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# 1,2-Stereochemical Induction in the $Pd^{II}$-Catalyzed Conjugate Addition of Boronic Acids

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Palladium(II) catalysis has been used in the substrate-controlled 1,2-chiral induction of the conjugate addition of boronic acids to enantiopure α,β-unsaturated ketones and esters without competition from the Mirozoki–Heck reaction. Bedford's palladacycle was found to control the stereoselectivity without the need for additional chiral ligands. We report that the $Pd^{II}$-catalyzed conjugate addition reaction between boronic acids and acyclic ketones or esters that bear a hydroxyl substituent at their γ-position (glyceraldehyde derivatives) can afford high levels of *anti* stereoselection, comparable to those reported previously using more expensive $Rh^{I}$ catalysts. On the other hand, high levels of *syn* stereoselectivity were observed with acyclic esters that bear an amino substituent at their γ-position (serine derivatives). In this case, the levels of stereoselection could be enhanced by using cyclic derivatives derived from Garner's aldehyde.

## Introduction

The development of new methods that allow for the stereoselective formation of C–C bonds is a hot topic of continuing interest in organic synthesis. Current research is focused on finding catalytic reactions that are highly selective and functional-group tolerant, and that make use of readily available starting materials.[1] Of the different methods available for C–C bond formation, the addition of carbon-centered nucleophiles to electron-deficient alkenes constitutes one of the most relevant towards this end.[2] Many types of organometallic reagents have been used for this type of transformation. Among them, boronic acids and their derivatives stand out because of their easy manipulation; they do not require handling under inert atmosphere, and they do not require the use of low temperatures or anhydrous solvents.[3] In addition, these reagents have low toxicity, as they are finally degraded to boric acid. The sum of all these characteristics makes boronic acids highly attractive chemicals for large-scale synthesis compared with other classes of reagents. Furthermore, many boronic acids have become commercially available or can be easily prepared. Another important feature of boronic acids is their relatively low intrinsic nucleophilicity. Mayr et al. developed a scale to quantify the nucleophilicity of commonly used reagents in C–C bond-forming reactions.[4] According to this rationale, the nucleophilicity of boronic acids has been established to be between that of organolithium and organosilicon compounds.[5] Thus, boronic acids tolerate sensitive functional groups that are readily attacked by conventional organometallic nucleophiles. Additionally, boronic acids are not Brønsted-basic, so their use is compatible with the presence of OH and NH groups.[3] This is important to minimize the number of protection–deprotection steps in multistep syntheses. In addition, the presence of this type of unprotected group on the substrate may help to control the stereochemistry of a C–C bonding process either by chelation effects or by hydrogen-bond formation. As a result of their low nucleophilicity, C–C bond-forming reactions with boronic acids usually require some type of activation. Most of these transformations have been promoted by transition-metal complexes under catalytic conditions.[6] In particular, the transition-metal-catalyzed conjugate addition of boronic acids and their derivatives to α,β-unsaturated carbonyl compounds, the Hayashi–Miyaura reaction, has been extensively developed. $Rh^{I}$ complexes have become the most popular catalysts for these reactions since they were first introduced in 1997.[7,8] Nevertheless, because of the high price of Rh, alternative catalysts with less expensive transition metals have also been pursued. In this regard, dicationic $Pd^{II}$ complexes and some $Pd^{II}$-palladacycles have proven to be useful in conjugate additions, with minor competition from the Mizoroki–Heck reaction typical of other Pd-based systems.[9] However, the number of examples reported for the Pd-catalyzed conjugate addition reaction of boronic acids remains low in comparison with those using $Rh^{I}$-catalysis.[10]

Control of the stereoselectivity is a fundamental issue in conjugate addition reactions. This has been achieved mainly by using a variety of chiral ligands attached to the transition-metal catalysts.[11] On the other hand, the exploitation

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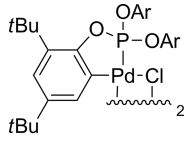
of 1,2-stereochemical induction in conjugate additions to enantiopure acceptor substrates in the absence of external chiral ligands has been much less often considered.[12] We have previously explored the 1,2-stereochemical induction in the $Rh^{I}$-catalyzed reactions of boronic acids both with acyclic and cyclic substrates.[13] These reactions gave rise to a variety of interesting intermediates with a diverse range of scaffolds. On the other hand, to our knowledge, $Pd^{II}$-catalysis has not been considered in this context. We wondered whether the use of $Pd^{II}$-catalysis could also be a valuable way to achieve good results in the substrate-controlled 1,2-stereoselective induction of conjugate addition reactions to enantiopure ketones and esters without competition from the Mirozoki–Heck reaction and without the need for chiral ligands on the metal.

## Results and Discussion

Acyclic γ-oxygen-substituted enones and enoates have been used as starting materials for the conjugate addition of arylcopper[14] and organolithium[15] reagents. These types of compounds are poor substrates for conjugate addition reactions because the heteroatom substituent at the γ-position makes the β-carbon less electrophilic. The products of these reactions are valuable intermediates in the synthesis of natural products and pharmaceuticals.

We started our research by considering the conjugate addition reactions of arylboronic acids to the D-glyceraldehyde acetonide derived acyclic ketone **1a** using different $Pd^{II}$ catalysts that have proven to be useful[16,17] to favor conjugate addition over the Mirozoki–Heck reaction (Table 1).[18]

We were pleased to find that the conjugate addition reaction occurred smoothly by using a set of different $Pd^{II}$ catalysts with no competition from the Mirozoki–Heck reactions. The *anti*-diastereomer was favored in all cases. However, our results showed that diastereoselectivities where not high when dicationic $Pd^{II}$ catalysts were used (Table 1, entries 1–5).[16] On the other hand, the use of one of the palladacycle catalysts developed by Bedford et al.[17] (Figure 1) allowed the conjugate addition reaction to take place with high diastereoselectivity (Table 1, entries 6–10). We observed that the base and the solvent played a role in the outcome of the reaction. Best results were obtained when $K_3PO_4$ or $Cs_2CO_3$ in toluene were used at room temp. (Table 1, entries 6 and 9).



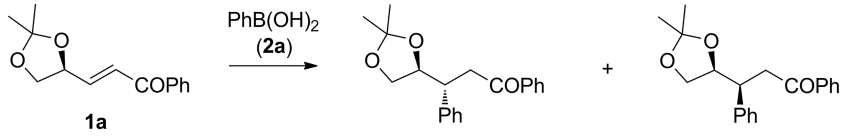

**4**

Figure 1. Bedford's catalyst **4** (Ar = 2,4-di-*t*Bu-$C_6H_3$).

We then extended the reaction using the $Pd^{II}$-palladacycle **4** to other δ-oxygen-substituted ketones **1b–f** (Table 2).[19,20]

The reaction also took place when alkyl ketone **1b** was used as starting material (Table 2, entry 1), although the diastereoselectivity was slightly lower than that observed with arylketone **1a** (Table 1, entry 6). Variations in the protection of the oxygen functionalities affected the level of diastereoselectivity. Thus, whereas the cyclohexanone acetal (Table 2, entry 2) afforded similar results to that of the acetone acetal (Table 1, entry 5), protection as a dioxane (Table 2, entry 3) gave poorer results. When the oxygen atoms were not engaged in ring formation (Table 2, entry 4), only a 70:30 *anti*/*syn* ratio was observed. It is worth mentioning that in all these cases (Table 1 and Table 2, en-

Table 1. Conjugate addition of phenylboronic acid **2a** to ketone **1a** under $Pd^{II}$ catalysis.[a]



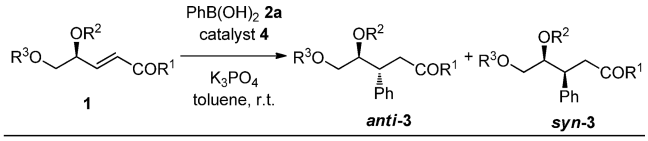

**1a** *anti*-**3a** *syn*-**3a**

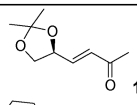
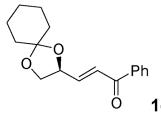
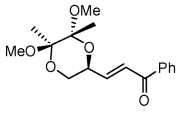
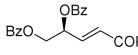
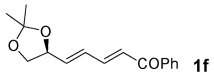
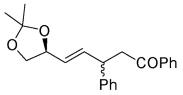
| Entry | $Pd^{II}$ catalyst (mol-%) | Additives [equiv.] | Solvent | *anti*-**3a**/*syn*-**3a** ratio[b] (% yield)[c] |
|---|---|---|---|---|
| 1 | $Pd(OCOCF_3)_2$ (10) | dppben (0.1), $HBF_4$ (1.0) | dioxane/$H_2O$, 10:1 | 70:30 (80)[d] |
| 2 | $Pd(OCOCF_3)_2$ (10) | dpp(ethy) (0.1), $HBF_4$ (1.0) | dioxane/$H_2O$, 10:1 | 70:30 (50)[d] |
| 3[e] | $Pd(OAc)_2$ (5) | bpy (0.06) | MeOH | 60:40 (70)[d] |
| 4[f] | $Pd(OAc)_2$ (6) | $P(OPh)_3$ (0.05), $CsCO_3$ (1.66) | DMF | 70:30 (80) |
| 5[e] | $Pd_2(dba)_3$·$CHCl_3$ (2.5) | $PPh_3$ (0.05), $Cs_2CO_3$ (1.0) | toluene | 80:20 (85) |
| 6 | **4** (5) | $K_3PO_4$ (1.0) | toluene | 90:10 (95) |
| 7 | **4** (5) | $K_3PO_4$ (1.0) | $CH_2Cl_2$ | 90:10 (90) |
| 8 | **4** (5) | $K_3PO_4$ (1.0) | THF | 80:20 (60) |
| 9 | **4** (5) | $Cs_2CO_3$ (1.0) | toluene | 90:10 (95) |
| 10 | **4** (5) | KF (1.0) | toluene | 90:10 (90) |

[a] Reactions were carried out at room temp. for 18 h unless otherwise stated. [b] Determined by integration of the signals of the $^1H$ NMR spectra (300 MHz, $CDCl_3$) of the crude reaction products. Key signals: $\delta$ = 4.32 (dt, *anti*-**3a**), 4.42 (ddd, *syn*-**3a**) ppm. [c] Combined yield after purification by column chromatography on silica gel. [d] No deprotection of the acetonide was observed despite the presence of $HBF_4$ in MeOH or $H_2O$. [e] Reaction carried out at 80 °C. [f] Reaction carried out at 75 °C.

Table 2. Conjugate addition of phenylboronic acid **2a** to ketones **1** catalyzed by palladacycle **4**.[a]



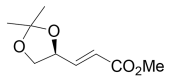
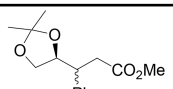
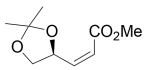
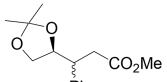
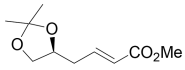
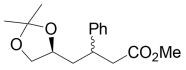
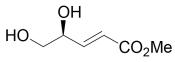
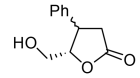
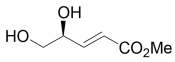
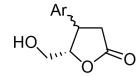
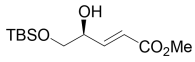
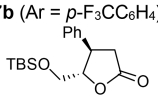
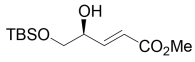
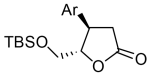
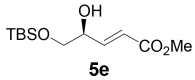
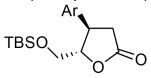
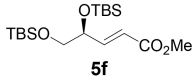
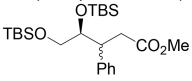

| Entry | 1 | *anti*-**3** : *syn*-**3** (ratio)[b] | % Yield[c] |
|---|---|---|---|
| 1 |  **1b** | **3b** (85:15) | 96 |
| 2 |  **1c** | **3c** (90:10) | 78 |
| 3 |  **1d** | **3d** (85:15) | 95 |
| 4 |  **1e** | **3e** (70:30) | 77 |
| 5 |  **1f** |  **3f** (50:50) | 88 |

[a] Reaction conditions: **2** (2.0 equiv.), base (1.0 equiv.), cat. **4** (5% mol), toluene, r.t., 18 h. [b] Determined by integration of the signals of the $^1$H NMR spectra (300 MHz, $CDCl_3$) of the crude reaction products. [c] Combined yield after purification by column chromatography on silica gel.

tries 1–4), the *anti*-diastereoisomer was the major reaction product, and no Mirozoki–Heck byproducts were detected in the crude reaction mixtures. Finally, reaction of phenylboronic acid **2a** with dienone **1f** (Table 2, entry 5) afforded exclusively the 1,4-addition product as a 50:50 mixture of the *anti* and *syn* diastereoisomers.

We then considered the reactions with γ-oxygen-substituted esters. In comparison with ketones, linear α,β-unsaturated esters are known to be less reactive to the transition-metal-catalyzed addition of boronic acids. Pd catalysis in the conjugate addition of boronic acids to esters has been much less attended in the literature in comparison with $Rh^I$-catalyzed reactions. By using the $Pd^{II}$-palladacycle **4** as catalyst under the same reaction conditions as previously used in the reactions of ketones (Table 3), we observed that both esters **5a** and **5b**, which differ in the geometry of the double bond, afforded the conjugate addition product upon reaction with phenylboronic acid **2a** with the same level of 1,2-stereoselective induction (Table 3, entries 1 and 2). This can be understood by assuming *Z*/*E* isomerization upon complexation between the substrates and the transition-metal complex prior to the addition of the nucleophile. The behavior of these esters, which have their γ- and δ-oxygen atoms protected as 1,3-dioxolane, was similar to that previously observed for arylketone **1a** (Table 1, entry 6) and alkylketone **1b** (Table 2, entry 1), which bear the same type of protection of the oxygen functionalities. Major formation of the *anti*-diastereoisomer was observed in all these cases. In contrast, 1,3-stereoselective induction was poor when starting from ester **5c** (Table 3, entry 3).

Table 3. Conjugate addition of arylboronic acids **2** to esters **5** catalyzed by palladacycle **4**.[a]

| Entry | 5 | Products | *anti*:*syn* / *trans*:*cis* ratio[b] (% yield)[c] |
|---|---|---|---|
| 1 |  **5a** |  **6a** | 90:10 (88) |
| 2 |  **5b** |  **6a** | 90:10 (86) |
| 3 |  **5c** |  **6b** | 60:40 (70) |
| 4 |  **5d** |  **7a** | 70:30 (76) |
| 5 |  **5d** |  **7b** (Ar = *p*-$F_3CC_6H_4$) | 75:25 (80) |
| 6 |  **5e** |  **8a** | >98:02 (70) |
| 7 |  **5e** |  **8b** (Ar = *p*F-$C_6H_4$) | >98:02 (70) |
| 8 |  **5e** |  **8c** (Ar = *p*-MeO$C_6H_4$) | >98:02 (75) |
| 9 |  **5f** |  **9** | 50:50 (20) |

[a] Reaction conditions: **2** (2.0 equiv.), base (1.0 equiv.), cat. **4** (5% mol), toluene, r.t., 18 h. [b] Determined by integration of the signals of the $^1$H NMR spectra (300 MHz, $CDCl_3$) of the crude reaction products. [c] Combined yield after purification by column chromatography on silica gel.

A drop in diastereoselectivity was experienced when the unprotected compound **5d** was used as substrate (Table 3, entries 4 and 5). In these cases, lactones **7**, which arise from intramolecular transesterification of the conjugate addition esters in situ, were obtained as the only reaction products. However, protection of the primary OH group as the TBS derivative afforded exclusively the TBSO-lactone *trans*-**8** (Table 3, entries 6–8). Simultaneous protection of the primary and secondary OH groups as TBS derivatives rendered the corresponding conjugate addition products **9** in low yield and as a 50:50 mixture of the *anti*- and *syn*-diastereoisomers (Table 3, entry 9).

These results indicate the strong influence of the functionalization of the hydroxyl groups of the substrate on the stereochemical outcome of the reaction. Taking into ac-

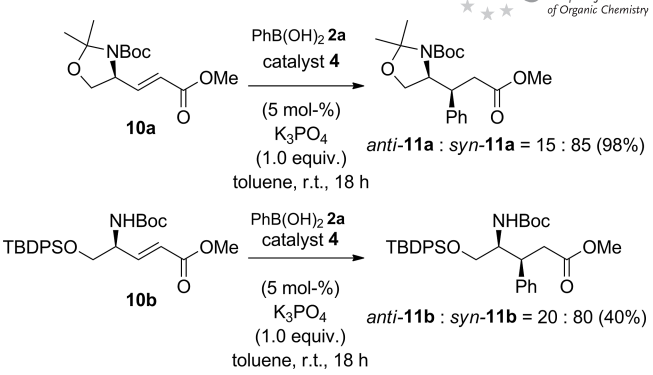
count the practical interest of transformations in the absence of protecting groups, we turned our attention back to the conjugate addition reactions of ester **5d**, where both γ- and δ-oxygen functionalities are free hydroxyl groups.

To enhance the diastereoselectivity of the conjugate addition reactions of boronic acids to this substrate, we devised an alternative protocol that consisted of using the boronic acid as a traceless protecting group of the 1,2-dihydroxy functionality in such a way that the transfer of the nucleophile could take place in an intramolecular fashion (Table 4). Therefore, a cyclic boronate ester was generated between reaction of **5d** and the corresponding boronic acid **2**.[21] Without isolation, these intermediates were treated with catalyst **6** in the presence of the base ($K_3PO_4$). This protocol furnished lactones **7** derived from the conjugate addition products (not isolated) with an increased diastereomeric ratio.

Finally, we studied the 1,2-stereoselective induction in α,β-unsaturated esters and lactones that bear a nitrogen substituent at their γ-position. The intermolecular conjugate addition of boronic acids to acyclic γ-nitrogen-substituted α,β-unsaturated carbonyl compounds has only been reported for Rh$^{I}$ catalysis.[22,23] These reactions required the aid of chiral ligands attached to the metal to achieve good levels of diastereoselectivity. To our knowledge, the addition of boronic acids to lactones derived from serine has not been reported.[24]

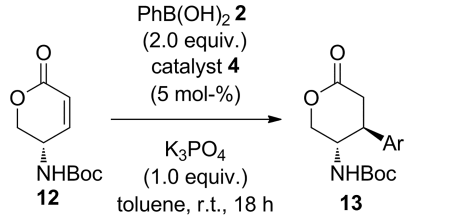
We have considered herein firstly the substrate-controlled addition of phenylboronic acid **2a** to the serine-derived acyclic compounds **10a** and **10b**, which differ in the protection of the δ-oxygen functionality (Scheme 1), using palladacycle **4**. In contrast to the γ-oxygen-substituted substrates, in these cases we have observed the formation of the *syn*-reaction products as the major diastereomers.

With regard to cyclic substrates, we have observed that the diastereoselectivity of the conjugate addition reaction of boronic acids to the γ-nitrogen-substituted esters could be greatly enhanced when serine-derived lactones **12** are used.




Scheme 1. Conjugate addition of phenylboronic acid **2a** to esters **10a** and **10b** catalyzed by palladacycle **4**.

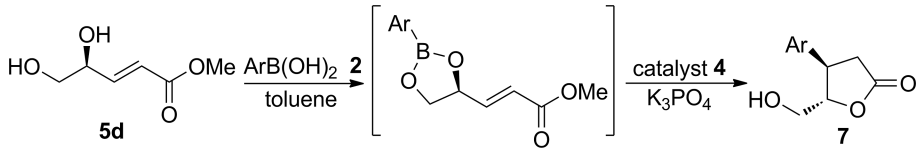
In these cases, we observed the exclusive formation of the *trans*-diastereomers **13** (Scheme 2) within the limits of NMR detection ($CDCl_3$, 300 MHz). The reaction was found to be very general, tolerating aryl groups with electron-withdrawing or electron-releasing substituents, as well as substitution at the *ortho* position.




**13a**, Ar = Ph (96 %)
**13b**, Ar = *p*CF$_3$-C$_6$H$_4$ (71 %)
**13c**, Ar = *p*F-C$_6$H$_4$ (84 %)
**13d**, Ar = *p*MeO-C$_6$H$_4$ (96 %)
**13e**, Ar = *o*F-C$_6$H$_4$ (85 %)
**13f**, Ar = *o*Br-C$_6$H$_4$ (84 %)

Scheme 2. Conjugate addition of arylboronic acids **2** to lactone **12** catalyzed by palladacycle **4**.

Table 4. Alternative protocol for the conjugate addition of arylboronic acids **2** to ester **5d** catalyzed by palladacycle **4**.[a]

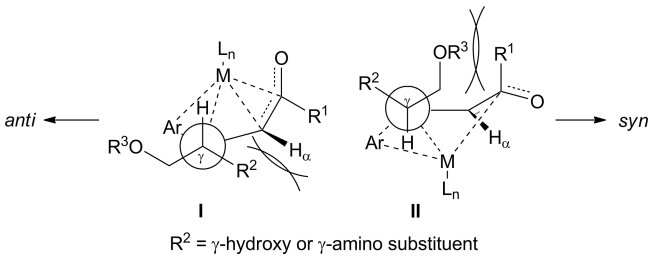



| Entry | Ar | *trans*-**7**/*cis*-**7** ratio[b] | Yield (%)[c] |
|---|---|---|---|
| 1 | Ph | **7a**, 91:09 | 74 |
| 2 | *p*-F$_3$CC$_6$H$_4$ | **7b**, 90:10 | 66 |
| 3 | *p*-FC$_6$H$_4$ | **7c**, 89:11 | 69 |
| 4 | *p*-BrC$_6$H$_4$ | **7d**, 90:10 | 65 |
| 5 | *p*-MeOC$_6$H$_4$ | **7e**, 90:10 | 80 |
| 6 | 3,4-(MeO)$_2$C$_6$H$_3$ | **7f**, 88:12 | 78 |
| 7 | 3,4,5-(MeO)$_3$C$_6$H$_2$ | **7g**, 85:15 | 76 |

[a] Reaction conditions: i. premix **2** (1.0 equiv.) with **5d** for 18 h; ii. base (1.0 equiv.), cat. **4** (5% mole), toluene, r.t., 18 h. [b] Determined by integration of the signals of the $^1$H NMR spectra (300 MHz, $CDCl_3$) of the crude reaction products. [c] Combined yield after purification by column chromatography on silica gel.

The stereochemistry of the conjugate addition reactions to acyclic substrates catalyzed by palladacycle **4** can be understood on the basis of the reductive model proposed by Kornienco et al.[25] for conjugate additions of cuprate reagents to α,β-unsaturated carbonyl compounds in the presence of γ-amino or γ-hydroxy stereocenters (Scheme 3).




Scheme 3. Transition-state models for the $Pd^{II}$-catalyzed conjugate addition reactions of organoboronic acids to acyclic enones and enoates.

Both transition-state models minimize the steric interactions between the metal and its ligands with the groups $R^2$ and $CH_2OR^3$. From steric arguments, model **I** is destabilized by 1,3-allylic strain between the α-H and the $R^2$ group, whereas model **II** is destabilized by 1,3-allylic strain between the $H_\alpha$ and the $CH_2OR^3$ group.

However, from an electronic standpoint, in model **I** the approach of the nucleophile takes place antiperiplanar to $C_\gamma$-$R^2$, which has the σ* orbital of lowest energy of the three bonds to $C_\gamma$ ($R^2$ = amino or hydroxyl substituent). This is not the case in model **II**, in which the attack takes place *anti* to a C–C bond ($CH_2OR^3$ group). This type of interaction permits the major formation of the *anti* isomers when $R^2$ is not a highly sterically demanding hydroxyl substituent to be understood, and explains the increase of the *anti* diastereoselectivity with a bulky $CH_2OR^3$ group. The situation is reversed for bulky $R^2$ groups, for which steric arguments override electronic considerations. This is the case for the NBoc derivatives, which render the *syn* products as the major isomers. Similarly, the *trans*-addition to lactones **12** can be understood by steric control of the bulky γ-amino substituent.

## Conclusions

We have developed the substrate-controlled 1,2-stereoselective induction of the $Pd^{II}$-catalyzed intermolecular conjugate addition of boronic acids to acyclic α,β-unsaturated esters or ketones that bear a γ-hydroxyl or γ-amino stereocenter. Our results show that Bedford's palladacycle **4** performed best in terms of yields and stereoselectivities, without competition from the Mirozoki–Heck reaction. No extra chiral ligands were required to achieve good levels of diastereoselectivity. The *anti* isomers where the major reaction products when starting from substrates with relatively nonbulky γ-hydroxyl substituents; steric bulk of the δ-substituents enhanced the diastereoselectivity. An alternative protocol was devised to deal with compounds with free γ,δ-diol moieties, which avoided the use of protecting groups. On the other hand, the *syn* isomers where obtained as the major reaction products when substrates with γ-amino substituents were used. The stereoselectivity of this type of reaction could be greatly increased by using lactones as starting materials.

## Experimental Section

**General Methods:** All starting materials were commercially available research-grade chemicals, and were used without further purification. The catalysts were commercially available. All solvents were dried by standard methods and distilled under argon. Silicagel 60 F254 was used for TLC, and the spots were detected with UV light or $KMnO_4$ solution. Flash column chromatography was carried out on silica gel 60. $^1H$ NMR spectra were recorded at 300 or 400 MHz and $^{13}C$ NMR spectra were recorded at 75 or 100 MHz, both in $CDCl_3$ solution, unless otherwise stated.

**Reaction of Ketones 1 or Esters 5 and Boronic Acids 2 Catalyzed by 4. General Procedure:** To a stirred solution of $ArB(OH)_2$ **2** (2.0 equiv.) in toluene (4 mL/mmol) were added the unsaturated substrate **1** or **5** (1.0 equiv.), $K_3PO_4$ (1.0 equiv.), and catalyst **4** (5% mol). The resulting mixture was stirred overnight at room temperature, quenched with water (15 mL), extracted with dichloromethane (3 × 10 mL), and dried ($MgSO_4$). The filtrate was concentrated under reduced pressure. The products were isolated by column chromatography (silica gel; hexane/EtOAc, 8:2).

**(*R*)-3-[(*S*)-2,2-Dimethyl-1,3-dioxolan-4-yl]-1,3-diphenylpropan-1-one (*anti*-3a):** Yield 43.2 mg (81%). $^1H$ NMR (300 MHz, $CDCl_3$): $\delta$ = 7.86–7.95 (m, 2 H, ArH), 7.48–7.56 (m, 1 H, ArH), 7.38–7.45 (m, 2 H, ArH), 7.15–7.32 (m, 5 H, ArH), 4.32 (dt, *J* = 9.1, 6.2 Hz, 1 H, O-C*H*), 3.76 (dd, *J* = 8.5, 6.2 Hz, 1 H, OC$H_2$), 3.68 (dd, *J* = 15.6, 2.3 Hz, 1 H, C$H_2$-COPh), 3.61 (dd, *J* = 8.5, 6.3 Hz, 1 H, OC$H_2$), 3.36–3.53 (m, 2 H, C*H*-Ph, C$H_2$-COPh), 1.44 (s, 3 H, C$H_3$), 1.37 (s, 3 H, C$H_3$) ppm. $^{13}C$ NMR (75 MHz, $CDCl_3$): $\delta$ = 198.6 (*C*=O), 141.1 ($C_{Ar}$), 137.3 ($C_{Ar}$), 133.0 ($C_{ArH}$), 128.8 (2$C_{ArH}$), 128.6 (2$C_{ArH}$), 128.2 (2$C_{ArH}$), 128.2 (2$C_{ArH}$), 127.2 ($C_{ArH}$), 109.8 (Me-*C*-Me), 79.4 (O-*C*H), 68.5 (*C*$H_2$-O), 45.8 (*C*H-$CH_2$-CO), 42.4 (CH-*C*$H_2$-CO), 27.0 (*C*$H_3$), 25.8 (*C*$H_3$) ppm. $C_{20}H_{20}O_3$ (310.39): calcd. C 77.39, H 7.14; found C 77.51, H 7.20.

**(*S*)-3-[(*S*)-2,2-Dimethyl-1,3-dioxolan-4-yl]-1,3-diphenylpropan-1-one (*syn*-3a):** Yield 4.8 mg (9%). $^1H$ NMR (300 MHz, $CDCl_3$): $\delta$ = 7.92–7.98 (m, 2 H, ArH), 7.50–7.58 (m, 1 H, ArH), 7.40–7.48 (m, 2 H, ArH), 7.18–7.32 (m, 5 H, ArH), 4.42 (ddd, *J* = 10.8, 6.3, 4.3 Hz, 1 H, O-C*H*), 3.95 (dd, *J* = 8.0, 6.3 Hz, 1 H, OC$H_2$), 3.67 (ddd, *J* = 10.3, 5.9, 4.3 Hz, 1 H, C$H_2$-COPh), 3.57 (t, *J* = 8.0 Hz, 1 H, OC$H_2$), 3.39–3.53 (m, 2 H, C*H*-Ph, C$H_2$-COPh), 1.31 (s, 3 H, C$H_3$), 1.27 (s, 3 H, C$H_3$) ppm. $^{13}C$ NMR (75 MHz, $CDCl_3$): $\delta$ = 198.5 (*C*=O), 140.2 ($C_{Ar}$), 137.3 ($C_{Ar}$), 133.2 ($C_{ArH}$), 129.2 (2$C_{ArH}$), 128.7 (2$C_{ArH}$), 128.4 (2$C_{ArH}$), 128.2 (2$C_{ArH}$), 127.1 ($C_{ArH}$), 109.2 (Me-*C*-Me), 78.2 (O-*C*H), 66.8 (*C*$H_2$-O), 42.6 (*C*H-$CH_2$-CO), 40.8 (CH-*C*$H_2$-CO), 26.4 (*C*$H_3$), 25.5 (*C*$H_3$) ppm. $C_{20}H_{20}O_3$ (310.39): calcd. C 77.39, H 7.14; found C 77.53, H 7.21.

**(*R*)-4-[(*S*)-2,2-Dimethyl-1,3-dioxolan-4-yl]-4-phenylbutan-2-one (*anti*-3b):** Yield 47.8 mg (85%). $^1H$ NMR (300 MHz, $CDCl_3$): $\delta$ = 7.09–7.26 (m, 5 H, ArH), 4.12 (dt, *J* = 9.3, 6.4 Hz, 1 H, O-C*H*), 3.64 (dd, *J* = 8.5, 6.4 Hz, 1 H, OC$H_2$), 3.48 (dd, *J* = 8.5, 6.4 Hz, 1 H, OC$H_2$), 3.20 (td, *J* = 9.3, 4.6 Hz, 1 H, C*H*-Ph), 3.03 (dd, *J* = 16.6, 4.6 Hz, 1 H, C$H_2$-COPh), 2.97 (dd, *J* = 16.6, 9.3 Hz, 1 H, C$H_2$-COPh), 1.91 (s, 3 H, CO-C$H_3$), 1.35 (s, 3 H, C$H_3$), 1.27 (s, 3 H, C$H_3$) ppm. $^{13}C$ NMR (75 MHz, $CDCl_3$): $\delta$ = 207.3 (*C*=O), 140.9 ($C_{Ar}$), 128.8 (2$C_{ArH}$), 128.1 (2$C_{ArH}$), 127.3 ($C_{ArH}$), 109.7 (Me-

*C*-Me), 79.4 (O-*C*H), 68.4 (*C*H$_2$-O), 47.3 (CH-*C*H$_2$-CO), 45.8 (*C*H-CH$_2$-CO), 30.7 (CO*C*H$_3$), 26.9 (*C*H$_3$), 25.8 (*C*H$_3$) ppm. $C_{15}H_{20}O_3$ (248.32): calcd. C 72.55, H 8.12; found C 72.51, H 8.20.

**(*S*)-4-[(*S*)-2,2-Dimethyl-1,3-dioxolan-4-yl]-4-phenylbutan-2-one (*syn*-3b):** Yield 8.4 mg (11%). $^1$H NMR (300 MHz, $CDCl_3$): $\delta$ = 7.10–7.27 (m, 5 H, ArH), 4.11–4.26 (m, 1 H, O-C*H*), 3.82 (dd, *J* = 8.1, 6.4 Hz, 1 H, OC$H_2$), 3.48 (t, *J* = 8.1 Hz, 1 H, OC$H_2$), 3.34–3.42 (m, 1 H, C*H*-Ph), 2.79–2.93 (m, 2 H, C$H_2$-COPh), 2.01 (s, 3 H, CO-C$H_3$), 1.24 (s, 3 H, C$H_3$), 1.21 (s, 3 H, C$H_3$) ppm. $^{13}$C NMR (75 MHz, $CDCl_3$): $\delta$ = 207.1 (*C*=O), 139.9 ($C_{Ar}$), 129.0 (2$C_{ArH}$), 128.5 (2$C_{ArH}$), 127.2 ($C_{ArH}$), 109.2 (Me-*C*-Me), 78.2 (O-*C*H), 66.7 (*C*H$_2$-O), 45.6 (CH-*C*H$_2$-CO), 42.5 (*C*H-CH$_2$-CO), 30.7 (CO*C*H$_3$), 26.4 (*C*H$_3$), 25.5 (*C*H$_3$) ppm. $C_{15}H_{20}O_3$ (248.32): calcd. C 72.55, H 8.12; found C 72.53, H 8.19.

**(*R*)-1,3-Diphenyl-3-[(*S*)-1,4-dioxaspiro[4.5]decan-2-yl]propan-1-one (*anti*-3c):** Yield 36.0 mg (70%). $^1$H NMR (300 MHz, $CDCl_3$): $\delta$ = 7.88–7.97 (m, 2 H, ArH), 7.48–7.56 (m, 1 H, ArH), 7.37–7.47 (m, 2 H, ArH), 7.14–7.32 (m, 5 H, ArH), 4.32 (dt, *J* = 9.0, 6.3 Hz, 1 H, O-C*H*), 3.67–3.80 (m, 2 H, OC$H_2$, C$H_2$-COPh), 3.60 (dd, *J* = 8.5, 6.3 Hz, 1 H, OC$H_2$), 3.33–3.53 (m, 2 H, C*H*-Ph, C$H_2$-COPh), 1.49–1.71 (m, 8 H, 4C$H_2$), 1.31–1.46 (m, 2 H, C$H_2$) ppm. $^{13}$C NMR (75 MHz, $CDCl_3$): $\delta$ = 198.7 (*C*=O), 141.2 ($C_{Ar}$), 137.3 ($C_{Ar}$), 132.9 ($C_{ArH}$), 128.7 (2$C_{ArH}$), 128.6 (2$C_{ArH}$), 128.2 (4$C_{ArH}$), 127.1 ($C_{ArH}$), 110.3 (CH$_2$-*C*-CH$_2$), 79.0 (O-*C*H), 68.2 (*C*H$_2$-O), 46.1 (*C*H-CH$_2$-CO), 42.5 (CH-*C*H$_2$-CO), 36.6 (*C*H$_2$), 35.3 (*C*H$_2$), 25.3 (*C*H$_2$), 24.1 (*C*H$_2$), 24.0 (*C*H$_2$) ppm. $C_{23}H_{26}O_3$ (350.45): calcd. C 78.83, H 7.48; found C 78.99, H 7.45.

**(*S*)-1,3-Diphenyl-3-[(*S*)-1,4-dioxaspiro[4.5]decan-2-yl]propan-1-one (*syn*-3c):** Yield 4.0 mg (8%). $^1$H NMR (300 MHz, $CDCl_3$): $\delta$ = 7.92–7.98 (m, 2 H, ArH), 7.50–7.58 (m, 1 H, ArH), 7.40–7.48 (m, 2 H, ArH), 7.16–7.33 (m, 5 H, ArH), 4.39 (ddd, *J* = 10.4, 6.2, 4.1 Hz, 1 H, O-C*H*), 3.93 (dd, *J* = 8.2, 6.2 Hz, 1 H, OC$H_2$), 3.62–3.71 (m, 1 H, C$H_2$-COPh), 3.50–3.61 (m, 2 H, OC$H_2$, C*H*-Ph), 3.44 (dd, *J* = 17.0, 7.7 Hz, 1 H, C$H_2$-COPh), 1.29–1.60 (m, 10 H, 5C$H_2$) ppm. $^{13}$C NMR (75 MHz, $CDCl_3$): $\delta$ = 198.6 (*C*=O), 140.2 (2$C_{Ar}$), 133.2 ($C_{ArH}$), 129.2 (2$C_{ArH}$), 128.7 (2$C_{ArH}$), 128.3 (2$C_{ArH}$), 128.3 (2$C_{ArH}$), 127.0 ($C_{ArH}$), 109.7 (CH$_2$-*C*-CH$_2$), 77.8 (O-*C*H), 66.4 (*C*H$_2$-O), 42.6 (*C*H-CH$_2$-CO), 40.8 (CH-*C*H$_2$-CO), 36.1 (*C*H$_2$), 35.2 (*C*H$_2$), 25.3 (*C*H$_2$), 24.1 (*C*H$_2$), 24.0 (*C*H$_2$) ppm. $C_{23}H_{26}O_3$ (350.45): calcd. C 78.83, H 7.48; found C 78.97, H 7.44.

**(*R*)-3-[(2*S*,5*R*,6*R*)-5,6-Dimethoxy-5,6-dimethyl-1,4-dioxan-2-yl]-1,3-diphenylpropan-1-one (*anti*-3d) and (*S*)-3-[(2*S*,5*R*,6*R*)-5,6-Dimethoxy-5,6-dimethyl-1,4-dioxan-2-yl]-1,3-diphenylpropan-1-one (*syn*-3d):** Yield 47.5 mg (95%); *anti*-**3d**/*syn*-**3d** ratio 85:15. $^1$H NMR (300 MHz, $CDCl_3$): $\delta$ = 7.87–7.93 (m, 2 H, ArH), 7.50–7.58 (m, 1 H, ArH), 7.39–7.49 (m, 2 H, ArH), 7.14–7.33 (m, 5 H, ArH), 4.05–4.16 (m, 1 H, O-C*H*), 3.81 (dd, *J* = 16.4, 4.0 Hz, 1 H, OC$H_2$), 3.42–3.62 (m, 2 H, C$H_2$-COPh, OC$H_2$), 3.35 (s, 3 H, OC$H_3$, *anti*), 3.28 (dd, *J* = 16.4, 6.9 Hz, 1 H, C$H_2$-COPh), 3.25 (s, 3 H, OC$H_3$, *anti*), 3.18 (s, 3 H, OC$H_3$, *syn*), 3.09 (dd, *J* = 11.4, 3.0 Hz, 1 H, C*H*-Ph), 3.06 (s, 3 H, OC$H_3$, *syn*), 1.32 (s, 3 H, C-C$H_3$), 1.29 (s, 3 H, C-C$H_3$) ppm. $^{13}$C NMR (75 MHz, $CDCl_3$): $\delta$ = 198.6 (*C*=O, *anti*), 198.4 (*C*=O, *syn*), 141.2 ($C_{Ar}$, *syn*), 140.3 ($C_{Ar}$, *anti*), 137.4 ($C_{Ar}$, *anti*), 137.2 ($C_{Ar}$, *syn*), 133.1 ($C_{ArH}$, *syn*), 132.9 ($C_{ArH}$, *anti*), 128.7 (2$C_{ArH}$, *syn*), 128.4 (2$C_{ArH}$, *anti*), 128.6 (2$C_{ArH}$), 128.2 (2$C_{ArH}$), 128.2 (2$C_{ArH}$, syn), 128.1 (2$C_{ArH}$, *anti*),127.2 ($C_{ArH}$, *anti*), 126.7 ($C_{ArH}$, *syn*), 99.6 (O-*C*- CH$_3$, *anti*), 99.4 (O-*C*- CH$_3$, *syn*), 97.9 (O-*C*- CH$_3$), 70.2 (O-*C*H, *anti*), 69.7 (O-*C*H, *syn*), 62.7 (*C*H$_2$-O, *anti*), 61.8 (*C*H$_2$-O, *syn*), 48.2 (O*C*H$_3$, *anti*), 48.1 (O*C*H$_3$, *anti*), 47.9 (O*C*H$_3$, *syn*), 43.6 (*C*H-CH$_2$-CO, *anti*), 42.2 (*C*H-CH$_2$-CO, *syn*), 41.4 (CH-*C*H$_2$-CO, *anti*), 41.0 (CH-*C*H$_2$-CO, *syn*), 17.9 (C-*C*H$_3$), 17.6 (C-*C*H$_3$, *anti*), 17.4 (C-*C*H$_3$, *syn*) ppm. $C_{23}H_{28}O_5$ (384.47): calcd. C 71.85, H 7.34; found C 71.98, H 7.45.

**(2*S*,3*R*)-5-Oxo-3,5-diphenylpentane-1,2-diyl Dibenzoate (*anti*-3e) and (2*S*,3*S*)-5-Oxo-3,5-diphenylpentane-1,2-diyl Dibenzoate (*syn*-3e):** Yield 40.0 mg (77%); *anti*-**3e**/*syn*-**3e** ratio 70:30. $^1$H NMR (300 MHz, $CDCl_3$): $\delta$ = 7.78–8.03 (m, 5 H, ArH), 7.20–7.61 (m, 15 H, ArH), 5.94 (dt, *J* = 7.4, 4.3 Hz, 1 H, O-C*H syn*), 5.81 (ddd, *J* = 10.2, 6.1, 2.8 Hz, 1 H, O-C*H anti*), 4.47 (dd, *J* = 12.0, 2.8 Hz, 1 H, OC$H_2$), 4.34 (dd, *J* = 12.0, 8.5 Hz, 1 H, OC$H_2$ *syn*), 4.21 (dd, *J* = 12.0, 6.1 Hz, 1 H, OC$H_2$ *anti*), 4.01–4.15 (m, 1 H C$H_2$-COPh), 3.54 (dd, *J* = 6.1, 3.5 Hz, 1 H, C*H*-Ph *anti*), 3.44–3.55 (m, 3 H, C*H*-Ph *syn*, C$H_2$-COPh) ppm. $^{13}$C NMR (75 MHz, $CDCl_3$): $\delta$ = 197.8 (Ph-*C*=O, *anti*), 197.5 (Ph-*C*=O, *syn*), 166.4 (O-*C*=O, *anti*), 166.2 (O-*C*=O, *syn*), 166.2 (O-*C*=O, *anti*), 166.1 (O-*C*=O, *syn*), 140.1 ($C_{Ar}$, *anti*), 139.2 ($C_{Ar}$, *syn*), 136.9 ($C_{Ar}$), 133.4 ($C_{ArH}$), 133.3 ($C_{ArH}$), 133.2 ($C_{ArH}$), 129.9 ($C_{ArH}$), 129.8 ($C_{ArH}$), 129.8 ($C_{ArH}$), 129.6 ($C_{Ar}$, *anti*), 129.2 ($C_{ArH}$), 129.0 ($C_{ArH}$), 128.8 ($C_{ArH}$), 128.7 ($C_{ArH}$), 128.6 ($C_{ArH}$), 128.6 ($C_{ArH}$), 128.5 ($C_{ArH}$), 128.4 ($C_{ArH}$), 128.2 ($C_{ArH}$), 128.1 ($C_{ArH}$), 127.7 ($C_{ArH}$), 127.5 ($C_{ArH}$), 75.0 (O-*C*H, *anti*), 73.7 (O-*C*H, *syn*), 64.7 (*C*H$_2$-O, *syn*), 64.5 (*C*H$_2$-O, *anti*), 42.6 (*C*H-CH$_2$-CO, *anti*), 42.0 (*C*H-CH$_2$-CO, *syn*), 41.7 (CH-*C*H$_2$-CO, *anti*), 40.8 (CH-*C*H$_2$-CO, *syn*) ppm. $C_{31}H_{26}O_5$ (478.54): calcd. C 71.81, H 5.48; found C 77.74, H 5.51.

**(*S*,*E*)-5-[(*S*)-2,2-Dimethyl-1,3-dioxolan-4-yl]-1,3-diphenylpent-4-en-1-one (*anti*-3f) and (*R*,*E*)-5-[(*S*)-2,2-Dimethyl-1,3-dioxolan-4-yl]-1,3-diphenylpent-4-en-1-one (*syn*-3f):** Yield 45.9 mg (88%); *anti*-**3f**/*syn*-**3f** ratio 50:50. $^1$H NMR (300 MHz, $C_6D_6$): $\delta$ = 7.65–7.76 (m, 2 H, ArH), 6.91–7.22 (m, 8 H, ArH), 5.88 (dt, *J* = 15.5, 6.8 Hz, 1 H, O-CH-CH=C*H*), 5.44 (dd, *J* = 15.5, 7.1 Hz, 1 H, O-CH-C*H*=CH), 4.30 (q, *J* = 6.8 Hz, 1 H, O-C*H*), 4.14–4.25 (m, 1 H, C*H*-Ph), 3.70–3.78 (m, 1 H, OC$H_2$), 3.36 (td, *J* = 7.9, 2.3 Hz, 1 H, OC$H_2$), 3.03 (t, *J* = 7.5 Hz, 2 H, C$H_2$-COPh), 1.39 (s, 3 H, C$H_3$), 1.36 (s, 3 H, C$H_3$), 1.34 (s, 3 H, C$H_3$), 1.33 (s, 3 H, C$H_3$) ppm. $^{13}$C NMR (75 MHz, $C_6D_6$): $\delta$ = 197.0 (Ph-*C*=O), 197.0 (Ph-*C*=O), 143.7 ($C_{Ar}$), 143.4 ($C_{Ar}$), 137.7 ($C_{Ar}$), 136.6 (O-CH-CH=*C*H), 136.6 (O-CH-CH=*C*H), 132.8 ($C_{ArH}$), 132.7 ($C_{ArH}$), 129.0 ($C_{ArH}$), 128.9 ($C_{ArH}$), 128.8 (2$C_{ArH}$), 128.6 (2$C_{ArH}$), 128.6 (2$C_{ArH}$), 126.8 ($C_{ArH}$), 126.8 ($C_{ArH}$), 109.3 (Me-*C*-Me), 77.2 (O-*C*H), 77.2 (O-*C*H), 69.7 (*C*H$_2$-O), 69.7 (*C*H$_2$-O), 44.4 (CH-*C*H$_2$-CO), 44.3 (CH-*C*H$_2$-CO), 43.6 (*C*H-CH$_2$-CO), 43.5 (*C*H-CH$_2$-CO), 27.0 (C-*C*H$_3$), 26.2 (C-*C*H$_3$) ppm. $C_{22}H_{24}O_3$ (336.42): calcd. C 78.54, H 7.19; found C 78.74, H 7.26.

**Methyl (*R*)-3-[(*S*)-2,2-Dimethyl-1,3-dioxolan-4-yl]-3-phenylpropanoate (*anti*-6a):** Yield 45.0 mg (79%). $^1$H NMR (300 MHz, $CDCl_3$): $\delta$ = 7.05–7.27 (m, 5 H, ArH), 4.15 (dt, *J* = 9.3, 6.1 Hz, 1 H, O-C*H*), 3.66 (dd, *J* = 8.5, 6.1 Hz, 1 H, OC$H_2$), 3.49 (dd, *J* = 8.5, 6.1 Hz, 1 H, OC$H_2$), 3.47 (s, 3 H, COO-C$H_3$), 3.14 (td, *J* = 9.3, 4.9 Hz, 1 H, C*H*-Ph), 2.96 (dd, *J* = 15.5, 4.9 Hz, 1 H, C$H_2$-COPh), 2.58 (dd, *J* = 15.5, 9.3 Hz, 1 H, C$H_2$-COPh), 1.37 (s, 3 H, C-C$H_3$), 1.28 (s, 3 H, C-C$H_3$) ppm. $^{13}$C NMR (75 MHz, $CDCl_3$): $\delta$ = 172.7 (*C*=O), 140.4 ($C_{Ar}$), 128.8 (2$C_{ArH}$), 128.1 (2$C_{ArH}$), 127.4 ($C_{ArH}$), 109.8 (Me-*C*-Me), 79.2 (O-*C*H), 68.4 (*C*H$_2$-O), 51.6 (O*C*H$_3$), 46.8 (*C*H-CH$_2$-CO), 38.3 (*C*H$_2$-CO), 27.0 (C-*C*H$_3$), 25.8 (C-*C*H$_3$) ppm. $C_{15}H_{20}O_4$ (264.32): calcd. C 68.16, H 7.63; found C 68.25, H 7.70.

**Methyl (*S*)-3-[(*S*)-2,2-Dimethyl-1,3-dioxolan-4-yl]-3-phenylpropanoate (*syn*-6a):** Yield 5.0 mg (9%). $^1$H NMR (300 MHz, $CDCl_3$): $\delta$ = 7.10–7.27 (m, 5 H, ArH), 4.22–4.31 (m, 1 H, O-C*H*), 3.83 (dd, *J* = 8.2, 6.4 Hz, 1 H, OC$H_2$), 3.52 (s, 3 H, COO-C$H_3$), 3.46–3.54 (m, 1 H, OC$H_2$), 3.29–3.40 (m, 1 H, C*H*-Ph), 2.77 (dd, *J* = 15.7, 6.2 Hz, 1 H, C$H_2$-COPh), 2.66 (dd, *J* = 15.7, 8.7 Hz, 1 H, C$H_2$-COPh), 1.24 (s, 3 H, C-C$H_3$), 1.22 (s, 3 H, C-C$H_3$) ppm. $^{13}$C NMR (75 MHz, $CDCl_3$): $\delta$ = 172.6 (*C*=O), 139.6 ($C_{Ar}$), 128.7 (2$C_{ArH}$),

128.5 (2$C_{ArH}$), 127.3 ($C_{ArH}$), 109.3 (Me-*C*-Me), 78.2 (O-*C*H), 66.6 (*C*$H_2$-O), 51.8 (O*C*$H_3$), 43.8 (*C*H-$CH_2$-CO), 36.3 (*C*$H_2$-CO), 26.4 (C-*C*$H_3$), 25.5 (C-*C*$H_3$) ppm. $C_{15}H_{20}O_4$ (264.32): calcd. C 68.16, H 7.63; found C 68.23, H 7.69.

**(4*S*,5*R*)-5-{[(*tert*-Butyldimethylsilyl)oxy]methyl}-4-phenyl-dihydrofuran-2(3*H*)-one (*trans*-8a):** Yield 24.7 mg (70%); $[\alpha]_D^{28}$ = –16.7 (*c* = 0.59, $CHCl_3$). $^1$H NMR (300 MHz, $CDCl_3$): δ = 7.17–7.41 (m, 5 H, ArH), 4.46–4.53 (m, 1 H, O-C*H*), 3.92 (dd, *J* = 11.8, 2.5 Hz, 1 H, OC$H_2$), 3.61–3.77 (m, 2 H, OC$H_2$, Ph-C*H*), 3.04 (dd, *J* = 17.7, 9.2 Hz, 1 H, C$H_2$-CO), 2.66 (dd, *J* = 17.7, 7.4 Hz, 1 H, C$H_2$-CO), 0.91 [s, 9 H, Si-C-(C$H_3$)$_3$], 0.08 (s, 6 H, Si-C$H_3$) ppm. $^{13}$C NMR (75 MHz, $CDCl_3$): δ = 176.4 (*C*=O), 141.4 ($C_{Ar}$), 129.3 (2$C_{ArH}$), 127.7 ($C_{ArH}$), 127.1 (2$C_{ArH}$), 87.0 (O-*C*H), 63.3 (*C*$H_2$-O), 42.3 (*C*H-Ph), 37.4 (*C*$H_2$-CO), 27.0 [3 Si-C-(*C*$H_3$)$_3$], 18.4 [Si-*C*-(CH$_3$)$_3$], –5.3 (Si-*C*$H_3$), –5.4 (Si-*C*$H_3$) ppm. $C_{17}H_{26}O_3Si$ (306.47): calcd. C 66.62, H 8.55; found C 66.72, H 8.59.

**(4*S*,5*R*)-5-{[(*tert*-Butyldimethylsilyl)oxy]methyl}-4-(4-fluorophenyl)-dihydrofuran-2(3*H*)-one (*trans*-8b):** Yield 39.3 mg (70%); $[\alpha]_D^{28}$ = –32.5 (*c* = 0.78, $CHCl_3$). $^1$H NMR (300 MHz, $CDCl_3$): δ = 7.16–7.23 (m, 2 H, ArH), 7.01–7.08 (m, 2 H, ArH), 4.45- (dt, *J* = 5.9, 2.8 Hz, 1 H, O-C*H*), 3.91 (dd, *J* = 11.6, 2.8 Hz, 1 H, OC$H_2$), 3.62–3.77 (m, 2 H, OC$H_2$, Ph-C*H*), 3.04 (dd, *J* = 17.8, 9.5 Hz, 1 H, C$H_2$-CO), 2.61 (dd, *J* = 17.8, 7.4 Hz, 1 H, C$H_2$-CO), 0.90 [s, 9 H, Si-C-(C$H_3$)$_3$], 0.08 (s, 6 H, Si-C$H_3$) ppm. $^{13}$C NMR (75 MHz, $CDCl_3$): δ = 168.2 (*C*=O), 139.5 ($C_{Ar}$), 128.7 ($C_{ArH}$), 128.6 ($C_{ArH}$), 116.3 ($C_{ArH}$), 116.0 ($C_{ArH}$), 86.9 (O-*C*H), 63.2 (*C*$H_2$-O), 41.7 (*C*H-Ph), 37.5 (*C*$H_2$-CO), 26.0 [3 Si-C-(*C*$H_3$)$_3$], 17.6 [Si-*C*-(CH$_3$)$_3$], –5.3 (Si-*C*$H_3$), –5.4 (Si-*C*$H_3$) ppm. $C_{17}H_{25}FO_3Si$ (324.46): calcd. C 62.93, H 7.77; found C 62.81, H 7.69.

**(4*S*,5*R*)-5-{[(*tert*-Butyldimethylsilyl)oxy]methyl}-4-(4-methoxyphenyl)dihydrofuran-2(3*H*)-one (*trans*-8c):** Yield 39.9 mg (75%); $[\alpha]_D^{28}$ = –28.4 (*c* = 0.66, $CHCl_3$). $^1$H NMR (300 MHz, $CDCl_3$): δ = 7.15 (d, *J* = 8.8 Hz, 2 H, ArH), 6.88 (d, *J* = 8.8 Hz, 2 H, ArH), 4.45 (dt, *J* = 6.2, 2.9 Hz, 1 H, O-C*H*), 3.90 (dd, *J* = 11.7, 2.9 Hz, 1 H, OC$H_2$), 3.80 (s, 3 H, O*C*H$_3$), 3.70 (dd, *J* = 11.7, 2.9 Hz, 1 H, OC$H_2$), 3.58–3.65 (m, 1 H, Ph-C*H*), 3.01 (dd, *J* = 17.9, 9.5 Hz, 1 H, C$H_2$-CO), 2.62 (dd, *J* = 17.9, 7.9 Hz, 1 H, C$H_2$-CO), 0.90 [s, 9 H, Si-C-(C$H_3$)$_3$], 0.08 (s, 6 H, Si-C$H_3$) ppm. $^{13}$C NMR (75 MHz, $CDCl_3$): δ = 176.4 (*C*=O), 159.1 ($C_{Ar}$-O), 132.8 ($C_{Ar}$), 128.1 (2$C_{ArH}$), 114.6 (2$C_{ArH}$), 87.2 (O-*C*H), 63.1 (*C*$H_2$-O), 55.5 (O*C*H$_3$), 41.5 (*C*H-Ph), 37.5 (*C*$H_2$-CO), 26.0 [3 Si-C-(*C*$H_3$)$_3$], 18.4 [Si-*C*-(CH$_3$)$_3$], –5.2 (Si-*C*$H_3$), –5.3 (Si-*C*$H_3$) ppm. $C_{18}H_{28}O_4Si$ (336.50): calcd. C 64.25, H 8.39; found C 64.15, H 8.46.

***tert*-Butyl (*S*)-4-[(*R*)-3-Methoxy-3-oxo-1-phenylpropyl]-2,2-dimethyloxazolidine-3-carboxylate (*anti*-11a) and *tert*-Butyl (*S*)-4-[(*S*)-3-Methoxy-3-oxo-1-phenylpropyl]-2,2-dimethyloxazolidine-3-carboxylate (*syn*-11a):** Yield 26.3 mg (98%). $^1$H NMR (300 MHz, $CDCl_3$, 40 °C): δ = 7.11–7.43 (m, 5 H, ArH), 3.99–4.23 (m, 1 H, N-C*H*), 3.90–3.99 (m, 1 H, OC$H_2$), 3.88 (dd, *J* = 9.8, 1.8 Hz, 1 H, OC$H_2$), 3.65–3.80 (m, 1 H, C*H*-Ph), 3.55 (s, 3 H, COO-C$H_3$ *syn*), 3.51 (s, 3 H, COO-C$H_3$ *anti*), 2.84 (d, *J* = 7.9 Hz, 2 H, C$H_2$-CO *syn*), 2.77 (d, *J* = 7.5 Hz, 2 H, C$H_2$-CO *anti*), 1.54 (s, 12 H, C$H_3$-Boc, C-*C*H$_3$), 1.43 (s, 3 H, C-C$H_3$) ppm. $^{13}$C NMR (75 MHz, $CDCl_3$): δ = 173.1 (*C*O$_2$Me), 157.0 (*C*O$_2$), 140.5 ($C_{Ar}$), 128.7 ($C_{ArH}$), 128.6 ($C_{ArH}$), 128.2 ($C_{ArH}$), 127.8 ($C_{ArH}$), 127.0 ($C_{ArH}$), 94.4 (O-*C*-N), 80.6 [O-*C*-(Me)$_3$], 63.7 (*C*$H_2$-O), 61.7 (N-*C*H), 51.8 (O*C*H$_3$), 43.0 (*C*H-$CH_2$-CO), 32.3 (*C*$H_2$-CO), 28.6 (5C-*C*$H_3$) ppm. $C_{20}H_{29}NO_5$ (363.45): calcd. C 66.09, H 8.04; found C 66.18, H 7.96.

**Alternative Protocol for the Conjugate Addition of Ester 5d with Arylboronic Acids 2 Catalyzed by Palladacycle 4:** A solution of **5d** (1 equiv.) and $ArB(OH)_2$ **2** (1.0 equiv.) in toluene (21 mL/mmol) was stirred at room temperature for 12 h. $K_3PO_4$ (1 equiv.) and catalyst **4** (5% mol) were then added and the resulting mixture was stirred overnight at room temperature. The reaction was quenched with water (15 mL) and the mixture was extracted with dichloromethane (3 × 10 mL), and dried ($MgSO_4$). The filtrate was concentrated under reduced pressure, and the products were isolated by column chromatography (silica gel; hexane/EtOAc, 8:2).

**(4*S*,5*R*)-5-(Hydroxymethyl)-4-phenyldihydrofuran-2(3*H*)-one (*trans*-7a):** Yield 21.8 mg (66%); $[\alpha]_D^{22}$ = +28.3 (*c* = 0.68, $CHCl_3$). $^1$H NMR (300 MHz, $CDCl_3$): δ = 7.24–7.42 (m, 5 H, ArH), 4.49–4.60 (m, 1 H, O-C*H*), 3.97 (d, *J* = 13.0 Hz, 1 H, OC$H_2$), 3.61–3.77 (m, 2 H, OC$H_2$, Ph-C*H*), 3.04 (dd, *J* = 17.7, 9.2 Hz, 1 H, C$H_2$-CO), 2.79 (dd, *J* = 17.7, 9.9 Hz, 1 H, C$H_2$-CO), 2.36 (br. s, 1 H, O*H*) ppm. $^{13}$C NMR (75 MHz, $CDCl_3$): δ = 176.1 (*C*=O), 139.2 ($C_{Ar}$), 129.3 (2$C_{ArH}$), 128.0 ($C_{ArH}$), 127.4 (2$C_{ArH}$), 87.1 (O-*C*H), 62.1 (*C*$H_2$-O), 42.2 (*C*H-Ph), 37.4 (*C*$H_2$-CO) ppm. $C_{11}H_{12}O_3$ (192.21): calcd. C 68.74, H 6.29; found C 68.66, H 6.24.

**(4*R*,5*R*)-5-(Hydroxymethyl)-4-phenyldihydrofuran-2(3*H*)-one (*cis*-7a):** Yield 2.4 mg (8%). $^1$H NMR (300 MHz, $CDCl_3$): δ = 7.20–7.42 (m, 5 H, ArH), 4.77–4.84 (m, 1 H, O-C*H*), 3.92 (q, *J* = 8.2 Hz, 1 H, Ph-C*H*), 3.36–3.58 (m, 2 H, OC$H_2$), 3.03 (dd, *J* = 17.4, 8.2 Hz, 1 H, C$H_2$-CO), 2.89 (dd, *J* = 17.4, 8.9 Hz, 1 H, C$H_2$-CO) ppm. $^{13}$C NMR (75 MHz, $CDCl_3$): δ = 176.8 (*C*=O), 136.6 ($C_{Ar}$), 129.1 (2$C_{ArH}$), 128.0 ($C_{ArH}$), 127.8 (2$C_{ArH}$), 83.4 (O-*C*H), 62.4 (*C*$H_2$-O), 43.2 (*C*H-Ph), 34.7 (*C*$H_2$-CO) ppm. $C_{11}H_{12}O_3$ (192.21): calcd. C 68.74, H 6.29; found C 68.67, H 6.22.

**(4*S*,5*R*)-5-(Hydroxymethyl)-4-[4-(trifluoromethyl)phenyl]dihydrofuran-2(3*H*)-one (*trans*-7b) and (4*S*,5*R*)-5-(Hydroxymethyl)-4-[4-(trifluoromethyl)phenyl]dihydrofuran-2(3*H*)-one (*cis*-7b):** Yield 29.3 mg (66%); *trans*-**7b**/*cis*-**7b** ratio 90:10. $^1$H NMR (300 MHz, $CDCl_3$): δ = 7.64 (d, *J* = 8.2 Hz, 2 H, ArH), 7.41 (d, *J* = 8.2 Hz, 2 H, ArH), 4.78–4.86 (m, 1 H, O-C*H cis*), 4.55 (dt, *J* = 7.6, 2.9 Hz, 1 H, O-C*H trans*), 3.99 (dd, *J* = 12.8, 2.3 Hz, 1 H, OC$H_2$ *trans*), 3.82 (q, *J* = 9.2 Hz, 1 H, Ph-C*H trans*), 3.67 (dd, *J* = 12.8, 3.3 Hz, 1 H, OC$H_2$ *trans*), 3.60 (dd, *J* = 12.6, 2.3 Hz, 1 H, OC$H_2$ *cis*), 3.38 (dd, *J* = 12.6, 4.7 Hz, 1 H, OC$H_2$ *cis*), 3.10 (dd, *J* = 17.4, 8.9 Hz, 1 H, C$H_2$-CO *cis*), 3.08 (dd, *J* = 17.8, 9.2 Hz, 1 H, C$H_2$-CO *trans*), 2.89 (dd, *J* = 17.4, 9.2 Hz, 1 H, C$H_2$-CO *cis*), 2.78 (dd, *J* = 17.8, 9.3 Hz, 1 H, C$H_2$-CO *trans*), 2.57 (br. s, 1 H, O*H*) ppm. $^{13}$C NMR (75 MHz, $CDCl_3$): δ = 176.5 (*C*=O *cis*), 175.6 (*C*=O *trans*), 143.5 ($C_{Ar}$ *trans*), 140.7 ($C_{Ar}$ *cis*), 130.7 ($C_{Ar}$), 128.4 ($C_{ArH}$), 127.8 (2$C_{ArH}$), 127.7 ($C_{ArH}$), 126.4 ($C_{ArH}$- $C_{Ar}$-$CF_3$ *trans*), 126.4 ($C_{ArH}$-, $C_{Ar}$-$CF_3$ *trans*), 126.3 ($C_{ArH}$-, $C_{Ar}$-$CF_3$ *trans*), 126.3 ($C_{ArH}$-, $C_{Ar}$-$CF_3$ *trans*), 126.1 ($C_{ArH}$-, $C_{Ar}$-$CF_3$ *cis*), 126.0 ($C_{ArH}$-, $C_{Ar}$-$CF_3$ *cis*), 126.0 ($C_{ArH}$-, $C_{Ar}$-$CF_3$ *cis*), 126.0 ($C_{ArH}$-, $C_{Ar}$-$CF_3$ *cis*), 86.6 (O-*C*H *trans*), 82.9 (O-*C*H *cis*), 62.0 (*C*$H_2$-O *cis*), 62.0 (*C*$H_2$-O *trans*), 43.4 (*C*H-Ph *cis*), 41.9 (*C*H-Ph *trans*), 37.2 (*C*$H_2$-CO *trans*), 34.6 (*C*$H_2$-CO *cis*) ppm. $C_{12}H_{11}F_3O_3$ (260.21): calcd. C 55.39, H 4.26; found C 55.48, H 4.31.

**(4*S*,5*R*)-4-(4-Fluorophenyl)-5-(hydroxymethyl)dihydrofuran-2(3*H*)-one (*trans*-7c) and (4*R*,5*R*)-4-(4-Fluorophenyl)-5-(hydroxymethyl)dihydrofuran-2(3*H*)-one (*cis*-7c):** Yield 24.8 mg (69%); *trans*-**7c**/*cis*-**7c** ratio 90:10. $^1$H NMR (300 MHz, $CDCl_3$): δ = 7.19–7.28 (m, 2 H, ArH), 7.01–7.11 (m, 2 H, ArH), 4.73–4.80 (m, 1 H, O-C*H cis*), 4.49 (ddd, *J* = 7.9, 3.6, 2.5 Hz, 1 H, O-C*H trans*), 3.96 (dd, *J* = 12.7, 2.5 Hz, 1 H, OC$H_2$ *trans*), 3.65–3.77 (m, 1 H, Ph-C*H trans*), 3.66 (dd, *J* = 12.7, 3.6 Hz, 1 H, OC$H_2$ *trans*), 3.06 (dd, *J* = 17.8, 8.9 Hz, 1 H, C$H_2$-CO *trans*), 2.74 (dd, *J* = 17.8, 9.8 Hz, 1 H, C$H_2$-CO *trans*), 1.94 (br. s, 1 H, O*H*) ppm. $^{13}$C NMR (75 MHz, $CDCl_3$): δ = 175.6 (*C*=O *trans*), 164.0 ($C_{Ar}$-F *trans*), 160.7 ($C_{Ar}$-F *trans*), 134.8 ($C_{Ar}$ *trans*), 129.0 ($C_{ArH}$ *trans*), 128.9 ($C_{ArH}$ *trans*), 116.4 ($C_{ArH}$ *trans*), 116.1 ($C_{ArH}$ *trans*), 86.9 (O-*C*H *trans*), 61.9 (*C*$H_2$-O *trans*),

41.5 (*C*H-Ph *trans*), 37.4 (*C*$H_2$-CO *trans*) ppm. $C_{11}H_{11}FO_3$ (210.20): calcd. C 62.85, H 5.27; found C 62.84, H 5.30.

**(4*S*,5*R*)-4-(4-Bromophenyl)-5-(hydroxymethyl)dihydrofuran-2(3*H*)-one (*trans*-7d) and (4*R*,5*R*)-4-(4-Bromophenyl)-5-(hydroxymethyl)dihydrofuran-2(3*H*)-one (*cis*-7d):** Yield 30.1 mg (65%); *trans*-**7d**/*cis*-**7d** ratio 90:10. $^1$H NMR (300 MHz, $CDCl_3$): $\delta$ = 7.47–7.53 (m, 2 H, ArH), 7.10–7.18 (m, 2 H, ArH), 4.48 (ddd, *J* = 7.9, 3.6, 2.7 Hz, 1 H, O-C*H trans*), 3.90–4.00 (m, 1 H, OC$H_2$ *trans*), 3.50–3.74 (m, 2 H, Ph-C*H*, OC$H_2$ *trans*), 3.03 (dd, *J* = 17.9, 9.1 Hz, 1 H, C$H_2$-CO *trans*), 2.73 (dd, *J* = 17.9, 9.7 Hz, 1 H, C$H_2$-CO *trans*), 1.89 (br. s, 1 H, O*H*) ppm. $^{13}$C NMR (75 MHz, $CDCl_3$): $\delta$ = 175.4 (*C*=O *trans*), 137.8 ($C_{Ar}$ *trans*), 132.5 (2$C_{ArH}$ *trans*), 129.0 (2$C_{ArH}$ *trans*), 120.1 ($C_{Ar}$-Br *trans*), 86.5 (O-*C*H *trans*), 62.0 (*C*$H_2$-O *trans*), 41.7 (*C*H-Ph *trans*), 37.2 (*C*$H_2$-CO *trans*) ppm. $C_{11}H_{11}BrO_3$ (271.11): calcd. C 48.73, H 4.09; found C 48.89, H 4.18.

**(4*S*,5*R*)-5-(Hydroxymethyl)-4-(4-methoxyphenyl)dihydrofuran-2(3*H*)-one (*trans*-7e) and (4*R*,5*R*)-5-(Hydroxymethyl)-4-(4-methoxyphenyl)dihydrofuran-2(3*H*)-one (*cis*-7e):** Yield 30.4 mg (80%); *trans*-**7e**/*cis*-**7e** ratio 90:10. $^1$H NMR (300 MHz, $CDCl_3$): $\delta$ = 7.18 (d, *J* = 8.7 Hz, 2 H, ArH), 6.90 (d, *J* = 8.2 Hz, 2 H, ArH), 4.76 (ddd, *J* = 7.3, 5.5, 3.6 Hz, 1 H, O-C*H cis*), 4.48 (ddd, *J* = 8.3, 4.0, 2.5 Hz, 1 H, O-C*H trans*), 3.89–3.98 (m, 1 H, OC$H_2$ *trans*), 3.80 (s, 3 H, OC$H_3$ *trans*), 3.60–3.71 (m, 2 H, Ph-C*H*, OC$H_2$ *trans*), 2.99 (dd, *J* = 17.7, 9.0 Hz, 1 H, C$H_2$-CO *trans*), 2.74 (dd, *J* = 17.7, 10.2 Hz, 1 H, C$H_2$-CO *trans*), 2.13 (br. s, 1 H, O*H*) ppm. $^{13}$C NMR (75 MHz, $CDCl_3$): $\delta$ = 175.9 (*C*=O *trans*), 159.3 ($C_{Ar}$-O), 130.8 ($C_{Ar}$ *trans*), 128.4 (2$C_{ArH}$ *trans*), 114.7 (2$C_{ArH}$ *trans*), 87.2 (O-*C*H *trans*), 62.0 (*C*$H_2$-O *trans*), 55.5 (O*C*$H_3$ *trans*), 41.5 (*C*H-Ph *trans*), 37.5 (*C*$H_2$-CO *trans*) ppm. $C_{12}H_{14}O_4$ (222.24): calcd. C 64.85, H 6.35; found C 64.74, H 6.30.

**(4*S*,5*R*)-4-(3,4-Dimethoxyphenyl)-5-(hydroxymethyl)dihydrofuran-2(3*H*)-one (*trans*-7f) and (4*R*,5*R*)-4-(3,4-Dimethoxyphenyl)-5-(hydroxymethyl)dihydrofuran-2(3*H*)-one (*cis*-7f):** Yield 33.6 mg (78%); *trans*-**7f**/*cis*-**7f** ratio 90:10. $^1$H NMR (300 MHz, $CDCl_3$): $\delta$ = 6.73–6.89 (m, 3 H, ArH), 4.75 (ddd, *J* = 7.5, 5.4, 3.7 Hz, 1 H, O-C*H cis*), 4.51 (dt, *J* = 8.2, 2.5 Hz, 1 H, O-C*H trans*), 3.95 (dd, *J* = 13.0, 2.5 Hz, 1 H, OC$H_2$ *trans*), 3.88 (s, 3 H, OC$H_3$ *trans*), 3.86 (s, 3 H, OC$H_3$ *trans*), 3.55–3.71 (m, 2 H, Ph-C*H*, OC$H_2$ *trans*), 3.00 (dd, *J* = 17.8, 9.1 Hz, 1 H, C$H_2$-CO *trans*), 2.75 (dd, *J* = 17.8, 9.8 Hz, 1 H, C$H_2$-CO *trans*), 2.31 (br. s, 1 H, O*H*) ppm. $^{13}$C NMR (75 MHz, $CDCl_3$): $\delta$ = 176.1 (*C*=O *trans*), 149.6 ($C_{Ar}$-O *trans*), 148.7 ($C_{Ar}$-O *trans*), 131.6 ($C_{Ar}$ *trans*), 119.4 ($C_{ArH}$ *trans*), 111.8 ($C_{ArH}$ *trans*), 110.4 ($C_{ArH}$ *trans*), 87.2 (O-*C*H *trans*), 62.0 (*C*$H_2$-O *trans*), 56.1 (O*C*$H_3$ *trans*), 56.1 (O*C*$H_3$ *trans*), 41.8 (*C*H-Ph *trans*), 37.5 (*C*$H_2$-CO *trans*) ppm. $C_{13}H_{16}O_5$ (252.26): calcd. C 61.90, H 6.39; found C 61.98, H 6.37.

**(4*S*,5*R*)-5-(Hydroxymethyl)-4-(3,4,5-trimethoxyphenyl)dihydrofuran-2(3*H*)-one (*trans*-7g) and (4*R*,5*R*)-5-(Hydroxymethyl)-4-(3,4,5-trimethoxyphenyl)dihydrofuran-2(3*H*)-one (*cis*-7g):** Yield 41.5 mg (76%); *trans*-**7g**/*cis*-**7g** ratio 90:10. $^1$H NMR (300 MHz, $CDCl_3$): $\delta$ = 6.45 (s, 2 H, ArH), 4.75 (ddd, *J* = 7.5, 5.2, 3.6 Hz, 1 H, O-C*H cis*), 4.54 (dt, *J* = 7.9, 2.5 Hz, 1 H, O-C*H trans*), 3.96 (dd, *J* = 12.7, 2.5 Hz, 1 H, OC$H_2$ *trans*), 3.86 (s, 6 H, 2OC$H_3$ *trans*), 3.82 (s, 3 H, OC$H_3$ *trans*), 3.55–3.73 (m, 2 H, Ph-C*H*, OC$H_2$ *trans*), 3.02 (dd, *J* = 17.7, 9.1 Hz, 1 H, C$H_2$-CO *trans*), 2.75 (dd, *J* = 17.7, 9.6 Hz, 1 H, C$H_2$-CO *trans*), 2.41 (br. s, 1 H, O*H*) ppm. $^{13}$C NMR (75 MHz, $CDCl_3$): $\delta$ = 176.0 (*C*=O *trans*), 153.8 (2$C_{Ar}$-O *trans*), 137.5 ($C_{Ar}$-O *trans*), 135.0 ($C_{Ar}$ *trans*), 104.2 (2$C_{ArH}$ *trans*), 87.0 (O-*C*H *trans*), 62.0 (*C*$H_2$-O *trans*), 61.0 (O*C*$H_3$ *trans*), 56.3 (2O*C*$H_3$ *trans*), 42.5 (*C*H-Ph *trans*), 37.5 (*C*$H_2$-CO *trans*) ppm. $C_{14}H_{18}O_6$ (282.29): calcd. C 59.57, H 6.43; found C 59.66, H 6.38.

**Reaction of Arylboronic Acids 2 and Lactone 12 with Catalyst 4. General Procedure:** To a stirred solution of $ArB(OH)_2$ **2** (2.0 equiv.) in toluene (6 mL/mmol) were added lactone **12** (1 equiv.), $K_3PO_4$ (1 equiv.), and catalyst **4** (20% mol). The resulting mixture was stirred for 48 h at room temperature, quenched with water (15 mL), extracted with dichloromethane (3× 10 mL), and dried ($MgSO_4$). The filtrate was concentrated under reduced pressure. The products were isolated by column chromatography (silica gel; hexane/EtOAc, 7:3).

***tert*-Butyl [(3*S*,4*S*)-6-Oxo-4-phenyltetrahydro-2*H*-pyran-3-yl]carbamate (*trans*-13a):** Yield 26.2 mg (96%). $^1$H NMR (400 MHz, $CDCl_3$): $\delta$ = 7.44–7.32 (m, 2 H, ArH), 7.34–7.25 (m, 1 H, ArH), 7.27–7.20 (m, 2 H, ArH), 4.61 (s, 1 H, N*H*), 4.51 (dd, *J* = 11.3, 4.2 Hz, 1 H, OC$H_2$), 4.17 (dd, *J* = 11.3, 7.0 Hz, 1 H, OC$H_2$), 4.10 (s, 1 H, NH-C*H*), 3.20 (d, *J* = 8.4 Hz, 1 H, *C*H-C$H_2$C$O_2$), 2.97 (dd, *J* = 17.7, 6.3 Hz, 1 H, *C*$H_2$C$O_2$), 2.77 (dd, *J* = 17.7, 9.5 Hz, 1 H, *C*$H_2$C$O_2$), 1.37 (s, 9 H, 3C$H_3$) ppm. $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta$ = 170.1 (*C*$O_2$), 155.2 (*C*ON), 140.0 ($C_{Ar}$), 129.4 (2$C_{ArH}$), 128.0 ($C_{ArH}$), 127.4 (2$C_{ArH}$), 80.6 [*C*-(Me)$_3$], 70.5 (O-*C*$H_2$), 50.4 (*C*H-N), 43.4 (*C*H-C$H_2$-CO), 35.8 (CH-*C*$H_2$-CO), 28.4 (3*C*$H_3$) ppm. $C_{16}H_{21}NO_4$ (291.34): calcd. C 65.96, H 7.27; found C 66.04, H 7.31.

***tert*-Butyl {(3*S*,4*S*)-6-Oxo-4-[4-(trifluoromethyl)phenyl]tetrahydro-2*H*-pyran-3-yl}carbamate (*trans*-13b):** Yield 24.0 mg (71%). $^1$H NMR (400 MHz, $CDCl_3$): $\delta$ = 7.73–7.53 (m, 2 H, ArH), 7.36 (d, *J* = 8.0 Hz, 2 H, ArH), 4.60 (br. s, 1 H, N*H*), 4.48 (dd, *J* = 11.3, 4.2 Hz, 1 H, OC$H_2$), 4.28–4.06 (m, 1 H, OC$H_2$), 3.29 (d, *J* = 8.2 Hz, NH-C*H*), 2.98 (dd, *J* = 17.6, 6.3 Hz, 1 H, C*H*-Ph), 2.76 (dd, *J* = 17.6, 9.6 Hz, 1 H, C$H_2$CO), 1.35 (s, 9 H, 3C$H_3$) ppm. $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta$ = 169.5 (*C*$O_2$), 155.1 (*C*ON), 144.0 ($C_{Ar}$), 130.6 ($C_{ArH}$), 130.2 ($C_{ArH}$), 128.1 ($C_{ArH}$), 127.9 ($C_{ArH}$), 126.9 ($C_{ArH}$), 126.3 ($C_{ArH}$), 126.3 ($C_{ArH}$), 126.3 ($C_{ArH}$), 125.4 ($C_{ArH}$), 122.7 ($C_{ArH}$), 80.9 [*C*-(Me)$_3$], 70.2 (O-*C*$H_2$), 50.3 (*C*H-N), 43.5 (*C*H-C$H_2$-CO), 35.6 (CH-*C*$H_2$-CO), 28.4 (3*C*$H_3$) ppm. $C_{17}H_{20}F_3NO_4$ (359.34): calcd. C 56.82, H 5.61; found C 56.70, H 5.55.

***tert*-Butyl [(3*S*,4*S*)-4-(4-Fluorophenyl)-6-oxotetrahydro-2*H*-pyran-3-yl]carbamate (*trans*-13c):** Yield 24.4 mg (84%). $^1$H NMR (400 MHz, $CDCl_3$): $\delta$ = 7.19 (dd, *J* = 8.6, 5.2 Hz, 2 H, ArH), 7.11–6.98 (m, 2 H, ArH), 4.60 (d, *J* = 7.7 Hz, 1 H, N*H*), 4.47 (dd, *J* = 11.4, 4.3 Hz, 1 H, OC$H_2$), 4.14 (dd, *J* = 11.4, 7.3 Hz, 1 H, OC$H_2$), 4.05 (s, 1 H, NH-C*H*), 3.18 (d, *J* = 9.6 Hz, 1 H, *C*H-C$H_2$C$O_2$), 2.94 (dd, *J* = 17.6, 6.2 Hz, 1 H, *C*$H_2$C$O_2$), 2.71 (dd, *J* = 17.6, 9.7 Hz, 1 H, *C*$H_2$C$O_2$), 1.35 (s, 9 H, 3C$H_3$) ppm. $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta$ = 169.9 (*C*$O_2$), 163.6 (*C*-F), 161.15 (*C*-F), 155.2 (*C*ON), 135.7 ($C_{Ar}$), 129.0 ($C_{ArH}$), 128.9 ($C_{ArH}$), 116.4 ($C_{ArH}$), 116.2 ($C_{ArH}$), 80.6 [*C*-(Me)$_3$], 70.4 (O-*C*$H_2$), 50.4 (*C*H-N), 42.8 (*C*H-C$H_2$-CO), 36.0 (CH-*C*$H_2$-CO), 28.4 (3*C*$H_3$) ppm. $C_{16}H_{20}FNO_4$ (309.33): calcd. C 62.12, H 6.52; found C 62.01, H 6.59.

***tert*-Butyl [(3*S*,4*S*)-4-(4-Methoxyphenyl)-6-oxotetrahydro-2*H*-pyran-3-yl]carbamate (*trans*-13d):** Yield 29.0 mg (96%). $^1$H NMR (400 MHz, $CDCl_3$): $\delta$ = 7.13 (d, *J* = 8.6 Hz, 2 H, ArH), 6.91–6.84 (m, 2 H, ArH), 4.60 (s, 1 H, N*H*), 4.49 (dd, *J* = 11.4, 4.3 Hz, 1 H, OC$H_2$), 4.13 (dd, *J* = 11.4, 7.1 Hz, 1 H, OC$H_2$), 4.02 (s, 1 H, NH-C*H*), 3.78 (s, 3 H, O*C*$H_3$), 3.12 (d, *J* = 8.5 Hz, 1 H, *C*H-C$H_2$C$O_2$), 2.92 (dd, *J* = 17.7, 6.2 Hz, 1 H, *C*$H_2$C$O_2$), 2.71 (dd, *J* = 17.7, 9.6 Hz, 1 H, *C*$H_2$C$O_2$), 1.36 (s, 9 H, 3C$H_3$) ppm. $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta$ = 170.2 (*C*$O_2$), 159.3 ($C_{Ar}$-O), 155.2 (*C*ON), 131.9 ($C_{Ar}$), 128.4 (2$C_{ArH}$), 114.7 ($C_{ArH}$), 114.6 ($C_{ArH}$), 80.6 [*C*-(Me)$_3$], 70.5 (O-*C*$H_2$), 55.5 (O*C*$H_3$), 50.5 (*C*H-N), 42.6 (CH-CH$_2$-

CO), 36.1 (CH-*C*$H_2$-CO), 28.4 (3*C*$H_3$) ppm. $C_{17}H_{23}NO_5$ (321.37): calcd. C 63.54, H 7.21; found C 63.70, H 7.31.

***tert*-Butyl [(3*S*,4*S*)-4-(2-Fluorophenyl)-6-oxotetrahydro-2*H*-pyran-3-yl]carbamate (*trans*-13e):** Yield 24.7 mg (85%). $^1$H NMR (400 MHz, $CDCl_3$): $\delta$ = 7.03–7.34 (m, 4 H, ArH), 4.76 (s ancho, 1 H, N*H*), 4.47–4.60 (m, 1 H, OC$H_2$), 4.11–4.29 (m, 2 H, OC$H_2$, NH-C*H*), 3.30–3.53 (m, 1 H, C*H*-Ph), 2.95 (dd, $J$ = 17.4, 6.4 Hz, 1 H, C$H_2$CO), 2.81 (dd, $J$ = 17.4, 10.3 Hz, 1 H, C$H_2$CO), 1.35 (s, 9 H, 3C$H_3$) ppm. $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta$ = 169.9 (*C*$O_2$), 162.2 (*C*-F), 159.7 (*C*-F), 156.0 (*C*ON), 129.6 ($C_{ArH}$), 129.6 ($C_{ArH}$), 128.7 ($C_{ArH}$), 126.9 ($C_{ArH}$), 126.8 ($C_{ArH}$), 125.0 ($C_{ArH}$), 125.0 ($C_{ArH}$), 116.3 ($C_{ArH}$), 116.0 ($C_{ArH}$), 80.6 [*C*-(Me)$_3$], 70.5 (O-*C*$H_2$), 49.5 (*C*H-N), 37.9 (CH-CH$_2$-CO), 34.9 (CH-*C*$H_2$-CO), 28.3 (3*C*$H_3$) ppm. $C_{16}H_{20}FNO_4$ (309.33): calcd. C 62.12, H 6.52; found C 62.00, H 6.59.

***tert*-Butyl [(3*S*,4*S*)-4-(2-Bromophenyl)-6-oxotetrahydro-2*H*-pyran-3-yl]carbamate (*trans*-13f):** Yield 29.2 mg (84%). $^1$H NMR (400 MHz, $CDCl_3$): $\delta$ = 7.57 (dd, $J$ = 8.1, 1.3 Hz, 1 H, ArH), 7.33 (td, $J$ = 7.5, 1.3 Hz, 1 H, ArH), 7.28–7.21 (m, 1 H, ArH), 7.14 (ddd, $J$ = 8.0, 7.2, 1.7 Hz, 1 H, ArH), 4.66–4.44 (m, 2 H, N*H*, OC$H_2$), 4.29 (d, $J$ = 10.1 Hz, 1 H, NH-C*H*), 4.14 (dd, $J$ = 11.2, 8.5 Hz, 1 H, OC$H_2$), 3.66 (td, $J$ = 10.2, 6.2 Hz, 1 H, *C*H-CH$_2$CO$_2$), 3.02 (dd, $J$ = 17.7, 6.2 Hz, 1 H, *C*H$_2$CO$_2$), 2.59 (dd, $J$ = 17.7, 10.6 Hz, 1 H, *C*H$_2$CO$_2$), 1.32 {s, 9 H, [*C*-(Me)$_3$]} ppm. $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta$ = 169.6 (*C*$O_2$), 155.2 (*C*ON), 138.8 ($C_{Ar}$), 133.6 ($C_{ArH}$), 129.4 ($C_{ArH}$), 128.7 ($C_{ArH}$), 127.9 ($C_{ArH}$), 124.8 ($C_{Ar}$-Br), 80.6 [*C*-(Me)$_3$], 70.6 (O-*C*$H_2$), 49.1 (*C*H-N), 42.4 (CH-CH$_2$-CO), 35.9 (CH-*C*$H_2$-CO), 28.4 (3*C*$H_3$) ppm. $C_{16}H_{20}BrNO_4$ (370.24): calcd. C 51.90, H 5.44; found C 51.78, H 5.37.

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