol) were added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The concentrated *in vacuo* and the residue was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 8% over 35 CV) to give 3,3'-dibromo-2'-hydroxy-5,5',6,6',7,7',8,8'-octahydro-[1,1'-binaphthalen]-2-yl 2,2-diphenylacetate (58 mg, 45%) as yellow gum. R_f = 0.31 (20% EtOAc in petroleum ether); ν_{max} (ATR): 3501 (O-H), 2932 (C-H), 1759 (C=O), 1447 (C=C), 1113 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H 7.39-6.88 (m, 12H, Ar*H*), 5.23 (s, 1H, -O*H*), 5.06 (s, 1H, -C*H*Ph_2), 2.80-1.50 (m, 16H, 8 × -CH_2); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 143.9, 133.2, 133.3, 131.4, 128.9, 128.7, 128.6, 128.4, 127.4, 127.3, 56.5 (-*C*HPh_2), 29.6 (-*C*H_2), 29.1 (-*C*H_2), 27.1 (-*C*H_2), 26.8 (-*C*H_2), 22.8 (-*C*H_2), 22.7 (-*C*H_2), 22.7 (-*C*H_2), 22.5 (-*C*H_2); HRMS (NSI$^+$) $C_{34}H_{30}Br_2O_3$ $[M+H]^+$ found 662.0896, requires 662.0900 (−0.6 ppm)

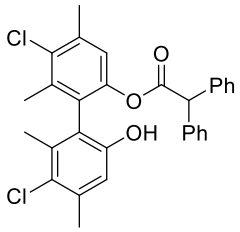
6'-Hydroxy-2',3',5,6-tetramethyl-[1,1'-biphenyl]-2-yl 2,2-diphenylacetate 69d



Following general procedure C: 5,5',6,6'-tetramethyl-[1,1'-biphenyl]-2,2'-diol (48.5 mg, 0.2 mmol) and (+)-BTM (0.5 mg, 0.002 mmol) were added into chloroform (4 mL, 0.05 M) at room temperature, giving a clear solution. 2,2-Diphenylacetic pivalic anhydride (32.6 mg,

0.11 mmol) was added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The solvent was removed *in vacuo* and the residue was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 20% over 35 CV), to give 6'-hydroxy-2',3',5,6-tetramethyl-[1,1'-biphenyl]-2-yl 2,2-diphenylacetate (34.6 mg, 39.6%) as a colorless gum. R_f = 0.38 (20% EtOAc in petroleum ether); $[\alpha]_D^{20}$ −43.1 (c = 0.1 in $CHCl_3$); Chiral HPLC analysis, ChiralPak AD-H (2% *i*PrOH:hexane, flow rate 1.0 mL min^{-1}, 211 nm, 30 °C), t_R major: 55.6 min, t_R minor: 43.5 min, 93.5:6.5 er; ν_{max} (ATR): 3503 (O-H), 3028 (C-H), 1748 (C=O), 1454 (C=C), 1123 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 7.23-7.20 (m, 7H, C(4)*H*, *p*-Ar*H, p'*-Ar*H,* 2 × *m*-Ar*H,* 2 × *m'*-Ar*H*), 7.05 (d, *J* 8.2, 1H, C(4')*H*), 7.01-6.99 (m, 2H, 2 × *o*-Ar*H*), 6.94-6.92 (m, 2H, 2 × *o'*-Ar*H*), 6.84 (d, *J* 8.2, 1H, C(3)*H*), 6.75 (d, *J* 8.2, 1H, C(5')*H*), 4.93(m, 1H, -C*H*-), 4.71 (s, 1H, -O*H*), 2.31 (s, 3H, -C(5)-CH_3), 2.17 (s, 3H, -C(3')-CH_3), 1.89 (s, 3H, -C(6)-CH_3), 1.67 (s, 3H, -(2')-CH_3); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 172.2 (*C*=O), 151.3 (*C*(6')), 147.7 (*C*(2)), 138.5 (*C*(6)), 138.0 (*i*-Ar*C*H), 138.0 (*i'*-Ar*C*H) 136.0 (*C*(2')), 135.7 (*C*(5)), 130.8 (*C*(4)), 130.5 (*C*(4')), 129.0 (*C*(3')), 128.8 (*C*(1)), 128.7 (2 × *m*-Ar*C*H), 128.7 (2 × *m'*-Ar*C*H), 128.6 (2 × *o*-Ar*C*H), 128.5 (2 × *o'*-Ar*C*H), 127.3 (*p*-Ar*C*H), 127.2 (*p'*-Ar*C*H), 123.6 (*C*(1')), 119.3 (*C*(3)), 113.7 (*C*(5')), 57.0 (-*C*H-), 20.5 (-C(5)-*C*H_3), 20.1 (-C(3')-*C*H_3), 16.5 (-C(2')-*C*H_3), 16.3 (-C(6)-*C*H_3); HRMS (NSI$^+$) $C_{30}H_{28}O_3$ $[M+H]^+$ found 454.2374, requires 454.2377 (−0.6 ppm)

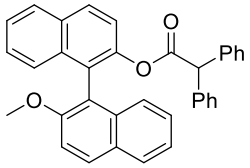
3',5-Dichloro-6'-hydroxy-2',4,4',6-tetramethyl-[1,1'-biphenyl]-2-yl 2,2-diphenylacetate 69e



Following general procedure C: 5,5'-dichloro-4,4',6,6'-tetramethyl-[1,1'-biphenyl]-2,2'-diol (62.2 mg, 0.2 mmol) and (+)-BTM (0.5 mg, 0.002 mmol) were added into chloroform (4 mL, 0.05 M) at room temperature, giving a clear solution. 2,2-Diphenylacetic pivalic anhydride (32.6 mg, 0.11 mmol) was added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The solvent was removed *in vacuo* and the residue was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 10% over 20 CV then 10% -> 10% over 10 CV), to give 3',5-dichloro-6'-hydroxy-2',4,4',6-tetramethyl-[1,1'-biphenyl]-2-yl 2,2-diphenylacetate (40.5 mg, 40.1%) as a colorless gum. R_f = 0.54 (20% EtOAc in petroleum ether); $[\alpha]_D^{20}$ +15.8 (c = 0.1 in $CHCl_3$); Chiral HPLC analysis, ChiralCel OD-H (0.1% *i*PrOH:hexane, flow rate 1.0 mL min^{-1}, 211 nm, 30 °C), t_R major: 59.1 min, t_R minor:

36.7 min, 81.5:18.5 er; ν_{max} (ATR): 3480 (O-H), 2924 (C-H), 1751 (C=O), 1454 (C=C), 1123 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 7.25-7.21 (m, 6H, *p*-Ar*H, p'*-Ar*H,* 2 × *m*-Ar*H,* 2 × *m'*-Ar*H*), 7.06-7.05 (m, 2H, 2 × *o*-Ar*H*), 7.00-6.98 (m, 2H, 2 × *o'*-Ar*H*), 6.89 (s, 1H, C(3)*H*), 6.66 (s, 1H, C(5')*H*), 4.95 (m, 1H, -C*H*-), 4.73 (s, 1H, -O*H*), 2.43 (s, 3H, -C(4)-CH_3), 2.36 (s, 3H, -C(4')-CH_3), 2.04 (s, 3H, -C(6)-CH_3), 1.84 (s, 3H, -(2')-CH_3); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 172.0 (*C*=O), 151.2 (*C*(6')), 147.4 (*C*(2)), 138.5 (*C*(6)), 138.2 (*C*(4)), 137.5 (*i*-Ar*C*H), 137.5 (*i'*-Ar*C*H), 137.5 (*C*(2')), 135.6 (*C*(4')), 133.6 (*C*(5)), 128.7 (2 × *m*-Ar*C*H), 128.7 (2 × *m'*-Ar*C*H), 128.5 (2 × *o*-Ar*C*H), 128.4 (2 × *o'*-Ar*C*H), 127.5 (*p*-Ar*C*H), 127.4 (*C*(3')), 127.4 (*p'*-Ar*C*H), 127.0 (*C*(1)), 122.1 (*C*(3)), 121.8 (*C*(1')), 116.7 (*C*(5')), 56.9 (-*C*H-), 21.7 (-C(4)-*C*H_3), 21.2 (-C(4')-*C*H_3), 17.8 (-C(6)-*C*H_3), 17.8 (-C(2')-*C*H_3); HRMS (ASAP$^+$) $C_{30}H_{26}Cl_2O_3$ $[M+H]^+$ found 505.1335, requires 505.1337 (−0.4 ppm)

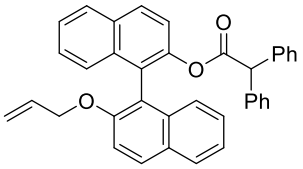
2'-Methoxy-[1,1'-binaphthalen]-2-yl 2,2-diphenylacetate 72a



Following general procedure C: 2'-methoxy-[1,1'-binaphthalen]-2-ol (60.1 mg, 0.2 mmol) and (+)-BTM (2.5 mg, 0.01 mmol) were added into chloroform (4 mL, 0.05 M) at room temperature, giving a clear solution. 2,2-Diphenylacetic pivalic anhydride (32.6 mg, 0.11 mmol) was added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The solvent was removed *in vacuo* and the residue was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 10% over 30 CV) to give 2'-methoxy-[1,1'-binaphthalen]-2-yl 2,2-diphenylacetate (18.1 mg, 18.3%) as a colorless gum. R_f = 0.44 (20% EtOAc in petroleum ether); $[\alpha]_D^{20}$ +4.5 (c = 0.1 in $CHCl_3$); Chiral HPLC analysis, ChiralPak AD-H (5% *i*PrOH:hexane, flow rate 1.0 mL min^{-1}, 211 nm, 30 °C), t_R major: 26.8 min, t_R minor: 38.7 min, 62:38 er; ν_{max} (ATR): 3061 (C-H), 1755 (C=O), 1454 (C=C), 1115 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 7.98-7.92 (m, 3H, C(4)*H,* C(4')*H,* C(5)*H*), 7.88 (d, *J* 8.2, 1H, C(5')*H*), 7.46-7.43 (m, 1H, C(6)*H*), 7.39 (d, *J* 8.9, 1H, C(3)*H*), 7.37-7.34 (m, 1H, C(6')*H*), 7.29-7.26 (m, 2H, C(3')*H,* C(7)*H*), 7.24-7.20 (m, 2H, C(7')*H,* C(8)*H*), 7.19-7.12 (m, 5H, C(8')*H, p*-Ar*H, p'*-Ar*H,* 2 × *m*-Ar*H*), 7.09-7.05 (m, 2H, 2 × *m'*-Ar*H*), 6.94-6.92 (m, 2H, 2 × *o*-Ar*H*), 6.80-6.78 (m, 2H, 2 × *o'*-Ar*H*), 4.82 (s, 1H, -C*H*-), 3.56 (s, 3H, -CH_3); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 170.8 (*C*=O), 155.0 (*C*(2')), 147.0 (*C*(2)), 138.2 (*i*-Ar*C*H/ *i'*-Ar*C*H), 138.0 (*i'*-Ar*C*H/ *i*-Ar*C*H), 133.8 (*C*(8a), *C*(8a')), 132.0 (*C*(4a)), 130.2 (*C*(4')), 129.2 (*C*(4)), 129.1 (*C*(4a')), 128.7 (2× *o*-Ar*C*H), 128.5 (2×

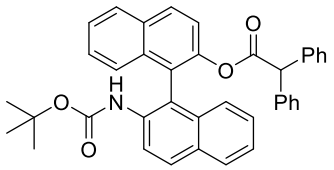
m-Ar*C*H, 2× *m'*-Ar*C*H), 128.3 (2× *o'*-Ar*C*H), 128.2 (*C*(5)), 127.9 (*C*(5')), 127.2 (*p*-Ar*C*H), 127.0 (*p'*-Ar*C*H), 126.8 (*C*(7')/ *C*(7)), 126.5 (*C*(7)/ *C*(7')), 126.3 (*C*(8)), 125.7 (*C*(6)), 125.5 (*C*(8')), 125.4 (*C*(1)), 123.8 (*C*(6')), 121.8 (*C*(3)), 117.5 (*C*(1')), 113.8 (*C*(3')), 56.9 (-*C*H-), 56.6 (-*C*H_3); HRMS (NSI$^+$) $C_{35}H_{26}O_3$ $[M+NH_4]^+$ found 512.2214, requires 512.2220 (−1.2 ppm)

2'-(Allyloxy)-[1,1'-binaphthalen]-2-yl 2,2-diphenylacetate 72b



Following general procedure B: 2'-(allyloxy)-[1,1'-binaphthalen]-2-ol (65.3 mg, 0.2 mmol) and DMAP (2.4 mg, 0.02 mmol) were added into CH_2Cl_2 (4 mL, 0.05 M) at room temperature, giving a clear solution. Diphenylacetic anhydride (121.8 mg, 0.3 mmol) and *i*Pr_2NEt (27.9 mg, 35 µL, 0.2 mmol) were added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The concentrated *in vacuo* and the residue was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 10% over 20 CV) to give 2'-(allyloxy)-[1,1'-binaphthalen]-2-yl 2,2-diphenylacetate (107 mg, 100%) as colorless gum. R_f = 0.5 (20% EtOAc in petroleum ether); ν_{max} (ATR): 3059 (C-H), 1751 (C=O), 1591 (C=C), 1262 (C-O), 1113 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 7.95 (d, *J* 8.9, 1H, C(4)*H*), 7.93-8.89 (m, 2H, C(5)*H,* C(4')*H*), 7.86 (d, *J* 8.1, 1H, C(5')*H*), 7.46-7.42 (m, 1H, C(6)*H*), 7.37 (d, *J* 8.9, 1H, C(3)*H*), 7.37-7.34 (m, 1H, C(6')*H*), 7.27-7.10 (m, 9H, C(3')*H,* C(7)*H,* C(7')*H,* C(8)*H,* C(8')*H, p*-Ar*H, p'*-Ar*H,* 2 × *m*-Ar*H*), 7.07-7.03 (m, 2H, 2 × *m'*-Ar*H*), 6.93-6.90 (m, 2H, 2 × *o*-Ar*H*), 6.76-6.74 (m, 2H, 2 × *o'*-Ar*H*), 5.69-5.61 (m, 1H, -C*H*=CH_2), 4.96-4.92 (m, 2H, -CH=CH_2), 4.81 (s, 1H, -C*H*-), 4.27 (ddt, *J* 13.9, 5.0, 1.7, 2H, -CH_2-); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 170.7 (*C*=O), 154.1 (*C*(2')), 146.9 (*C*(2)), 138.1 (*i*-Ar*C*H/ *i'*-Ar*C*H), 138.0 (*i'*-Ar*C*H/ *i*-Ar*C*H), 133.9 (*C*(8a)/*C*(8a')), 133.8 (*C*(8a')/*C*(8a)), 133.7 (-*C*H=CH_2), 131.9 (*C*(4a)), 130.0 (*C*(4')), 129.3 (*C*(4a')), 129.1 (*C*(4)), 128.7 (2 × *o*-Ar*C*H), 128.5 (2 × *m*-Ar*C*H, 2 × *m'*-Ar*C*H), 128.3 (2 × *o'*-Ar*C*H), 128.2 (*C*(5)), 127.9 (*C*(5')), 127.2 (*p*-Ar*C*H), 127.0 (*p'*-Ar*C*H), 126.8 (*C*(7')), 126.5 (*C*(7)), 126.3 (*C*(8)), 125.6 (*C*(6), *C*(8')), 125.4 (*C*(1)), 123.9 (*C*(6')), 121.7 (*C*(3)), 118.3 (*C*(1')), 116.6 (-CH=*C*H_2), 115.5 (*C*(3')), 69.9 (-*C*H_2-), 56.9 (-*C*H-); HRMS (NSI$^+$) $C_{37}H_{28}O_3$ $[M+NH_4]^+$ found 538.2369, requires 538.2377 (−1.4 ppm)

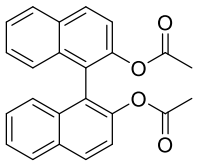
2'-((*Tert*-butoxycarbonyl)amino)-[1,1'-binaphthalen]-2-yl 2,2-diphenylacetate 77



Following general procedure C: Crude *tert*-butyl (2'-hydroxy-[1,1'-binaphthalen]-2-yl)carbamate (64.6 mg, 0.2 mmol) and (+)-BTM (2.5 mg, 0.01 mmol) were added into chloroform (4 mL, 0.05 M) at room temperature, giving a clear solution. 2,2-Diphenylacetic pivalic anhydride (32.6 mg, 0.11 mmol) was added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The solvent was removed *in vacuo* and the residue was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 8% over 35 CV) to give 2'-((tert-butoxycarbonyl)amino)-[1,1'-binaphthalen]-2-yl 2,2-diphenylacetate (42.6 mg, 36.7%) as a black gum. R_f = 0.24 (10% EtOAc in petroleum ether); Chiral HPLC analysis, ChiralPak AD-H (2% *i*PrOH:hexane, flow rate 1.0 mL min^{-1}, 211 nm, 30 °C), t_R major: 16.4 min, t_R minor: 62.2 min, 88.5:11.5 er; ν_{max} (ATR): 3414 (C=O), 2978 (C-H), 1726 (C=O), 1495 (C=C), 1155 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 8.02 (d, *J* = 8.8 Hz, 1H, C(4)*H*), 7.94 (d, *J* = 8.0 Hz, 1H, C(5)*H*), 7.91 (d, *J* = 9.2 Hz, 1H, C(4')*H*), 7.85 (d, *J* = 8.1 Hz, 1H, C(5')*H*), 7.50-7.47 (m, 1H, C(6)*H*), 7.39-7.35 (m, 1H, C(6')*H*), 7.32 (d, *J* = 8.7 Hz, 1H, C(3)*H*), 7.32-7.29 (m, 1H, C(7)*H*), 7.22-7.07 (m, 9H, C(8)*H*, C(7')*H*, C(3')*H*, *p*-Ar*H, p'*-Ar*H,* 2 × *m*-Ar*H,* 2 × *m'*-Ar*H*), 7.02 (d, *J* = 8.5 Hz, 1H, C(8')*H*), 6.87-6.85 (m, 2H, 2 × *o*-Ar*H*), 6.75-6.73 (m, 2H, 2 × *o'*-Ar*H*), 6.29 (s, 1H, -N*H*-), 4.81 (s, 1H, -O*H*), 1.28 (s, 9H, 3 ×-CH_3); **^{13}C{^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 171.3 (-*C*OCHPh$_2$), 153.1 (-*C*ONHAr), 147.3 (*C*(2)), 137.6 (*i/i'*-Ar*C*H), 135.2 (*C*(2')), 133.1 (*C*(8a)), 132.5 (*C*(8a')), 132.2 (*C*(4a)), 130.6 (*C*(4)), 130.6 (*C*(4a')), 129.3 (*C*(4')), 128.6 (2 × *m*-Ar*C*H, 2 × *m'*-Ar*C*H), 128.5 (2 × *o*-Ar*C*H), 128.4 (*C*(5), 2 × *m'*-Ar*C*H), 128.0 (*C*(5')), 127.5 (*C*(7)), 127.3 (*p*-Ar*C*H), 127.2 (*p'*-Ar*C*H), 126.6 (*C*(7')), 126.3 (*C*(6)), 125.9 (*C*(8)), 125.4 (*C*(8')), 124.9 (*C*(1), *C*(1')), 124.8 (*C*(6')), 121.5 (*C*(3), *C*(3')), 80.2 (-*C*(CH_3)$_3$), 56.7 (-*C*H-), 28.2 (3 × -*C*H_3); HRMS waiting for data

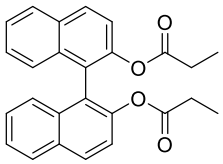
Preparation of diesters:

[1,1'-Binaphthalene]-2,2'-diyl diacetate



Following general procedure B: BINOL (57.3 mg, 0.2 mmol) and DMAP (2.4 mg, 0.02 mmol) were added into CH_2Cl_2 (4 mL, 0.05 M) at room temperature, giving a clear solution. Acetic anhydride (30.6 mg, 28 µL, 0.3 mmol) and *i*Pr_2NEt (27.9 mg, 35 µL, 0.2 mmol) were added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The solution was diluted with EtOAc (10 mL), washed with HCl (1 M. 2 × 10 mL), $NaHCO_3$ (sat., 2 × 10 mL) and brine (10 mL). The organic layer was dried over $MgSO_4$, filtered and concentrated *in vacuo*, to give pale brown gum, which was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 20% over 20 CV) to give [1,1'-binaphthalene]-2,2'-diyl diacetate (16.1 mg, 22%) as white solids; R_f = 0.31 (20% EtOAc in petroleum ether); mp 104-105.5 °C; ν_{max} (ATR): 2922 (C-H), 1753 (C=O), 1504 (C=C), 1186 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 8.00 (d, *J* 8.9, 2H, C(4)*H,* C(4')*H*), 7.93 (d, *J* 8.3, 2H, C(5)*H,* C(5')*H*), 7.48-7.45 (m, 2H, C(6)*H,* C(6')*H*), 7.43 (d, *J* 8.9, 2H, C(3)*H,* C(3')*H*), 7.30-7.27 (m, 2H, C(7)*H,* C(7')*H*), 7.18 (d, *J* 8.5, 2H, C(8)*H,* C(8')*H*), 1.86 (s, 6H, 2 × -C*H*$_3$); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 169.6 (2 × *C*=O), 146.9 (*C*(2), *C*(2')), 133.5 (*C*(8a), *C*(8a')), 131.7 (*C*(4a), *C*(4a')), 129.7 (*C*(4), *C*(4'), 128.2 (*C*(5), *C*(5')), 126.9 (*C*(7), *C*(7')), 126.3 (*C*(8), *C*(8')), 125.9 (*C*(6), *C*(6')), 123.5 (*C*(1), *C*(1')), 122.0 (*C*(3), *C*(3')), 20.8 (2 × -*C*H_3); HRMS (ASAP$^+$) $C_{24}H_{18}O_4$ $[M+H]^+$ found 371.1285, requires 371.1283 (+0.5 ppm). Data in agreement with literature.[104]

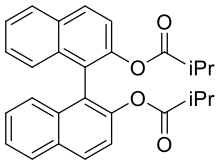
[1,1'-Binaphthalene]-2,2'-diyl dipropionate



Following general procedure B: BINOL (57.3 mg, 0.2 mmol) and DMAP (2.4 mg, 0.02 mmol) were added into tert-Amyl alcohol (4 mL, 0.05 M) at room temperature, giving a clear solution. Propionic anhydride (67.9 mg, 0.3 mmol) and *i*Pr_2NEt (27.9 mg, 35 µL, 0.2 mmol) were added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The solution was diluted with EtOAc (10 mL), washed with HCl (1 M. 2

× 10 mL), $NaHCO_3$ (sat., 2 × 10 mL) and brine (10 mL). The organic layer was dried over $MgSO_4$, filtered and concentrated *in vacuo*, to give pale brown oil, which was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 20% over 20 CV) to give [1,1'-binaphthalene]-2,2'-diyl dipropionate (39.2 mg, 49%) as white solids, R_f = 0.38 (20% EtOAc in petroleum ether); mp 107-108 °C [lit 105 °C]; ν_{max} (ATR): 2980 (C-H), 1751 (C=O), 1460 (C=C), 1173 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 7.99 (d, *J* 8.9, 2H, C(4)*H,* C(4')*H*), 7.93 (d, *J* 8.3, 2H, C(5)*H,* C(5')*H*), 7.47-7.44 (m, 2H, C(6)*H,* C(6')*H*), 7.42 (d, *J* 8.9, 2H, C(3)*H,* C(3')*H*), 7.31-7.28 (m, 2H, C(7)*H,* C(7')*H*), 7.22 (d, *J* 8.6, 2H, C(8)*H,* C(8')*H*), 2.14-2.05 (m, 4H, 2 × -C*H*$_2$CH$_3$), 0.71 (d, *J* 7.6, 6H, 2 × -CH$_2$*CH*$_3$); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 172.8 (2 × *C*=O), 146.9 (*C*(2), *C*(2')), 133.5 (*C*(8a), *C*(8a')), 131.6 (*C*(4a), *C*(4a')), 129.5 (*C*(4), *C*(4'), 128.1 (*C*(5), *C*(5')), 126.8 (*C*(7), *C*(7')), 126.3 (*C*(8), *C*(8')), 125.8 (*C*(6), *C*(6')), 123.6 (*C*(1), *C*(1')), 122.1 (*C*(3), *C*(3')), 27.6 (2 × -*C*H$_2$-), 8.7 (2 × -*C*H$_3$); HRMS (ASAP$^+$) $C_{26}H_{22}O_4$ $[M+H]^+$ found 399.1597, requires 399.1596 (+0.3 ppm). Data in agreement with literature.[105]

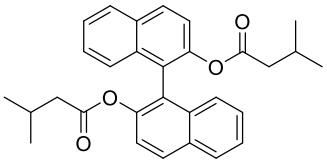
[1,1'-Binaphthalene]-2,2'-diyl bis(2-methylpropanoate)



Following general procedure B: BINOL (57.3 mg, 0.2 mmol) and DMAP (2.4 mg, 0.02 mmol) were added into CH_2Cl_2 (4 mL, 0.05 M) at room temperature, giving a clear solution. Isobutyric anhydride (47.5 mg, 49.7 µL, 0.3 mmol) and *i*Pr$_2$NEt (27.9 mg, 35 µL, 0.2 mmol) were added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The solution was diluted with EtOAc (10 mL), washed with HCl (1 M, 2 × 10 mL), $NaHCO_3$ (sat., 2 × 10 mL) and brine (10 mL). The organic layer was dried over $MgSO_4$, filtered and concentrated *in vacuo*, to give pale brown oil, which was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 20% over 20 CV) to give [1,1'-binaphthalene]-2,2'-diyl bis(2-methylpropanoate) (23.7 mg, 28%) as white solids, R_f = 0.56 (20% EtOAc in petroleum ether); mp 72-73 °C; ν_{max} (ATR): 2976 (C-H), 1749 (C=O), 1465 (C=C), 1111 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H 7.98 (d, *J* 8.9, 2H, C(4)*H*, C(4')*H*), 7.92 (d, *J* 8.3, 2H, C(5)*H*, C(5')*H*), 7.47-7.44 (m, 2H, C(6)*H*, C(6')*H*), 7.41 (d, *J* 8.8, 2H, C(3)*H*, C(3')*H*), 7.32-7.26 (m, 4H, C(7)*H*, C(7')*H*, C(8)*H*, C(8')*H*), 2.33 (sept, *J* 7.0, 2H, -C*H*(CH$_3$)$_2$), 0.71 (d, *J* 7.0, 6H, -C*H*$_3$), 0.62 (d, *J* 7.0, 6H, -C*H*$_3$); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 175.1 (2 × *C*=O), 146.8 (*C*(2), *C*(2')), 133.4 (*C*(8a), *C*(8a')), 131.5 (*C*(4a), *C*(4a')), 129.3 (*C*(4), *C*(4')), 127.9 (*C*(5), *C*(5')), 126.7 (*C*(7), *C*(7')), 126.1 (*C*(8), *C*(8')), 125.7 (*C*(6), *C*(6')), 123.6 (*C*(1), *C*(1')), 122.0 (*C*(3), *C*(3')), 33.8 (2 × -

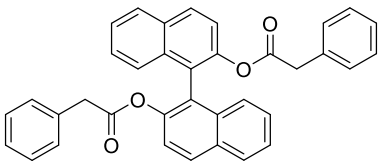
*C*H(CH_3)$_2$), 18.2 (-*C*H_3), 18.1 (-*C*H_3); HRMS (ASAP$^+$) $C_{28}H_{26}O_4$ [M+H]$^+$ found 427.1910, requires 427.1909 (+0.2 ppm)

[1,1'-Binaphthalene]-2,2'-diyl bis(3-methylbutanoate)



Following general procedure B: BINOL (57.3 mg, 0.2 mmol) and DMAP (2.4 mg, 0.02 mmol) were added into CH_2Cl_2 (4 mL, 0.05 M) at room temperature, giving a clear solution. 3-Methylbutanoic anhydride (55.9 mg, 0.3 mmol) and *i*Pr_2NEt (27.9 mg, 35 µL, 0.2 mmol) were added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The solution was diluted with EtOAc (10 mL), washed with HCl (1 M. 2 × 10 mL), $NaHCO_3$ (sat., 2 × 10 mL) and brine (10 mL). The organic layer was dried over $MgSO_4$, filtered and concentrated *in vacuo*, to give pale brown oil, which was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 20% over 20 CV) to give [1,1'-binaphthalene]-2,2'-diyl bis(3-methylbutanoate) (32.7 mg, 36%) as colorless crystals; R_f = 0.59 (20% EtOAc in petroleum ether); mp 82-83 °C; ν_{max} (ATR): 2957 (C-H), 1755 (C=O), 1510 (C=C), 1076 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 7.98 (d, *J* 8.9, 2H, C(4)*H,* C(4')*H*), 7.91 (d, *J* 8.3, 2H. C(5)*H,* C(5')*H*), 7.46-7.43 (m, 2H, C(6)*H,* C(6')*H*), 7.39 (d, *J* 8.9, 2H, C(3)*H,* C(3')*H*), 7.30-7.27 (m, 2H, C(7)*H,* C(7')*H*), 7.22 (d, *J* 8.4, 2H, C(8)*H,* C(8')*H*), 2.03-1.94 (m, 4H, 2 × –CH_2-), 1.64 (sept, *J* 6.8, 2H, 2× -C*H*-), 0.56 (d, *J* 6.6, 6H, 2 × -CH_3), 0.55 (d, *J* 6.6, 6H, 2 × -CH_3); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 171.4 (2 × *C*=O), 146.9 (*C*(2), *C*(2')), 133.5 (*C*(8a), *C*(8a')), 131.7 (*C*(4a), *C*(4a')), 129.6 (*C*(4), *C*(4'), 128.0 (*C*(5), *C*(5')), 126.8 (*C*(7), *C*(7')), 126.4 (*C*(8), *C*(8')), 125.8 (*C*(6), *C*(6')), 123.8 (*C*(1), *C*(1')), 122.0 (*C*(3), *C*(3')), 43.0 (2 × -*C*H_2-), 25.5 (2 × -*C*H-), 22.0 (2 × -*C*H_3), 22.0 (2 × -*C*H_3); HRMS (ASAP$^+$) $C_{30}H_{30}O_4$ [M+H]$^+$ found 455.2227, requires 455.2222 (+1.1 ppm)

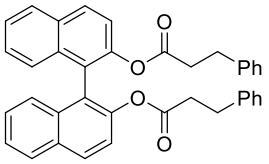
[1,1'-Binaphthalene]-2,2'-diyl bis(2-phenylacetate)



Following general procedure B: BINOL (57.3 mg, 0.2 mmol) and DMAP (2.4 mg, 0.02 mmol) were added into CH_2Cl_2 (4 mL, 0.05 M) at room temperature, giving a clear solution.

Phenylacetic anhydride (76.3 mg, 0.3 mmol) was added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The crude oil was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 10% over 20 CV then 10% - 20% over 10 CV) to give [1,1'-binaphthalene]-2,2'-diyl bis(2-phenylacetate) (69.1 mg, 66%) as colorless gum; R_f = 0.39 (20% EtOAc in petroleum ether); ν_{max} (ATR) 2980 (C-H), 1748 (C=O), 1497 (C=C), 1125 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 7.95 (d, *J* 8.9, 2H, C(4)*H,* C(4')*H*), 7.91 (d, *J* 8.2, 2H, C(5)*H,* C(5')*H*), 7.47-7.43 (m, 2H, C(6)*H,* C(6')*H*), 7.36 (d, *J* 8.9, 2H, C(3)*H,* C(3')*H*), 7.26-7.22 (m, 2H, C(7)*H,* C(7')*H*), 7.15-7.04 (m, 8H, C(8)*H,* C(8')*H*, 4 × *m*-Ar*H*, 2 × *p*-Ar*H*), 6.83-6.80 (m, 4H, 4 × *o*-Ar*H*), 3.40 (d, *J* 17.5, 2H, -CH_2), 3.36 (d, *J* 17.5, 2H, -CH_2); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 170.0 (2 × *C*=O), 146.8 (*C*(2), *C*(2')), 133.4 (*C*(8a), *C*(8a')), 133.1 (2 × *i*-Ar*C*H), 131.7 (*C*(4a), *C*(4a')), 129.6 (*C*(4), *C*(4'), 129.2 (4 × *o*-Ar*C*H), 128.4 (4 × *m*-Ar*C*H), 128.1 (*C*(5), *C*(5')), 126.9 (2 × *p*-Ar*C*H), 126.9 (*C*(7), *C*(7')), 126.2 (*C*(8), *C*(8')), 125.8 (*C*(6), *C*(6')), 123.4 (*C*(1), *C*(1')), 121.9 (*C*(3), *C*(3')), 40.9 (2 × -*C*H_2-); HRMS (ASAP$^+$) $C_{36}H_{26}O_4$ $[M+H]^+$ found 523.1916, requires 523.1909 (+1.3 ppm)

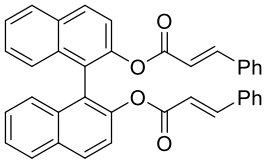
[1,1'-Binaphthalene]-2,2'-diyl bis(3-phenylpropanoate)



Following general procedure B: BINOL (57.3 mg, 0.2 mmol) and DMAP (2.4 mg, 0.02 mmol) were added into CH_2Cl_2 (4 mL, 0.05 M) at room temperature, giving a clear solution. 3-phenylpropionic anhydride (84.7 mg, 0.3 mmol) and *i*Pr_2NEt (27.9 mg, 35 µL, 0.2 mmol) were added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The solution was diluted with EtOAc (10 mL), washed with HCl (1 M. 2 × 10 mL), $NaHCO_3$ (sat., 2 × 10 mL) and brine (10 mL). The organic layer was dried over $MgSO_4$, filtered and concentrated *in vacuo*, to give pale brown oil, which was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 20% over 30 CV), giving) to give [1,1'-binaphthalene]-2,2'-diyl bis(3-phenylpropanoate) (19.4 mg, 18%) as white gum; R_f = 0.45 (20% EtOAc in petroleum ether); ν_{max} (ATR): 2890 (C-H), 1755 (C=O), 1454 (C=C), 1122 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 7.98 (d, *J* 8.9, 2H, C(4)*H*, C(4')*H*), 7.93 (d, *J* 8.2, 2H, C(5)*H*, C(5')*H*), 7.49-7.46 (m, 2H, C(6)*H*, C(6')*H*), 7.37 (d, *J* 8.8, 2H, C(3)*H*, C(3')*H*), 7.32-7.29 (m, 2H, C(7)*H*, C(7')*H*), 7.24 (d, *J* 8.3, 2H, C(8)*H*, C(8')*H*), 7.21-7.18 (m, 4H, 4 × *m*-Ar*H*), 7.16-7.12 (m, 2H, 2 × *p*-Ar*H*), 7.00-6.96 (m, 4H, 4 × *o*-Ar*H*), 2.51-2.34 (m, 8H, 4 × -*C*H_2-); **^{13}C NMR** (125 MHz, $CDCl_3$) δ_C: 171.2 (2× C=O), 146.8 (*C*(2), *C*(2')), 140.3 (2 × *i*-Ar*C*H), 133.4 (*C*(8a), *C*(8a')), 131.7

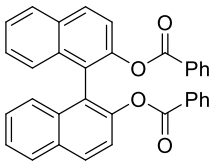
(*C*(4a), *C*(4a')), 129.7 (*C*(4), *C*(4'), 128.5 (4 × *m*-Ar*C*H), 128.3 (4 × *o*-Ar*C*H), 128.2 (*C*(5), *C*(5')), 126.9 (*C*(7), *C*(7')), 126.3 (2 × *p*-Ar*C*H), 126.3 (*C*(8), *C*(8')), 125.9 (*C*(6), *C*(6')), 123.6 (*C*(1), *C*(1')), 122.0 (*C*(3), *C*(3')), 35.6 (-CO-*C*H_2-), 30.5 (-*C*H_2-Ph); HRMS (ASAP$^+$) $C_{38}H_{30}O_4$ $[M+H]^+$ found 551.2227, requires 551.2222 (+0.9 ppm)

[1,1'-Binaphthalene]-2,2'-diyl (2*E*,2'*E*)-bis(3-phenylacrylate)



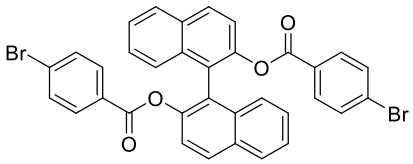
Following general procedure B: BINOL (57.3 mg, 0.2 mmol) and DMAP (2.4 mg, 0.02 mmol) were added into CH_2Cl_2 (4 mL, 0.05 M) at room temperature, giving a clear solution. (*E*)-Cinnamic anhydride (83.5 mg, 0.3 mmol) and *i*Pr_2NEt (27.9 mg, 35 µL, 0.2 mmol) were added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The solution was diluted with EtOAc (10 mL), washed with HCl (1 M. 2 × 10 mL), $NaHCO_3$ (sat., 2 × 10 mL) and brine (10 mL). The organic layer was dried over $MgSO_4$, filtered and concentrated *in vacuo*, to give pale brown oil, which was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 20% over 20 CV) to give [1,1'-binaphthalene]-2,2'-diyl (2E,2'E)-bis(3-phenylacrylate) (26.8 mg, 25%) as colorless crystals, R_f = 0.44 (20% EtOAc in petroleum ether); mp 211-212 °C; ν_{max} (ATR): 2890 (C-H), 1736 (C=O), 1632 (C=C), 1449 (C=C aromatic) 1117 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 7.99 (d, *J* 8.9, 2H, C(4)*H*, C(4')*H*), 7.93 (d, *J* 8.2, 2H, C(5)*H*, C(5')*H*), 7.54 (d, *J* 8.8, 2H, C(3)*H*, C(3')*H*), 7.49-7.45 (m, 2H, C(6)*H*, C(6')*H*), 7.36-7.30 (m, 16H, C(8)*H*, C(8')*H*, C(7)*H*, C(7')*H*, 4 × *o*-Ar*H*, 4 × *m*-Ar*H*, 2 × *p*-Ar*H*, 2 × -CO-CH=C*H*-Ph), 6.22 (d, *J* 16.0, 2H, 2 × -CO-C*H*=CH-Ph); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 165.1 (2 × C=O), 147.0 (*C*(2), *C*(2')), 146.3 (2 × -CO-CH=*C*H-Ph), 134.3 (2 × *i*-Ar*C*H), 133.6 (*C*(8a), *C*(8a')), 131.7 (*C*(4a), *C*(4a')), 130.6 (2 × *p*-Ar*C*H), 129.6 (*C*(4), *C*(4'), 128.9 (4 × *m*-Ar*C*H), 128.4 (4 × *o*-Ar*C*H), 128.2 (*C*(5), *C*(5')), 126.9 (*C*(7), *C*(7')), 126.3 (*C*(8), *C*(8')), 125.8 (*C*(6), *C*(6')), 123.7 (*C*(1), *C*(1')), 122.0 (*C*(3), *C*(3')), 117.0 2 × -CO-*C*H=CH-Ph); HRMS (ASAP$^+$) $C_{38}H_{26}O_4$ $[M+H]^+$ found 547.1918, requires 547.1909 (+1.6 ppm)

[1,1'-Binaphthalene]-2,2'-diyl dibenzoate



Following general procedure B: BINOL (57.3 mg, 0.2 mmol) and DMAP (2.4 mg, 0.02 mmol) were added into CH_2Cl_2 (4 mL, 0.05 M) at room temperature, giving a clear solution. Benzoic anhydride (67.9 mg, 0.3 mmol) and *i*Pr_2NEt (27.9 mg, 35 µL, 0.2 mmol) were added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The solution was diluted with EtOAc (10 mL), washed with HCl (1 M. 2 × 10 mL), $NaHCO_3$ (sat., 2 × 10 mL) and brine (10 mL). The organic layer was dried over $MgSO_4$, filtered and concentrated *in vacuo*, to give pale brown oil, which was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 20% over 20 CV), to give [1,1'-binaphthalene]-2,2'-diyl dibenzoate (18.9 mg, 19%) as white crystals, R_f = 0.32 (20% EtOAc in petroleum ether); mp 156.5-158 °C [lit[1] 162-165 °C]; ν_{max} (ATR): 1730 (C=O), 1600 (C=C, aromatic), 1204 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 7.98 (d, *J* 9.1, 2H, C(4)*H,* C(4')*H*), 7.90 (d, *J* 8.4, 2H, C(5)*H,* C(5')*H*), 7.65-7.63 (m, 4H, 4 × *o*-Ar*C*H), 7.56 (d, *J* 8.7, 2H, C(3)*H,* C(3')*H*), 7.46-7.42 (m, 4H, C(6)*H,* C(6')*H*, 2 × *p*-Ar*H*), 7.40-7.38 (m, 2H, C(8)*H,* C(8')*H*), 7.35-7.31 (m, 2H, C(7)*H,* C(7')*H*), 7.27-7.23 (m, 4H, 4 × *m*-Ar*C*H); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 164.9 (2 × *C*=O), 147.1 (*C*(2), *C*(2')), 133.5 (*C*(8a), *C*(8a')), 133.3 (2 × *p*-Ar*C*H), 131.7 (*C*(4a), *C*(4a')), 130.0 (4 × *o*-Ar*C*H), 129.7 (*C*(4), *C*(4'), 129.4 (2× *i*-Ar*C*H), 128.4 (4 × *m*-Ar*C*H), 128.2 (*C*(5), *C*(5')), 127.0 (*C*(7), *C*(7')), 126.2 (*C*(8), *C*(8')), 125.8 (*C*(6), *C*(6')), 123.8 (*C*(1), *C*(1')), 121.9 (*C*(3), *C*(3')); HRMS (NSI$^+$) $C_{34}H_{22}O_4$ $[M+H]^+$ found 495.1584, requires 495.1591 (−1.4 ppm). Data in agreement with literature.[106]

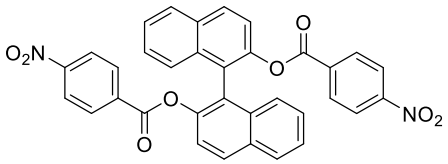
[1,1'-Binaphthalene]-2,2'-diyl bis(4-bromobenzoate)



Following general procedure B: BINOL (57.3 mg, 0.2 mmol) and DMAP (2.4 mg, 0.02 mmol) were added into CH_2Cl_2 (4 mL, 0.05 M) at room temperature, giving a clear solution. 4-Bromobenzoic anhydride (115 mg, 0.3 mmol) was added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The crude oil was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 10% over 20 CV then

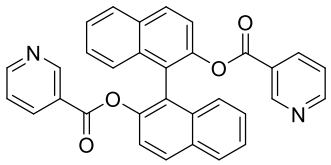
10% - 20% over 10 CV) to give [1,1'-binaphthalene]-2,2'-diyl bis(4-bromobenzoate) (40.9 mg, 31%) as white solids; R_f = 0.5 (20% EtOAc in petroleum ether); mp 206.5-207.5 °C; ν_{max} (ATR): 3050 (C-H), 1732 (C=O), 1520 (C=C) 1206 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 7.99 (d, *J* 8.9, 2H, C(4)*H,* C(4')*H*), 7.92 (d, *J* 8.9, 2H, C(5)*H,* C(5')*H*), 7.53 (d, *J* 8.9, 2H, C(3)*H,* C(3')*H*), 7.48-7.45 (m, 2H, C(6)*H,* C(6')*H*), 7.44-7.42 (m, 4H, 4 × *o*-Ar*H*-Br), 7.39-7.33 (m, 4H, C(7)*H,* C(7')*H,* C(8)*H,* C(8')*H*), 7.38-7.36 (m, 4H, 4 × *m*-Ar*H*-NO_2); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 164.2 (2 × *C*=O), 146.8 (*C*(2), *C*(2')), 133.4 (*C*(8a), *C*(8a')), 131.8 (4 × *m*-Ar*C*H), 131.7 (*C*(4a), *C*(4a')), 131.4 (4 × *o*-Ar*C*H), 129.8 (*C*(4), *C*(4'), 128.6 (2 × *i*-Ar*C*H), 128.3 (*C*(5), *C*(5')), 128.2 (2 × *p*-Ar*C*H), 127.1 (*C*(7), *C*(7')), 126.1 (*C*(8), *C*(8')), 126.0 (*C*(6), *C*(6')), 123.6 (*C*(1), *C*(1')), 121.7 (*C*(3), *C*(3')); HRMS (ASAP$^+$) $C_{34}H_{20}Br_2O_4$ $[M+H]^+$ found 650.9824, requires 650.9807 (+2.6 ppm)

[1,1'-Binaphthalene]-2,2'-diyl bis(4-nitrobenzoate)



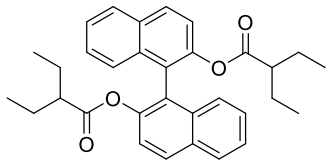
Following general procedure B: BINOL (57.3 mg, 0.2 mmol) and DMAP (2.4 mg, 0.02 mmol) were added into CH_2Cl_2 (4 mL, 0.05 M) at room temperature, giving a clear solution. 4-Nitrobenzoic anhydride (94.9 mg, 0.3 mmol) was added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The crude oil was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 20% over 30 CV) to give [1,1'-binaphthalene]-2,2'-diyl bis(4-nitrobenzoate) (44.5 mg, 38%) as yellow crystals; R_f = 0.25 (20% EtOAc in petroleum ether); mp 170-171 °C; ν_{max} (ATR); 2920 (C-H), 1740 (C=O), 1420 (C=C), 1094 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 8.07 (d, *J* 8.9, 4H, 4 × *m*-Ar*H*-NO_2), 8.02 (d, *J* 8.9, 2H, C(4)*H*, C(4')*H*), 7.95 (d, *J* 8.2, 2H, C(5)*H*, C(5')*H*), 7.69 (d, *J* 8.9, 4H, 4 × *o*-Ar*H*-NO_2), 7.55 (d, *J* 8.9, 2H, C(3)*H*, C(3')*H*), 7.53-7.50 (m, 2H, C(6)*H*, C(6')*H*), 7.44-7.38 (m, 4H, C(7)*H*, C(7')*H,* C(8)*H*, C(8')*H*); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 163.1 (2 × C=O), 150.7 (2 × *p*-Ar*C*-NO_2), 146.6 (*C*(2), *C*(2')), 134.6 (2 × *i*-Ar*C*-NO_2), 133.3 (*C*(8a), *C*(8a'), 131.8 (*C*(4a), *C*(4a')), 130.9 (4 × *o*-Ar*C*-NO_2), 130.2 (*C*(4), *C*(4')), 128.4 (*C*(5), *C*(5')), 127.4 (*C*(7), *C*(7')), 126.4 (*C*(6), *C*(6')), 126.0 (*C*(8), *C*(8')), 123.6 (*C*(1), *C*(1'), 4 × *m*-Ar*C*-NO_2), 121.4 (*C*(3), *C*(3')); HRMS (ASAP$^+$) $C_{34}H_{20}N_2O_8$ $[M+H]^+$ found 585.1312, requires 585.1298 (+2.4 ppm)

[1,1'-Binaphthalene]-2,2'-diyl dinicotinate



Following general procedure B: BINOL (57.3 mg, 0.2 mmol) and DMAP (2.4 mg, 0.02 mmol) were added into tert-Amyl alcohol (4 mL, 0.05 M) at room temperature, giving a clear solution. Nicotinic anhydride (76.3 mg, 0.3 mmol) was added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The crude oil was purified by column chromatography (Isolera 4, MeOH in DCM, 0% -> 2% over 25 CV, then 2% over 10 CV) to give [1,1'-binaphthalene]-2,2'-diyl dinicotinate (7.5 mg, 8%) as white solids; R_f = 0.11 (2% MeOH in CH_2Cl_2); mp 158-159 °C; ν_{max} (ATR): 2890 (C-H), 1740 (C=O), 1587 (C=C), 1269 (C=C), 1080 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 8.75 (d, *J* 1.4, 2H, hetero-Ar*H*(2), hetero-Ar*H*(2')), 8.65 (dd, *J* 4.8, 1.7, 2H, hetero-Ar*H*(6), hetero-Ar*H*(6')) 8.01 (d, *J* 8.9, 2H, C(4)*H,* C(4')*H*), 7.93 (d, *J* 8.2, 2H, C(5)*H,* C(5')*H*), 7.87 (dt, *J* 8.0, 2.0, 2H, hetero-Ar*H*(4), hetero-Ar*H*(4')), 7.54 (d, *J* 8.9, 2H, C(3)*H,* C(3')*H*), 7.50-7.47 (m, 2H, C(6)*H,* C(6')*H*), 7.40-7.35 (m, 4H, C(8)*H,* C(8')*H*), C(7)*H,* C(7')*H*), 7.21 (dd, *J* 8.0, 4.8, 2H, hetero-Ar*H*(5), hetero-Ar*H*(5')); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 163.6 (2 × *C*=O), 153.8 (hetero-Ar*C*(6)H, hetero-Ar*C*(6')H), 151.1 (hetero-Ar*C*(2)H, hetero-Ar*C*(2')H), 146.5 (*C*(2), *C*(2')), 137.3 (hetero-Ar*C*(4)H, hetero-Ar*C*(4')H), 133.3 (*C*(8a), *C*(8a')), 131.8 (*C*(4a), *C*(4a')), 130.1 (*C*(4), *C*(4'), 128.3 (*C*(5), *C*(5')), 127.3 (*C*(7), *C*(7')), 126.2 (*C*(6), *C*(6')), 126.1 (*C*(8), *C*(8')), 123.6 (*C*(1), *C*(1')), 123.3 (hetero-Ar*C*(5)H, hetero-Ar*C*(5')H), 121.5 (*C*(3), *C*(3')); HRMS (NSI$^+$) $C_{32}H_{20}N_2O_4$ $[M+H]^+$ found 497.1389, requires 497.1496 (-1.4 ppm)

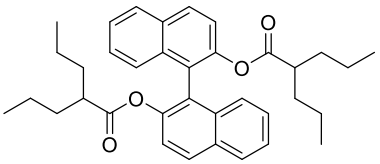
[1,1'-Binaphthalene]-2,2'-diyl bis(2-ethylbutanoate)



Following general procedure B: BINOL (57.3 mg, 0.2 mmol) and DMAP (2.4 mg, 0.02 mmol) were added into CH_2Cl_2 (4 mL, 0.05 M) at room temperature, giving a clear solution. 2-Ethylbutanoic anhydride (64.3 mg, 0.3 mmol) and *i*Pr_2NEt (27.9 mg, 35 µL, 0.2 mmol) were added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The solution was diluted with EtOAc (10 mL), washed with HCl (1 M. 2 × 10 mL), $NaHCO_3$ (sat., 2 × 10 mL) and brine (10 mL). The organic layer was dried over $MgSO_4$,

filtered and concentrated *in vacuo*, to give pale brown oil, which was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 20% over 25 CV) to give [1,1'-binaphthalene]-2,2'-diyl bis(2-ethylbutanoate) (26.5 mg, 28%) as a colorless gum; R_f = 0.61 (20% EtOAc in petroleum ether); ν_{max} (ATR): 2965 (C-H), 1753 (C=O), 1458 (C=C), 1107 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 7.98 (d, *J* 8.9, 2H, C(4)*H,* C(4')*H*), 7.90 (d, *J* 8.3, 2H. C(5)*H,* C(5')*H*), 7.45-7.42 (m, 2H, C(6)*H,* C(6')*H*), 7.38 (d, *J* 8.9, 2H, C(3)*H,* C(3')*H*), 7.30-7.29 (m, 2H, C(7)*H,* C(7')*H*), 7.26-7.24 (m, 2H, C(8)*H,* C(8')*H*) 2.04 (tt, *J* 8.7, 5.4, 2H, 2 × -C*H*-), 1.29-1.08 (m, 8H, 4× -CH_2-), 0.55 (t, *J* 6.5, 6H, 2 × -CH_3), 0.43 (t, *J* 6.5, 6H, 2 × -CH_3); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 174.3 (2 × *C*=O), 147.0 (*C*(2), *C*(2')), 133.6 (*C*(8a), *C*(8a')), 131.7 (*C*(4a), *C*(4a')), 129.5 (*C*(4), *C*(4'), 128.0 (*C*(5), *C*(5')), 126.8 (*C*(7), *C*(7')), 126.4 (*C*(8), *C*(8')), 125.7 (*C*(6), *C*(6')), 123.8 (*C*(1), *C*(1')), 122.0 (*C*(3), *C*(3')), 48.7 (2 × -*C*H-), 24.7 (-*C*H_2-), 24.6 (-CH_2-), 11.4 (2 × -*C*H_3), 11.1 (2 × -*C*H_3); HRMS (ASAP$^+$) $C_{32}H_{34}O_4$ $[M+H]^+$ found 483.2547, requires 483.2535 (+2.5 ppm)

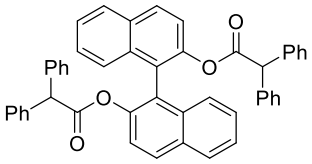
[1,1'-Binaphthalene]-2,2'-diyl bis(2-propylpentanoate)



Following general procedure B: BINOL (57.3 mg, 0.2 mmol) and DMAP (2.4 mg, 0.02 mmol) were added into CH_2Cl_2 (4 mL, 0.05 M) at room temperature, giving a clear solution. 3-Propylpentanoic anhydride (81.1 mg, 0.3 mmol) and *i*Pr_2NEt (27.9 mg, 35 µL, 0.2 mmol) were added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The solution was diluted with EtOAc (10 mL), washed with HCl (1 M. 2 × 10 mL), $NaHCO_3$ (sat., 2 × 10 mL) and brine (10 mL). The organic layer was dried over $MgSO_4$, filtered and concentrated *in vacuo*, to give pale brown oil, which was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 20% over 30 CV) to give [1,1'-binaphthalene]-2,2'-diyl bis(2-propylpentanoate) (28.4 mg, 26%) as a cloudy gum; R_f = 0.64 (20% EtOAc in petroleum ether; ν_{max} (ATR): 2957 (C-H), 1751 (C=O), 1508 (C=C), 1103 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 7.96 (d, *J* 8.9, 2H, C(4)*H,* C(4')*H*), 7.90 (d, *J* 8.1, 2H. C(5)*H,* C(5')*H*), 7.45-7.42 (m, 2H, C(6)*H,* C(6')*H*), 7.36 (d, *J* 8.9, 2H, C(3)*H,* C(3')*H*), 7.30-7.26 (m, 2H, C(7)*H,* C(7')*H*), 7.23 (d, *J* 8.5, 2H, C(8)*H,* C(8')*H*), 2.19 (sept, *J* 5.3, 2H, 2 × -C*H*-), 1.26-0.76 (m, 16H, 8 × -CH_2-), 0.66 (t, *J* 7.3, 6H, 2 × -CH_3), 0.60 (t, *J* 7.3, 6H, 2 × -CH_3); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 174.5 (2 × *C*=O), 147.0 (*C*(2), *C*(2')), 133.7 (*C*(8a), *C*(8a')), 131.7 (*C*(4a), *C*(4a')), 129.4 (*C*(4), *C*(4'), 128.0 (*C*(5), *C*(5')), 126.8 (*C*(7), *C*(7')), 126.4 (*C*(8), *C*(8')), 125.7 (*C*(6), *C*(6')),

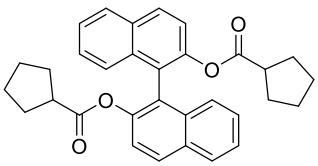
123.7 (*C*(1), *C*(1')), 122.0 (*C*(3), *C*(3')), 45.4 (2 × -*C*H-), 20.4 (2 × -*C*H_2-), 20.2 (2 × -*C*H_2-), 14.1 (2 × -*C*H_3), 14.1 (2 × -*C*H_3)

[1,1'-Binaphthalene]-2,2'-diyl bis(2,2-diphenylacetate)



Following general procedure B: BINOL (57.3 mg, 0.2 mmol) and DMAP (2.4 mg, 0.02 mmol) were added into CH_2Cl_2 (4 mL, 0.05 M) at room temperature, giving a clear solution. Diphenylacetic anhydride (121.8 mg, 0.3 mmol) was added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The crude oil was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 20% over 25 CV) to give 2,3-dihydro-[1,1'-binaphthalene]-2,2'-diyl bis(2,2-diphenylacetate) as white solids (54.8 mg, 41%); R_f = 0.33 (20% EtOAc in petroleum ether); mp 149-150 °C; ν_{max} (ATR): 2990 (C-H), 1748 (C=O), 1497 (C=C), 1109 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 7.88 (d, *J* 8.7, 4H, C(4)*H*, C(4')*H*, C(5)*H*, C(5')*H*), 7.45-7.41 (m, 2H, C(6)*H*, C(6')*H*), 7.25 (d, *J* 9.0, 2H, C(3)*H*, C(3')*H*), 7.22-7.20 (m, 2H, C(7)*H*, C(7')*H*), 7.19-7.17 (m, 2H, 2 × *p*-ArC*H*), 7.16-7.11 (m, 6H, C(8)*H*, C(8')*H*, 4 × *o*-ArC*H*), 7.08-7.06 (m, 2H, 2 × *p*-ArC*H*), 7.05-7.02 (m, 4H, 4 × *m*-ArC*H*), 7.00-6.97 (m, 4H, 4 × *m*-ArC*H*), 6.72-7.71 (m, 4H, 4 × *o*-ArC*H*), 4.80 (s, 2H, -C*H*Ph_2); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 170.8 (2 × C=O), 146.8 (*C*(2), *C*(2')), 137.9 (*i*-Ar*C*H), 137.8 (*i*-Ar*C*H), 133.3 (*C*(8a), *C*(8a'), 131.7 (*C*(4a), *C*(4a')), 129.7 (*C*(4), *C*(4')), 128.8 (2 × *m*-Ar*C*H), 128.6 (2 × *o*-Ar*C*H), 128.3 (2 × *m*-Ar*C*H), 128.2 (2 × *o*-Ar*C*H), 128.1 (*C*(5), *C*(5')), 127.3 (*p*-Ar*C*H), 126.9 (*p*-Ar*C*H), 126.9 (*C*(7), *C*(7')), 126.4 (*C*(8), *C*(8')), 125.8 (*C*(6), *C*(6')), 123.5 (*C*(1), *C*(1')), 121.6 (*C*(3), *C*(3')), 56.8 (-*C*H-); HRMS (NSI$^+$) $C_{48}H_{36}O_4$ $[M-H]^-$ found 675.2542, requires 391.1329 (+0.1 ppm)

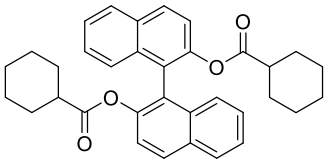
[1,1'-Binaphthalene]-2,2'-diyl dicyclopentanecarboxylate



Following general procedure B: BINOL (57.3 mg, 0.2 mmol) and DMAP (2.4 mg, 0.02 mmol) were added into CH_2Cl_2 (4 mL, 0.05 M) at room temperature, giving a clear solution. Cyclopetanecarboxylic anhydride (63.1 mg, 0.3 mmol) and *i*Pr_2NEt (27.9 mg, 35 µL, 0.2 mmol) were added to the previous solution. The resulted clear solution was left stirring for 18 hours

at room temperature. The solution was diluted with EtOAc (10 mL), washed with HCl (1 M. 2 × 10 mL), $NaHCO_3$ (sat., 2 × 10 mL) and brine (10 mL). The organic layer was dried over $MgSO_4$, filtered and concentrated *in vacuo*, to give pale brown oil, which was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 20% over 30 CV) to give [1,1'-binaphthalene]-2,2'-diyl dicyclopentanecarboxylate (28.3 mg, 30%) as a white solid; R_f = 0.53 (20% EtOAc in petroleum ether); mp 164-166 °C; ν_{max} (ATR): 2955 (C-H), 1749 (C=O), 1508 (C=C), 1117 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 7.98 (d, *J* 8.9, 2H, C(4)*H,* C(4')*H*), 7.92 (d, *J* 8.2, 2H, C(5)*H,* C(5')*H*), 7.47-7.43 (m, 2H, C(6)*H,* C(6')*H*), 7.41 (d, *J* 8.9, 2H, C(3)*H,* C(3')*H*), 7.31-7.26 (m, 4H, C(7)*H,* C(7')*H,* C(8)*H,* C(8')*H*), 2.56-2.49 (m, 2H, 2 × -C(1'')*H*-), 1.43-0.98 (m, 16H, 4 × -C(2'')H_2-, 4 × -C(3'')H_2-); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 174.8 (2× *C*=O), 147.0 (*C*(2), *C*(2')), 133.5 (*C*(8a), *C*(8a')), 131.6 (*C*(4a), *C*(4a')), 129.4 (*C*(4), *C*(4'), 128.0 (*C*(5), *C*(5')), 126.8 (*C*(7), *C*(7')), 126.3 (*C*(8), *C*(8')), 125.7 (*C*(6), *C*(6')), 123.8 (*C*(1), *C*(1)'), 122.1 (*C*(3), *C*(3')), 43.6 (2 × -*C*H-), 29.5 (2 × -*C*H_2-), 29.3 (2 × -*C*H_2-), 25.6 (2 × -*C*H_2-), 25.5 (2 × -*C*H_2-); HRMS (ASAP$^+$) $C_{32}H_{30}O_4$ $[M+H]^+$ found 479.2226, requires 479.2222 (+0.8 ppm)

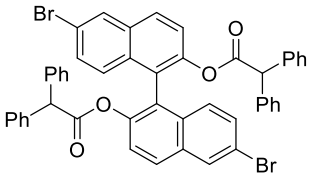
[1,1'-Binaphthalene]-2,2'-diyl dicyclohexanecarboxylate



Following general procedure B: BINOL (57.3 mg, 0.2 mmol) and DMAP (2.4 mg, 0.02 mmol) were added into CH_2Cl_2 (4 mL, 0.05 M) at room temperature, giving a clear solution. Cyclohexanecarboxylic anhydride (71.5 mg, 0.3 mmol) and *i*Pr_2NEt (27.9 mg, 35 µL, 0.2 mmol) were added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The solution was diluted with EtOAc (10 mL), washed with HCl (1 M. 2 × 10 mL), $NaHCO_3$ (sat., 2 × 10 mL) and brine (10 mL). The organic layer was dried over $MgSO_4$, filtered and concentrated *in vacuo*, to give pale brown oil, which was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 20% over 30 CV) to give [1,1'-binaphthalene]-2,2'-diyl dicyclohexanecarboxylate (20.3 mg, 20%) as a white solid; R_f = 0.61 (20% EtOAc in petroleum ether); mp 164-166 °C; ν_{max} (ATR): 2926 (C-H), 1753 (C=O), 1447 (C=C), 1109 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 7.97 (d, *J* 8.9, 2H, C(4)*H,* C(4')*H*), 7.91 (d, *J* 8.3, 2H, C(5)*H,* C(5')*H*), 7.47-7.43 (m, 2H, C(6)*H,* C(6')*H*), 7.39 (d, *J* 8.9, 2H, C(3)*H,* C(3')*H*), 7.32-7.28 (m, 4H, C(7)*H,* C(7')*H,* 7.28-7.26 (m, 2H, C(8)*H,* C(8')*H*), 2.12-2.06 (m, 2H, 2 × -C(1'')*H*-), 1.47-0.73 (m, 20H, 4 × -C(2'')H_2-, 4 × -C(3'')H_2-, 2 × -C(4'')H_2-); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 174.2 (2 × *C*=O), 146.9 (*C*(2), *C*(2')), 133.5 (*C*(8a), *C*(8a')), 131.6 (*C*(4a), *C*(4a')),

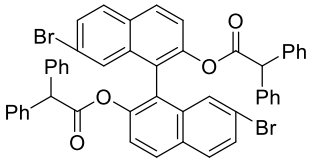
129.4 (*C*(4), *C*(4'), 128.0 (*C*(5), *C*(5')), 126.8 (*C*(7), *C*(7')), 126.3 (*C*(8), *C*(8')), 125.7 (*C*(6), *C*(6')), 123.8 (*C*(1), *C*(1)'), 122.1 (*C*(3), *C*(3')), 42.8 (2 × –*C*(1'')H-), 28.2 (2 × -*C*H_2-), 28.2 (2 × -*C*H_2-), 25.6 (2 × -*C*H_2-), 25.1 (2 × -*C*H_2-),25.1 (2 × -*C*H_2-); HRMS (ASAP$^+$) $C_{34}H_{34}O_4$ $[M+H]^+$ found 507.2538, requires 507.2535 (+0.6 ppm)

6,6'-Dibromo-[1,1'-binaphthalene]-2,2'-diyl bis(2,2-diphenylacetate)



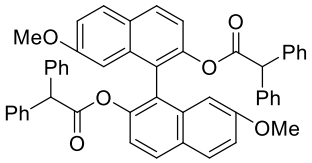
Following general procedure B: 6,6'-dibromo-[1,1'-binaphthalene]-2,2'-diol (88.8 mg, 0.2 mmol) and DMAP (2.4 mg, 0.02 mmol) were added into CH_2Cl_2 (4 mL, 0.05 M) at room temperature, giving a clear solution. Diphenylacetic anhydride (121.8 mg, 0.3 mmol) and *i*Pr_2NEt (27.9 mg, 35 µL, 0.2 mmol) were added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The concentrated *in vacuo* and the residue was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 10% over 30 CV) to give 6,6'-dibromo-[1,1'-binaphthalene]-2,2'-diyl bis(2,2-diphenylacetate) (78.2 mg, 47%) as colorless gum. R_f = 0.71 (20% EtOAc in petroleum ether); ν_{max} (ATR): 3040 (C-H), 1757 (C=O), 1495 (C=C), 1115 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 8.00 (d, *J* 2.0, 2H, C(5)*H,* C(5')*H*), 7.76 (d, *J* 9.0, 2H, C(4)*H,* C(4')*H*), 7.26 (d, *J* 8.9, 2H, C(3)*H,* C(3')*H*), 7.25 (dd, *J* 9.0, 2.0, 2H, C(7)*H,* C(7')*H*), 7.22-7.10 (m, 8H, 2 × *p*-Ar*H*, 4 × *m*-Ar*H*, 2 × *p'*-Ar*H*), 7.04 (d, *J* 7.5, 4H, 4 × *o*-Ar*H*), 7.01 (d, *J* 7.5, 4H, 4 × *m'*-Ar*H*), 6.94 (d, *J* 9.0, 2H, C(8)*H,* C(8')*H*)), 6.75 (d, *J* 7.5, 4H, 4 × *o'*-Ar*H*), 4.78 (s, 2H, 2 × -C*H*-); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 171.6 (2 × *C*=O), 147.0 (*C*(2), *C*(2')), 137.6 (*i*-Ar*C*H), 137.5 (*i'*-Ar*C*H), 132.7 (*C*(4a), *C*(4a')), 131.6 (*C*(8a), *C*(8a')), 130.3 (*C*(7), *C*(7')), 130.2 (*C*(5), *C*(5')), 128.9 (*C*(4), *C*(4'), 128.6 (2 × *m*-Ar*C*H), 128.6 (2 × *m'-/o*-Ar*C*H), 128.4 (2 × *m'*-/o-Ar*C*H), 128.1 (2 × *o'*-Ar*C*H), 127.8 (*C*(8), *C*(8')), 127.4 (*p*-Ar*C*H), 127.4 (*p'*-Ar*C*H), 123.2 (*C*(1), *C*(1)'), 122.8 (*C*(3), *C*(3')), 120.2 (*C*(6), *C*(6')), 56.6 (2 × -*C*H-); HRMS (NSI$^+$) $C_{48}H_{32}Br_2O_4$ $[M+NH_4]^+$ found 848.1010, requires 848.1006 (+0.5 ppm)

7,7'-Dibromo-[1,1'-binaphthalene]-2,2'-diyl bis(2,2-diphenylacetate)



Following general procedure B: 7,7'-dibromo-[1,1'-binaphthalene]-2,2'-diol (88.8 mg, 0.2 mmol) and DMAP (2.4 mg, 0.02 mmol) were added into CH_2Cl_2 (4 mL, 0.05 M) at room temperature, giving a clear solution. Diphenylacetic anhydride (121.8 mg, 0.3 mmol) and *i*Pr_2NEt (27.9 mg, 35 µL, 0.2 mmol) were added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The concentrated *in vacuo* and the residue was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 15% over 35 CV) to give 7,7'-dibromo-[1,1'-binaphthalene]-2,2'-diyl bis(2,2-diphenylacetate) (78.9 mg, 47%) as yellow solids. R_f = 0.52 (20% EtOAc in petroleum ether); mp 126-128 °C; ν_{max} (ATR): 3028 (C-H), 1757 (C=O), 1495 (C=C), 1110 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 7.82 (d, *J* 8.8, 2H, C(4)*H,* C(4')*H*), 7.70 (d, *J* 8.8, 2H, C(5)*H,* C(5')*H*), 7.49 (d, *J* 8.7, 2.0, 2H, C(5)*H,* C(5')*H*), 7.28 (d, *J* 8.9, 2H, C(3)*H,* C(3')*H*), 7.24 (d, *J* 1.9, 2H, C(8)*H,* C(8')*H*), 7.20-7.13 (m, 6H, 2 × *p*-Ar*H*, 4 × *m*-Ar*H*), 7.11-7.08 (m, 2H, 2 × *p'*-Ar*H*), 7.05-7.02 (m, 8H, 4 × *m'*-Ar*H,* 4× *o*-Ar*H*)), 6.84-6.82 (m, 4H, 4 × *o'*-Ar*H*), 4.78 (s, 2H, 2 × -C*H*-); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 170.4 (2 × *C*=O), 147.6 (*C*(2), *C*(2')), 137.6 (*i*-Ar*C*H, *i'*-Ar*C*H), 134.3 (*C*(8a), *C*(8a')), 130.1 (*C*(4a), *C*(4a')), 129.9 (*C*(4), *C*(4'), 129.9 (*C*(5), *C*(5')), 129.5 (*C*(6), *C*(6')), 128.6 (2 × *m*-Ar, 2 × *o*-Ar*C*H), 128.4 (2 × *m*-Ar*C*H), 128.2 (2 × *o'*-Ar*C*H), 127.9 (*C*(8), *C*(8')), 127.3 (*p*-Ar*C*H), 127.1 (*p'*-Ar*C*H), 122.1 (*C*(3), *C*(3')), 122.0 (*C*(1), *C*(1)'), 56.7 (2 × -*C*H-); HRMS (NSI$^+$) $C_{48}H_{32}Br_2O_4$ $[M+NH_4]^+$ found 848.1011, requires 848.1006 (+0.6 ppm)

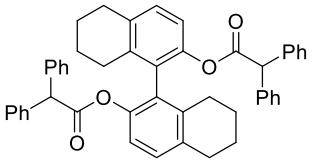
7,7'-Dimethoxy-[1,1'-binaphthalene]-2,2'-diyl bis(2,2-diphenylacetate)



Following general procedure B: 7,7'-dimethoxy-[1,1'-binaphthalene]-2,2'-diol (69.3 mg, 0.2 mmol) and DMAP (2.4 mg, 0.02 mmol) were added into CH_2Cl_2 (4 mL, 0.05 M) at room temperature, giving a clear solution. Diphenylacetic anhydride (121.8 mg, 0.3 mmol) and *i*Pr_2NEt (27.9 mg, 35 µL, 0.2 mmol) were added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The solution was diluted with EtOAc (10 mL), washed with HCl (1 M. 2 × 10 mL), $NaHCO_3$ (sat., 2 × 10 mL) and brine (10 mL).

The organic layer was dried over $MgSO_4$, filtered and concentrated *in vacuo*, to give pale brown oil, which was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 20% over 35 CV) to give 7,7'-dimethoxy-[1,1'-binaphthalene]-2,2'-diyl bis(2,2-diphenylacetate) (20.6 mg, 14%) as white solids; R_f = 0.375 (20% EtOAc in petroleum ether); mp 152-154 °C; ν_{max} (ATR): 2980 (C-H), 1746 (C=O), 1506 (C=C), 1224 (C-O), 1150 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 7.81 (d, *J* 8.8, 2H, C(4)*H,* C(4')*H*), 7.76 (d, *J* 8.9, 2H, C(5)*H,* C(5')*H*), 7.20-7.14 (m, 6H, 2 × *p*-Ar*H*, 4 × *o*-Ar*H*), 7.12 (d, *J* 8.9, 2H, C(3)*H,* C(3')*H*), 7.11-7.05 (m, 4H, 2 × *p'*-Ar*H*, C(6)*H,* C(6')*H*), 7.04-7.00 (m, 8H, 4 × *m*-Ar*H,* 4 × *m'*-Ar*H*),), 6.69 (d, *J* 7.3, 4H, 4 × *o'*-Ar*H*), 6.50 (d, *J* 2.6, 2H, C(8)*H,* C(8')*H*), 4.74 (s, 2H, 2 × -C*H*-), 3.42 (s, 6H, 2 × -OC*H*$_3$); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 171.0 (2 × *C*=O), 158.4 (*C*(7), *C*(7')), 147.4 (*C*(2), *C*(2')), 137.9 (*i*-Ar*C*H), 137.8 (*i'*-Ar*C*H), 134.7 (*C*(8a), *C*(8a')), 129.6 (*C*(5), *C*(5')), 129.3 (*C*(4), *C*(4'), 128.7 (2 × *o*-Ar*C*H), 128.6 (2 × *m*-Ar*C*H), 128.4 (2 × *m'*-Ar*C*H), 128.3 (2 × *o'*-Ar*C*H), 127.3 (*p*-Ar*C*H), 127.2 (*C*(4a), *C*(4a')), 127.0 (*p'*-Ar*C*H), 122.4 (*C*(1), *C*(1)'), 119.1 (*C*(3), *C*(3')), 118.8 (*C*(6), *C*(6')), 104.5 (*C*(8), *C*(8')), 56.7 (2 × -*C*H-), 55.2 (2 × -O*C*H$_3$); HRMS (NSI$^+$) $C_{50}H_{38}O_6$ $[M+NH_4]^+$ found 752.3003, requires 752.3007 (−0.5 ppm)

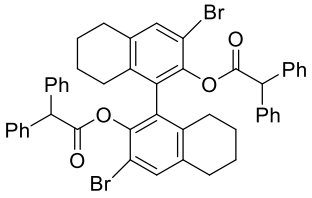
5,5',6,6',7,7',8,8'-Octahydro-[1,1'-binaphthalene]-2,2'-diyl bis(2,2-diphenylacetate)



Following general procedure B: 5,5',6,6',7,7',8,8'-Octahydro-1,1'-bi-2-naphthol (58.9 mg, 0.2 mmol) and DMAP (2.4 mg, 0.02 mmol) were added into CH_2Cl_2 (4 mL, 0.05 M) at room temperature, giving a clear solution. Diphenylacetic anhydride (121.8 mg, 0.3 mmol) and *i*Pr_2NEt (27.9 mg, 35 µL, 0.2 mmol) were added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The solution was diluted with EtOAc (10 mL), washed with HCl (1 M. 2 × 10 mL), $NaHCO_3$ (sat., 2 × 10 mL) and brine (10 mL). The organic layer was dried over $MgSO_4$, filtered and concentrated *in vacuo*, to give pale brown oil, which was purified by column chromatography (Isolera 4, Et_2O in petrol, 0% -> 10% over 20 CV) to give 5,5',6,6',7,7',8,8'-octahydro-[1,1'-binaphthalene]-2,2'-diyl bis(2,2-diphenylacetate) (59.3 mg, 43%) as a cloudy gum; R_f = 0.4 (10% Et_2O in petroleum ether); ν_{max} (ATR): 2930 (C-H), 1753 (C=O), 1472 (C=C), 1115 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 7.22-7.19 (m, 6H, 2 × *p*-Ar*H*, 4 × *o/m*-Ar*H*), 7.18-7.12 (m, 10H, 2 × *p*-Ar*H*, 4 × *o*-Ar*H,* 4 × *m*-Ar*H*), 7.02 (d, *J* 8.3, 2H, C(4)*H,* C(4')*H*), 7.00-6.96 (m, 4H, 4 × *o/m*-Ar*H*), 6.83 (d, *J* 8.3, 2H, C(3)*H,* C(3')*H*), 4.89 (s, 2H, 2 × -C*H*-), 2.76-2.72 (m, 2H, C(5)H_2), 2.66-2.61 (m, 2H, C(5')H_2),

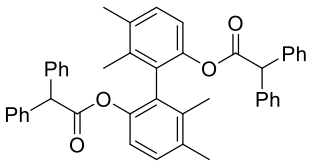
2.18-2.12 (m, 2H, C(8)H_2), 2.08-2.02 (m, 2H, C(8')H_2), 1.65-1.23 (m, 8H, C(6)H_2, C(6')H_2, C(7)H_2, C(7')H_2); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 171.0 (2 × *C*=O), 146.1 (*C*(2), *C*(2')), 138.6 (*i*-Ar*C*H), 138.2 (*i'*-Ar*C*H), 137.6 (*C*(8a), *C*(8a')), 135.2 (*C*(4a), *C*(4a'), 129.4 (*C*(4), *C*(4'), 128.8 (2 × *o/m*-Ar*C*H), 128.7 (2 × *o/m*-Ar*C*H), 128.6 (2 × *o'/m'*-Ar*C*H), 128.4 (2× *o'/m'*-Ar*C*H), 128.2 (*C*(1), *C*(1)'), 127.1 (*p*-Ar*C*H), 127.0 (*p'*-Ar*C*H), 119.3 (*C*(3), *C*(3'), 56.9 (2 × -*C*H-), 29.6 (*C*(5), *C*(5')), 27.0 (*C*(8), *C*(8')), 22.8 (*C*(7), *C*(7')), 22.7 (*C*(6), *C*(6')); HRMS (NSI$^+$) $C_{48}H_{42}O_4$ $[M+H]^+$ found 683.3163, requires 683.3156 (+1.0 ppm)

3,3'-Dibromo-5,5',6,6',7,7',8,8'-octahydro-[1,1'-binaphthalene]-2,2'-diyl bis(2,2-diphenylacetate)



Following general procedure B: 3,3'-Dibromo-5,5',6,6',7,7',8,8'-octahydro-[1,1'-binaphthalene]-2,2'-diol (90.4 mg, 0.2 mmol) and DMAP (2.4 mg, 0.02 mmol) were added into CH_2Cl_2 (4 mL, 0.05 M) at room temperature, giving a clear solution. Diphenylacetic anhydride (121.8 mg, 0.3 mmol) and *i*Pr_2NEt (27.9 mg, 35 µL, 0.2 mmol) were added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The concentrated *in vacuo* and the residue was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 8% over 35 CV) to give 3,3'-dibromo-5,5',6,6',7,7',8,8'-octahydro-[1,1'-binaphthalene]-2,2'-diyl bis(2,2-diphenylacetate) (36.2 mg, 22%) as colorless gum. R_f = 0.44 (20% EtOAc in petroleum ether); ν_{max} (ATR): 2934 (C-H), 1763 (C=O), 1450 (C=C), 1107 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 7.34-6.91 (m, 22H, Ar*H*), 4.99 (s, 2H, 2 × -C*H*-), 1.65-1.52 (m, 16H, 8 × -*C*H_2); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 137.2, 133.4, 128.7, 128.6, 128.4, 127.2, 29.3, 22.4; HRMS (ASAP$^+$) $C_{48}H_{20}Br_2O_4$ $[M+H]^+$ found 839.1364, requires 839.1372 (−1.0 ppm)

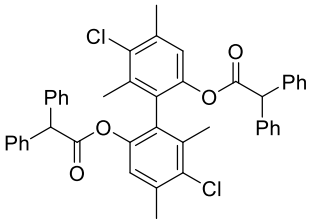
5,5',6,6'-Tetramethyl-[1,1'-biphenyl]-2,2'-diyl bis(2,2-diphenylacetate)



Following general procedure B: 5,5',6,6'-tetramethyl-[1,1'-biphenyl]-2,2'-diol (48.5 mg, 0.2 mmol) and DMAP (2.4 mg, 0.02 mmol) were added into CH_2Cl_2 (4 mL, 0.05 M) at room

temperature, giving a clear solution. 2,2-diphenylacetic anhydride (121.8 mg, 0.3 mmol) and *i*Pr_2NEt (27.9 mg, 35 µL, 0.2 mmol) were added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The solution was concentrated *in vacuo* to give a crude oil, which was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 10% over 40 CV) to give 5,5',6,6'-tetramethyl-[1,1'-biphenyl]-2,2'-diyl bis(2,2-diphenylacetate) (31.5 mg, 24%) as white solids. R_f = 0.49 (20% EtOAc in petroleum ether); mp 113-114 °C; ν_{max} (ATR): 3028 (C-H), 1755 (C=O), 1454 (C=C), 1117 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 7.22-7.20 (m, 6H, 2 × *p'*-Ar*H,* 4 × *m'*-Ar*H*), 7.17-7.08 (m, 10H, 2 × *p*-Ar*H,* 4 × *m*-Ar*H,* 4 × *o*-Ar*H*), 7.08 (d, *J* 8.2, 2H, C(4)*H,* C(4')*H*), 6.92-6.90 (m, 4H, 4 × *o'*-Ar*H*), 6.79 (d, *J* 8.2, 2H, C(3)*H,* C(3')*H*), 4.85 (s, 2H, 2 × -C*H*-), 2.17 (s, 6H, C(5)-CH_3, C(5')-CH_3), 1.74 (s, 6H, C(6)-CH_3, C(6')-CH_3); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 171.1 (× *C*=O), 146.7 (*C*(2), *C*(2')), 138.5 (2 × *i*-Ar*C*H), 138.1 (2 × *i'*-Ar*C*H), 137.4 (*C*(6), *C*(6')), 134.6 (*C*(5), *C*(5')) 129.7 (*C*(4), *C*(4'), 129.1 (*C*(1), *C*(1)), 128.8 (4 × *m*-Ar*C*H), 128.6 (4 × *m'*-Ar*C*H), 128.6 (4 × *o*-Ar*C*H), 128.4 (4 × *o'*-Ar*C*H), 127.2 (2 × *p*-Ar*C*H), 127.0 (2 × *p'*-Ar*C*H), 119.1 (*C*(3), *C*(3')), 56.7 (2 × -*C*H-), 20.4 (2 × -*C*H_3), 16.4 (2 × -*C*H_3); HRMS (NSI$^+$) $C_{44}H_{38}O_4$ $[M+NH_4]^+$ found 648.3100, requires 648.3108 (−1.3 ppm)

5,5'-Dichloro-4,4',6,6'-tetramethyl-[1,1'-biphenyl]-2,2'-diyl bis(2,2-diphenylacetate)



Following general procedure B: 5,5'-dichloro-4,4',6,6'-tetramethyl-[1,1'-biphenyl]-2,2'-diol (62.2 mg, 0.2 mmol) and DMAP (2.4 mg, 0.02 mmol) were added into CH_2Cl_2 (4 mL, 0.05 M) at room temperature, giving a clear solution. 2,2-diphenylacetic anhydride (121.8 mg, 0.3 mmol) and *i*Pr_2NEt (27.9 mg, 35 µL, 0.2 mmol) were added to the previous solution. The resulted clear solution was left stirring for 18 hours at room temperature. The solution was concentrated *in vacuo* to give a crude oil, which was purified by column chromatography (Isolera 4, EtOAc in petrol, 0% -> 10% over 35 CV) to give 5,5'-dichloro-4,4',6,6'-tetramethyl-[1,1'-biphenyl]-2,2'-diyl bis(2,2-diphenylacetate) (17.3 mg, 12.4%) as white solids. R_f = 0.69 (20% EtOAc in petroleum ether); mp 207-208 °C; ν_{max} (ATR): 3030 (C-H), 1757 (C=O), 1454 (C=C), 1119 (C-O); **^{1}H NMR** (500 MHz, $CDCl_3$) δ_H: 7.24-7.21 (m, 6H, 2 × *p*-Ar*H,* 4 × *m*-Ar*H*), 7.20-7.15 (m, 10H, 2 × *p'*-Ar*H,* 4 × *m'*-Ar*H,* 4 × *o*-Ar*H*), 6.98-6.96 (m, 4H, 4 × *o'*-Ar*H*), 6.73 (s, 2H, 2 × C(3)*H*), 4.87 (s, 2H, 2 × -C*H*-), 2.35 (s, 6H, C(5)-CH_3, C(5')-CH_3), 1.90 (s, 6H, C(6)-CH_3,

C(6')-C*H*$_3$); **^{13}C {^{1}H} NMR** (125 MHz, $CDCl_3$) δ_C: 170.7 (2 × *C*=O), 146.4 (*C*(2), *C*(2')), 137.9 (2 × *i*-Ar*C*H), 137.9 (2 × *i'*-Ar*C*H), 137.0 (*C*(6), *C*(6'), *C*(4), *C*(4')), 132.6 (*C*(5), *C*(5')), 128.7 (4 × *m/m'/o*-Ar*C*H), 128.7 (4 × *m/m'/o*-Ar*C*H), 128.5 (4 × *o*-Ar*C*H), 128.4 (4 × *m/m'/o*-Ar*C*H), 127.5 (*C*(1), *C*(1)), 127.4 (2 × *p*-Ar*C*H), 127.2 (2 × *p'*-Ar*C*H), 121.9 (*C*(3), *C*(3')), 56.6 (2 × -*C*H-), 21.2 (2 × -*C*H_3), 17.8 (2 × -*C*H_3); HRMS (NSI$^+$) $C_{44}H_{36}Cl_2O_4$ $[M+NH_4]^+$ found 716.2324, requires 716.2329 (−0.7 ppm)

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