Enantioselective Iridium-Catalyzed Allylic Aminations of Allylic Carbonates with Functionalized Side Chains. Asymmetric Total Synthesis of (*S*)-Vigabatrin

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Dedicated to Professor Andreas Pfaltz on the occasion of his 60th birthday.

Abstract: Iridium-catalyzed aminations of allylic carbonates containing a variety of O-functional groups have been explored. High degrees of regio- as well as enantioselectivity were achieved with diacylamides under salt-free conditions and with arylamines. The results allowed the antiepilepsy drug (*S*)-vigabatrin to be prepared via a very short route.

Key words: aminations, iridium, asymmetric catalysis, nucleophiles, regioselectivity

The asymmetric allylic substitution reaction is a powerful and widely employed tool in organic synthesis.[1] For many years palladium catalysts were mainly used. However, excepting a number of important examples,[2] palladium catalysts mainly give rise to the achiral linear substitution product in reactions of monosubstituted allylic substrates. In contrast, iridium catalysts induce preferential formation of the branched regioisomer. Over the last few years, iridium complexes of phosphoramidites have been developed that induce high degrees of regio- as well as enantioselectivity (Scheme 1).[3] With the particularly effective ligands **L1**–**L3** (Figure 1),[4] regioselectivities >95:5 in favor of the branched products and enantioselectivities >97% ee can be achieved routinely with C-,[5] N-,[6–8] and O-nucleophiles[9] with substrates containing R = aryl, small alkyl, and alkenyl groups.

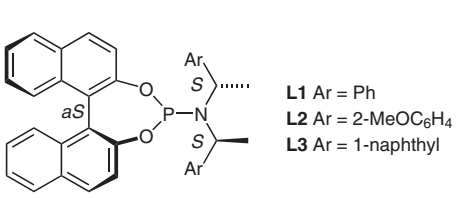
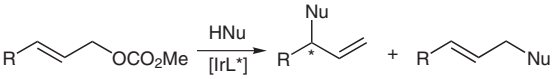


Figure 1 Phosphoramidites used as ligands

Often only allylic substrates with benchmark character are investigated. Compounds containing functional groups have been rarely used and have, indeed, revealed limitations. For example, allylic carbonates with R = 2-$MeOC_6H_4$ gave products with <90% ee in alkylations[5e] as well as aminations.[6a] Regioselectivity with *para*-acceptor-substituted cinnamyl carbonates is slightly reduced in comparison to the parent cinnamyl carbonate.[6a] Similarly, allylic substitutions of substrates with substituents R = CH_2OPG proceeded with a high degree of enantioselectivity, however, with a variable (high[8c] or low[5c]) degree of regioselectivity, depending on the nucleophile. We have been particularly interested in functionalized substrates, because they yield products, for example vinylglycinol derivatives, that can be transformed into chiral building blocks of interest for the synthesis of biologically active compounds. In this area, Trost et al. have published important work based on the palladium-catalyzed allylic amination of vinyloxirane.[10] In order to further develop applications of the iridium-catalyzed allylic substitution, we have extended our studies to aminations with the broad range of substrates with O-functional groups that are listed in Scheme 1.



R = CH_2OH, CH_2OSiMe_2t-Bu, CH_2OSiPh_2t-Bu, CH_2OCPh_3
$CH_2CH_2OCPh_3$, $CH_2CH_2CO_2Me$
$CH{=}CHCH_2OCPh_3$

Scheme 1 Allylic substitution with substrates with a functional group containing oxygen

The preparation of the allylic carbonates, which followed standard procedures, is only described in the experimental section. Some of the compounds have appeared repeatedly in the chemical literature, however, experimental details were lacking. For those cases spectroscopic data are given.

Allylic substitutions with N-nucleophiles have mostly been carried out with amines (aliphatic,[6] aromatic[7]) as nu-

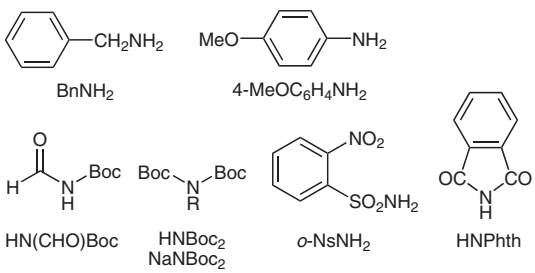


Figure 2 Nucleophiles and pronucleophiles used for allylic aminations

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Biographical Sketches

Christian Gnamm was born in Heidelberg in 1979. He studied chemistry at the Ruprecht-Karls-Universität Heidelberg and received his diploma degree in 2005. He is currently carrying out his Ph.D. studies in the group of Prof. Helmchen and is funded by a Ph.D. grant from the 'Studienstiftung des deutschen Volkes'. His research is focused on iridium-catalyzed allylic substitution reactions and their application in syntheses of piperidine alkaloids.

Géraldine Franck, who is currently carrying out her Ph.D. studies in the group of Prof. Helmchen, was born in Munich (Germany) in 1979. She studied chemistry in Heidelberg and Bristol and received her diploma degree from the Ruprecht-Karls-Universität Heidelberg in 2006. Her research interests are the application of iridium-catalyzed allylic substitution reactions in syntheses of chiral building blocks and natural products.

Nicole Miller was born in Immenstadt im Allgäu (Germany). She studied chemistry in Ulm and received her Ph.D. under the guidance of Prof. Helmchen at the Ruprecht-Karls-Universität Heidelberg in 2007. Afterwards she became a postdoctoral research fellow in the group of Margaret A. Brimble at the University of Auckland. Her current research focuses on the synthesis of neoglycopeptides using a 'click chemistry' approach.

Timon Stork was born in Ludwigshafen/Oggersheim (Germany) in 1981. He studied chemistry at the Ruprecht-Karls-Universität Heidelberg and received his diploma in 2007. His diploma thesis was carried out in the group of Prof. Helmchen. He is currently pursuing his Ph.D. studies in the group of Professor Fürstner at the Max-Planck-Institut für Kohlenforschung in Mülheim/Ruhr.

Kerstin Brödner was born in Würzburg (Germany) in 1978. She did her apprenticeship as laboratory technician at the Julius-Maximilians-Universität Würzburg between 1996 and 1999. Then she moved to Heidelberg to join the group of Prof. Helmchen. She is working in the field of asymmetric catalysis as well as natural product synthesis.

Günter Helmchen (b. 1940) is a Full Professor at the Ruprecht-Karls-Universität Heidelberg and director of the Institute of Organic Chemistry. He pursued undergraduate studies at the TH Hannover (Dipl.-Chem. 1965). His graduate work, completed in 1971, was carried out under the guidance of Prof. V. Prelog at the ETH Zürich in the area of stereochemistry. He then carried out a Habilitationsarbeit at the TU Stuttgart (1975–1980). In 1980 he was appointed Professor C3 at the Universität Würzburg. In 1985 he moved to his present position. His interest in catalysis dates back to ca. 1990. His scientific work has found recognition by a variety of scientific prizes and research awards, international lectureships, and the invitation to join the advisory boards of scientific journals.

cleophiles, for example benzylamine and 4-methoxyaniline, leading to compounds with an N-protecting group, which can be removed by dissolving metal reduction, catalytic hydrogenation, or oxidation. Being interested in natural products synthesis and ammonia equivalents, we have extensively investigated reactions with *N*-sulfonylamines and *N*,*N*-diacylamines as pronucleophiles (cf. Figure 2, lower line).[8] These compounds are sufficiently acidic to allow the application of salt-free conditions,[8a] i.e. the use of the conjugate acid of an anionic nucleophile rather than a salt, which often displays low solubility in tetrahydrofuran. These conditions are further advantageous, because the catalyst is prepared by reaction of the procatalyst $[Ir(cod)Cl]_2$/**L*** with strong base in excess, which can effect catalyst decomposition. The excess of base is neutralized under salt-free conditions.

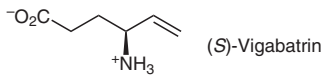
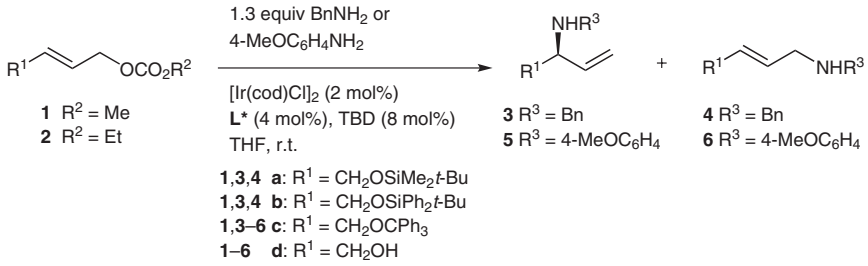


Figure 3

As an application, a short enantioselective synthesis of (*S*)-vigabatrin (Figure 3), a drug with anticonvulsant activity, is presented.

First, aminations with the O-protected and O-unprotected carbonates **1** and **2** were examined. The carbonates were prepared according to standard procedures. Benzylamine and 4-methoxyaniline were used as nucleophiles (Scheme 2, Table 1). Amination of the carbonates **1a–c** with benzylamine gave unsatisfactory results (Table 1, entries 1–9). While enantioselectivity was often acceptable (84.5–98% ee), regioselectivity, with a value of 83:17 at best, was generally low.



Scheme 2 Allylic aminations with benzylamine and 4-methoxyaniline as nucleophiles

Table 1 Iridium-Catalyzed Allylic Aminations with Benzylamine and 4-Methoxyaniline According to Scheme 2 and General Procedure 2

Entry	Substrate	Nucleophile	L*	Time (h)	Yield[a] (%)	Ratio[b] b/l	ee[c] (%)
1[d]	**1a**	$BnNH_2$	**L1**	20	65	60:40	84.5 (*S*)
2	**1a**	$BnNH_2$	**L2**	2	78	72:28	96 (*S*)
3[d]	**1a**	$BnNH_2$	**L3**	2	87	83:17	97 (*S*)
4[d]	**1b**	$BnNH_2$	**L1**	20	57	80:20	98
5	**1b**	$BnNH_2$	**L2**	2	68	73:27	97
6	**1b**	$BnNH_2$	**L3**	2	80	76:24	98
7	**1c**	$BnNH_2$	**L1**	1	70	81:19[e]	96
8	**1c**	$BnNH_2$	**L2**	4.5	51	67:33[e]	96
9	**1c**	$BnNH_2$	**L3**	4	61	66:34[e]	98
10	**1c**	4-$MeOC_6H_4NH_2$	**L1**	1	81	81:19	92.5
11	**1c**	4-$MeOC_6H_4NH_2$	**L2**	1	70	88:12	92.5
12	**1c**	4-$MeOC_6H_4NH_2$	**L3**	0.5	90	94:6	96
13[d]	**1d**	$BnNH_2$	**L3**	2.5	68	98:2	88.5
14	**2d**	$BnNH_2$	**L1**	5	73	90:10	87
15	**2d**	$BnNH_2$	**L2**	5	67	96:4	85
16	**2d**	$BnNH_2$	**L3**	5	69	>99:1	93

Table 1 Iridium-Catalyzed Allylic Aminations with Benzylamine and 4-Methoxyaniline According to Scheme 2 and General Procedure 2 (continued)

Entry	Substrate	Nucleophile	L*	Time (h)	Yield[a] (%)	Ratio[b] b/l	ee[c] (%)
17	**1d**	4-$MeOC_6H_4NH_2$	**L1**	5	72	>99:1	75
18	**1d**	4-$MeOC_6H_4NH_2$	**L2**	4	74	>99:1	77
19	**1d**	4-$MeOC_6H_4NH_2$	**L3**	1	96	>99:1	84

[a] Isolated yield of combined regioisomers.
[b] Ratio of branched/linear isomers as determined by ^1H NMR spectroscopy of the crude products or isolation of the regioisomers.
[c] Determined by HPLC on chiral columns. Assignment of absolute configuration is given for cases in which it was independently confirmed.
[d] This reaction was run with 20 mol% of tetrahydrothiophene (THT) as additive (cf. general procedure 2).
[e] The reaction of $BnNH_2$ with the carbonate **1c** gave the branched product **3c** and the bis-allylated linear product $BnN(CH_2CH{=}CHCH_2OCPh_3)_2$ (**4c′**); the monoallylated linear product **4c** was not found.

In contrast, with 4-methoxyaniline as nucleophile a higher level of regioselectivity, up to 94:6, high enantiomeric excess (up to 96% ee), and comparatively short reaction times were typical (Table 1, entries 10–12). Hartwig et al. have already established that unusually high levels of regio- as well as enantioselectivity are general characteristics of reactions with arylamines, particularly in conjunction with ligand **L3**.[7]

Substitutions at the unprotected substrates **1d** and **2d** proceeded with high regioselectivity (Table 1, entries 13–19). However, enantioselectivity was comparatively low (75–93% ee). This may be caused by the free hydroxy group creating a microenvironment resembling a polar solvent. With ethanol as solvent, iridium-catalyzed allylic substitutions generally display high regio- and comparatively low enantioselectivity.

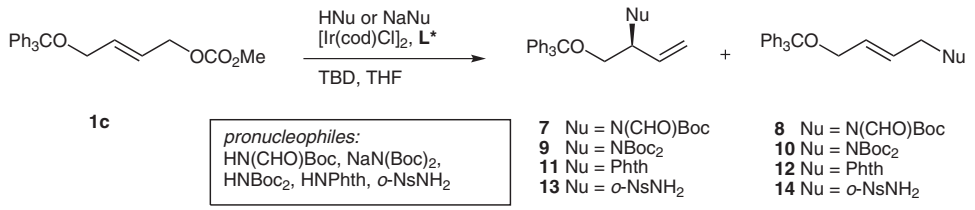
The above mentioned *N*,*N*-diacylamines and *N*-sulfonylamines were next explored as pronucleophiles. The readily available carbonate **1c** was used for this study (Scheme 3, Table 2).

With the pronucleophile HN(CHO)Boc,[8a] under salt-free conditions, the amide **7** was formed in very good yield, also on a preparatively significant scale of 50 mmol of **1c** with a reduced catalyst loading of 2 mol% of iridium (Table 2, entry 2). Using **L2** as ligand, regioselectivity of b/l 89:11 and enantioselectivity of 97% ee were achieved (Table 2, entry 3). Products derived from the pronucleophile HN(CHO)Boc are particularly versatile because the formyl and the Boc protecting group can be selectively removed under mild conditions.[8a]

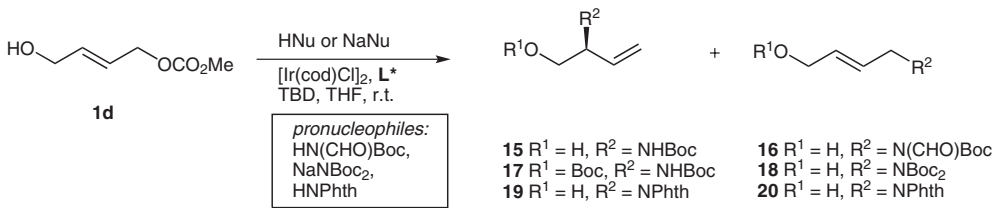
With $NaNBoc_2$ as pronucleophile, reaction rates were slightly higher than with HN(CHO)Boc, and yields as well as selectivities were excellent (Table 2, entries 5–7). With the optimal ligand **L2**, the allylated product **9** was obtained in 88% yield with a regioselectivity of 91:9 and excellent enantioselectivity of 98% ee (Table 2, entry 6). Almost identical results were obtained with $HNBoc_2$ as pronucleophile at a reaction temperature of 50 °C (Table 2, entries 8–10).

Products derived from the pronucleophiles phthalimide and *o*-nosylamide are useful as they can be deprotected under very mild conditions, with 1,2-diamines or thiophenol, respectively.[11] Compared to the results with the Boc containing pronucleophiles, yields and regioselectivities were slightly lower, while enantioselectivities were similarly high (Table 2, entries 11–16).

After these encouraging results, reactions of the carbonate **1d**, with a free hydroxy group, were again examined



Scheme 3 Allylic aminations with *N*,*N*-diacylamines and *N*-sulfonylamines as pronucleophiles



Scheme 4 Allylic aminations with O-unprotected substrates and *N*,*N*-diacylamines as pronucleophiles

Table 2 Iridium-Catalyzed Allylic Aminations with *N*,*N*-Diacylamines and *N*-Sulfonylamines According to Scheme 3 and General Procedure 2

Entry	Nucleophile	Equiv	Ir (mol%)	L*	Temp (°C)	Time (h)	Yield[a] (%)	Ratio[b] b/l	ee[c] (%)
1	HN(CHO)Boc	1.0	4	**L1**	r.t.	24	98	88:12	97[e]
2[d]	HN(CHO)Boc	1.3	2	**L1**	50	26	93	85:15	96[e]
3	HN(CHO)Boc	1.0	4	**L2**	r.t.	2	89	89:11	97[e]
4	HN(CHO)Boc	1.0	4	**L3**	r.t.	24	90	81:19	96[e]
5	$NaNBoc_2$	1.0	4	**L1**	50	7	94	74:26	97
6	$NaNBoc_2$	1.0	4	**L2**	50	14	88	91:9	98
7	$NaNBoc_2$	1.0	4	**L3**	50	14	79	82:18	97
8	$HNBoc_2$	1.0	4	**L1**	50	2.5	85	85:15	95
9	$HNBoc_2$	1.0	4	**L2**	50	3	85	92:8	98
10	$HNBoc_2$	1.0	4	**L3**	50	1	77	83:17	98
11	HNPhth	1.3	4	**L1**	r.t.	26	55 (100)	79:21	96
12	HNPhth	1.3	4	**L2**	r.t.	24	58	79:21	98
13	HNPhth	1.3	4	**L3**	r.t.	24	91	55:45	93
14	*o*-$NsNH_2$	1.3	4	**L1**	50	24	85	89:11	92
15	*o*-$NsNH_2$	1.3	4	**L2**	50	18	69	88:12	97
16	*o*-$NsNH_2$	1.3	4	**L3**	50	24	87	75:25	95

[a] Isolated yield of combined regioisomers; the corrected yield given in parentheses.
[b] Ratio of branched/linear isomers as determined by ^1H NMR spectroscopy of the crude products or isolation of the regioisomers.
[c] Determined by HPLC on chiral columns.
[d] This reaction was run on a 50 mmol scale.
[e] The enantiomeric excess was determined after cleavage of the formyl protecting group.

Table 3 Iridium-Catalyzed Allylic Aminations of Carbonate **1d** with *N*,*N*-Diacylamines and *N*-Sulfonylamines According to Scheme 4 and General Procedure 2

Entry	Nucleophile	Equiv	L*	Time (h)	Product	Yield[a] (%)	Ratio[b] b/l	ee[c] (%)
1	HN(CHO)Boc	1.5	**L1**	60	**15**	42 (52)	>95:5	81[d] (*S*)
2	HN(CHO)Boc	1.5	**L2**	48	**15**	73	>95:5	93[d] (*S*)
3	HN(CHO)Boc	1.3	**L3**	24	**15**	65	>95:5	95[d] (*S*)
4	$NaNBoc_2$	1.0	**L1**	24	**17**	18 (26)[e]	>99:1	80
5	$NaNBoc_2$	1.0	**L2**	3.5	**17**	75[e]	>99:1	89
6	$NaNBoc_2$	1.0	**L3**	3.5	**17**	68[e]	>99:1	93
7	HNPhth	1.5	**L1**	48	**19**	60 (85)	>99:1	83 (*S*)
8	HNPhth	1.5	**L2**	24	**19**	95	>99:1	87 (*S*)
9	HNPhth	1.3	**L3**	18	**19**	70	>99:1	92 (*S*)

[a] Isolated yield of combined regioisomers; the corrected yield is given in parentheses.
[b] Ratio of branched/linear isomers as determined by ^1H NMR spectroscopy of the crude products or isolation of the regioisomers.
[c] Determined by HPLC on chiral columns. Assignment of absolute configuration is given for cases in which it was independently confirmed.
[d] The amination product was benzylated before measuring the enantiomeric excess.
[e] Additionally, *tert*-butyl 2-oxo-4-vinyloxazolidinone-3-carboxylate[12] was also isolated in 10–15% yield.

(Scheme 4, Table 3). Reactions with HN(CHO)Boc as nucleophile gave directly the *N*-Boc-protected vinylglycinol derivative **15**, i.e. the formyl group was removed under the reaction conditions. Only traces of the linear product **16** could be detected (GC/MS). Accordingly, regioselectivities were high (>95:5) (Table 3, entries 1–3). The reaction rate and yield were optimal with ligand **L2** and enantioselectivity was best upon use of ligand **L3** (95% ee) (Table 3, entry 3).

Similarly, the substitution reaction with the pronucleophile $NaNBoc_2$ was accompanied by N,O-migration of one of the Boc groups to give the *N*,*O*-di-Boc-protected vinylglycinol derivative **17** as the main product (Table 3, entries 4–6). In addition, the cyclization product *tert*-butyl 2-oxo-4-vinyloxazolidinone-3-carboxylate was isolated in 10–15% yield. Again, reaction products did not contain the linear amination product **18** according to GC and HPLC. Reaction rates were significantly higher with the ligands **L2** and **L3** than with ligand **L1**. The results again show that the hydroxy group of the allylic side chain gives rise to very high regioselectivity, however, it is detrimental for enantioselectivity.

Reactions with phthalimide as pronucleophile were not accompanied by acyl migration (Table 3, entries 7–9). As above, results with ligands **L2** and **L3** were superior to those with **L1**. The vinylglycinol derivative **19** was obtained in up to 95% yield with perfect regioselectivity (>99:1) and tolerable enantioselectivity (87–92% ee). Trost et al. have previously prepared this compound by a highly selective palladium-catalyzed allylic amination of vinyloxirane.[13]

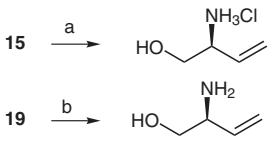
The above results clearly showed that O-protection is advisable for iridium-catalyzed amination of allylic substrates with hydroxy-containing substituents. With a view to applications in natural product chemistry, examples with an O-functional group at C_β and C_γ of the allylic side chain were investigated (Scheme 5). *N*,*N*-Diacylamines were mainly used as pronucleophiles. Benzylamine and 4-methoxyaniline were additionally probed in the case of carbonate **1f** with $R^1 = CH_2CH_2CO_2Me$.

The reactions of substrate **1e** with the three standard *N*,*N*-diacylamines proceeded, under salt-free conditions, with very good regio- as well as enantioselectivity (Table 4, entries 1–9), although values typical for substrates with R^1 = Ph or *n*-Pr were not quite reached. Once more, **L2** was the preferable ligand.

The substrate **1f**, starting material for vigabatrin, was first reacted with benzylamine (Table 4, entry 10). The result was very similar to that obtained with the carbonate **1c**, i.e. the reaction proceeded with a very low degree of regioselectivity. The branched substitution product **21f** was not isolated because of in situ further reaction to the lactam (5*S*)-1-benzyl-5-vinylpyrrolidin-2-one (**21f′**). Results with 4-methoxyaniline as nucleophile also closely resemble those obtained with **1c**. Improved results were obtained with $NaNBoc_2$ as well as $HNBoc_2$, i.e. under salt-free conditions, as pronucleophiles (Table 4, entries 14–18). Remarkably, the latter reacted even at room temperature at about the same rate as the former. Conditions as described in Table 4, entry 17 furnished an excellent result.

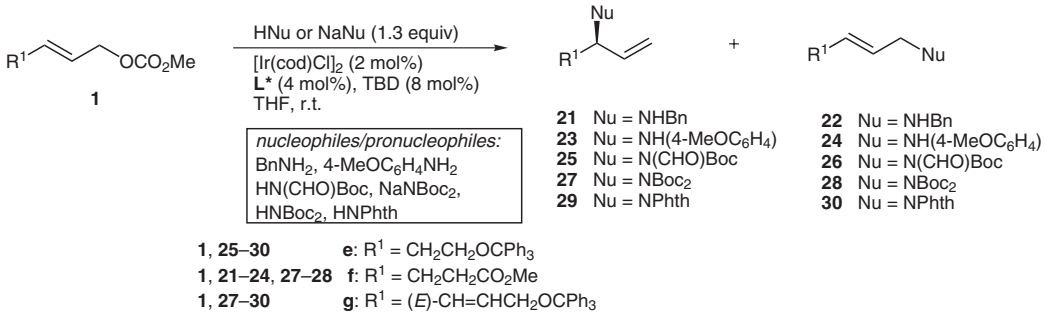
Amination products derived from substrate **1g** can be transformed into aminosugars and other types of natural products. The reactions with $NaNBoc_2$ and with phthalimide gave the substitution products with very high yield and >99% ee upon use of **L2** as ligand. The regioselectivity was 90:10 at best, somewhat lower than anticipated.

The chiral amination products **19** and **15** were transformed into (*S*)-2-aminobut-3-en-1-ol (vinylglycinol) and its hydrochloride, respectively, using standard procedures (Scheme 6). Enantiomerically enriched vinylglycinol is an important building block in organic synthesis.[13]



Scheme 6 Deprotection of amination products. *Reagents and conditions*: (a) 5% HCl–EtOH, reflux, 2 h, quant. (b) $(CH_2NH_2)_2$ (5 equiv), MeOH, reflux, 2 h, quant.

(*S*)-Vigabatrin is currently used as antiepilepsy drug. It acts as an irreversible inhibitor of γ-aminobutyric acid transaminase (GABA-T), an enzyme that degrades GABA. Enantioselective synthesis of this compound has been a probe for asymmetric syntheses of amines. Exchiral pool syntheses as well as routes based on palladium-catalyzed allylic substitution, asymmetric epoxida-

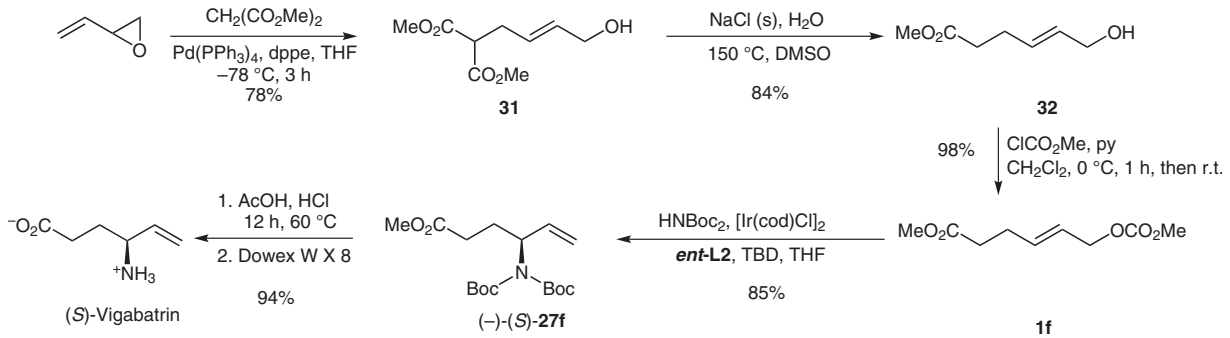


Scheme 5 Iridium-catalyzed allylic substitutions with substituents containing O-functionality in β- and γ-positions of R^1

Table 4 Allylic Substitutions According to Scheme 5 and General Procedure 2

Entry	Substrate	R^1	Pronucleophile	L*	Time (h)	Temp (°C)	Yield[a] (%)	Ratio[b] b/l	ee[c] (%)
1	**1e**	$CH_2CH_2OCPh_3$	HN(CHO)Boc	**L1**	1	r.t.	93	93:7	91
2	**1e**	$CH_2CH_2OCPh_3$	HN(CHO)Boc	*ent*-**L2**	1	r.t.	94	94:6	92
3	**1e**	$CH_2CH_2OCPh_3$	HN(CHO)Boc	**L3**	1	r.t.	90	89:11	89
4	**1e**	$CH_2CH_2OCPh_3$	$HNBoc_2$	**L1**	24	r.t.	92	95:5	95
5	**1e**	$CH_2CH_2OCPh_3$	$HNBoc_2$	**L2**	3	r.t.	93	96:4	97
6	**1e**	$CH_2CH_2OCPh_3$	$HNBoc_2$	**L3**	6	r.t.	79	92:8	98
7	**1e**	$CH_2CH_2OCPh_3$	PhthNH	**L1**	72	r.t.	88	88:12	91
8	**1e**	$CH_2CH_2OCPh_3$	PhthNH	*ent*-**L2**	1	r.t.	90	93:7	93
9	**1e**	$CH_2CH_2OCPh_3$	PhthNH	**L3**	2	r.t.	80	84:16	88
10	**1f**	$CH_2CH_2CO_2Me$	$BnNH_2$	*ent*-**L2**	3	r.t.	72[d]	74:26	93[d]
11	**1f**	$CH_2CH_2CO_2Me$	4-$MeOC_6H_4NH_2$	**L1**	2.5	r.t.	72	90:10	89
12	**1f**	$CH_2CH_2CO_2Me$	4-$MeOC_6H_4NH_2$	**L2**	0.25	r.t.	70	96:4	90
13	**1f**	$CH_2CH_2CO_2Me$	4-$MeOC_6H_4NH_2$	**L3**	1	r.t.	86	93:7	94
14	**1f**	$CH_2CH_2CO_2Me$	$NaNBoc_2$	**L1**	24	r.t.	73	85:15	91 (*R*)[e]
15	**1f**	$CH_2CH_2CO_2Me$	$NaNBoc_2$	*ent*-**L2**	17	r.t.	72	95:5	95 (*S*)[e]
16	**1f**	$CH_2CH_2CO_2Me$	$NaNBoc_2$	**L3**	15	r.t.	70	93:7	96 (*R*)[e]
17	**1f**	$CH_2CH_2CO_2Me$	$HNBoc_2$	*ent*-**L2**	24	r.t.	85	97:3	98 (*S*)[e]
18	**1f**	$CH_2CH_2CO_2Me$	$HNBoc_2$	**L3**	24	r.t.	69	95:5	97 (*R*)[e]
19	**1g**	(*E*)-$CH{=}CHCH_2OCPh_3$	$NaNBoc_2$	**L2**	3	r.t.	99	87:13	>99
20[f]	**1g**	(*E*)-$CH{=}CHCH_2OCPh_3$	$NaNBoc_2$	**L2**	3	r.t.	99	90:10	>99
21	**1g**	(*E*)-$CH{=}CHCH_2OCPh_3$	PhthNH	*ent*-**L2**	3	r.t.	90	82:18	>99
22	**1g**	(*E*)-$CH{=}CHCH_2OCPh_3$	PhthNH	*ent*-**L1**	5	50	82	78:22	94

[a] Entries 1–9, 19–22: isolated yield of the combined regioisomers; entry 10–18: isolated yield of the branched regioisomer.
[b] Ratio of branched/linear isomers as determined by ^1H NMR spectroscopy of the crude products.
[c] Determined by HPLC on chiral columns. Assignment of absolute configuration is given for cases in which it was independently confirmed.
[d] The reaction of $BnNH_2$ with carbonate **1f** did not yield the expected product **21f**, but the lactam (5*S*)-1-benzyl-5-vinylpyrrolidin-2-one (**21f'**), which was formed by intramolecular nucleophilic substitution.
[e] Determined by HPLC after removal of one Boc-protecting group.
[f] These reactions were carried out with a reduced catalyst loading of 2% of Ir.



Scheme 7 Synthesis of (*S*)-vigabatrin starting from vinyloxirane

tion, and allylic rearrangement reactions have been reported.[13,14]

Our synthesis (Scheme 7), like the synthesis of Trost et al.,[13] begins with the readily available vinyloxirane, which was used as the substrate in a palladium-catalyzed allylic alkylation with dimethyl malonate. Using a modified procedure of Echavarren et al.[15] [2.5 mol% $Pd_2(dba)_3$/dppe, r.t.], we obtained **31** in 74% yield with a 3:1 ratio of *E*- and *Z*-isomers. This ratio was improved to 15:1 by running the reaction at –78 °C with $Pd(PPh_3)_4$/dppe as catalyst.

Demethoxycarbonylation under Krapcho conditions[16] gave the ester **32** in 84% yield. This was converted into the carbonate **1f** in 98% yield. The key allylic amination of **1f** furnished intermediate (–)-(*S*)-**27f** in excellent yield and selectivity. Initially, $NaNBoc_2$ was used as pronucleophile (Table 4, entries 14–16). Better results, regioselectivity of 97:3 and enantiomeric excess of 98% ee, were obtained with $HNBoc_2$ under salt-free conditions (Table 4, entry 17). The amide (–)-(*S*)-**27f** was deprotected with acetic acid/hydrochloric acid to give (*S*)-vigabatrin in 94% yield; the overall yield from vinyloxirane via five steps was 51%.

^{1}H NMR spectra were recorded at r.t. on the following spectrometers: Bruker DRX-200 (200 MHz), Bruker AC-300 (300 MHz), and Bruker Avance 500 (500 MHz) with $CHCl_3$ (δ_H = 7.26) as reference. ^{13}C NMR spectra were recorded on the following spectrometers: Bruker AC-300 (75 MHz) and Bruker Avance 500 MHz (125 MHz) with $CHCl_3$ [δ_C = 77.16 (central line of the triplet)] as reference. The assignments of signals were confirmed by H,H-COSY, H,C-COSY, and DEPT spectra. Optical rotations were measured with a Perkin Elmer 341 Polarimeter in a 1-dm thermostated cuvette using a Hg lamp. HRMS were recorded on a Jeol JMS-700 (EI+, FAB+) or on a Bruker ApexQe FT-ICR (ESI+) mass spectrometer. Elemental analyses were carried out at the Organisch-Chemisches Institut, Universität Heidelberg.

Enantiomeric excess was determined by HPLC on a HP 1100 instrument. The following columns from Daicel were used: Chiralpak AD-H (250 × 4.6 mm, 5 μm) with guard cartridge AD-H (10 × 4 mm, 5 μm), Chiralcel OD-H (250 × 4.6 mm, 5 μm), with guard cartridge OD-H (10 × 4 mm, 5 μm) and Chiralcel OJ-H (250 × 4.6 mm, 5 μm) with guard cartridge OJ-H (10 × 4 mm, 5 μm). Kugelrohr distillation was carried out with a Büchi B-580 instrument; boiling points correspond to air bath temperatures. Flash column chromatography was carried out with silica gel (0.032–0.062 mm) of Macherey, Nagel and Co. Petroleum ether = PE. Decomposition on column is possible with allylamines. This can be minimized by the addition of Et_3N (ca. 1%) to the solvent, the use of a small column, and fast elution.

THF was dried over benzophenone ketyl and the H_2O content was determined by Karl Fischer titration. 1,5,7-Triazabicyclo[4.4.0]dec-5-ene (TBD) was stored in a desiccator over KOH (alternative small amounts were stored under argon in a Schlenk tube).

The following compounds were prepared as previously reported: (2*E*)-4-(*tert*-butyldimethylsiloxy)but-2-en-1-ol from (2*E*)-4-(*tert*-butyldimethylsiloxy)but-2-en-1-al[17a] by reduction with DIBAL-H, (2*E*)-4-(*tert*-butyldiphenylsiloxy)but-2-en-1-ol,[17b] (2*E*)-4-(trityloxy)but-2-en-1-ol,[18] (2*E*)-but-2-ene-1,4-diol,[19] 1-(trityloxy)but-3-yne,[20] and (2*Z*)-4-(trityloxy)but-2-en-1-ol.[21]

Unless stated otherwise, linear amination products were obtained from the Ir-catalyzed allylic substitution by flash column chromatography under the conditions stated. In cases of very high regioselectivity in favor of the branched product, the linear products were prepared separately via Pd-catalyzed allylic substitution, noncatalyzed nucleophilic substitution at the corresponding allylic bromide, or, in case of some unprotected substitution products, by cleavage of the protecting group from the corresponding protected substitution product. Yields were generally not optimized.

Absolute configurations for new nonracemic chiral compounds were assigned on the basis of a general rule concerning the steric course of the Ir-catalyzed allylic substitution.[3a] This rule was found to be correct for all cases that were verified.

Synthesis of Allylic Carbonates 1a–g, 2d; General Procedure 1

A soln of the alcohol (10 mmol) and pyridine (15 mmol) in anhyd CH_2Cl_2 (20 mL) was cooled to 0 °C and methyl chloroformate (15 mmol) was added dropwise. In the case of but-2-ene-1,4-diol, only 11 mmol of methyl chloroformate or ethyl chloroformate were used in order to minimize diacylation. The mixture was stirred at 0 °C for 1 h, allowed to warm up to r.t., and then stirred until complete conversion (TLC). H_2O (20 mL) was added, the phases were separated, and the aqueous layer was extracted with CH_2Cl_2 (3 × 20 mL). The combined organic phases were washed with sat. aq $CuSO_4$ (20 mL) and NH_4Cl soln (2 × 30 mL), dried (Na_2SO_4), filtered, and concentrated in vacuo. The crude product was purified by flash chromatography (silica gel, PE–EtOAc; detection: UV and $KMnO_4$).

(2*E*)-4-(*tert*-Butyldimethylsiloxy)but-2-enyl Methyl Carbonate (1a)

Following general procedure 1 using (2*E*)-4-(*tert*-butyldimethylsiloxy)but-2-en-1-ol[17a] gave **1a** as a colorless oil; yield: 88%; TLC: R_f = 0.34 [(2*E*)-4-(*tert*-butyldimethylsiloxy)but-2-en-1-ol], 0.60 (**1a**) (PE–EtOAc, 3:1, $KMnO_4$).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.06 [s, 6 H, $Si(CH_3)_2$], 0.90 [s, 9 H, $SiC(CH_3)_3$], 3.78 (s, 3 H, OCH_3), 4.17–4.19 (m, 2 H, CH_2OSi), 4.62–4.64 (m, 2 H, CH_2OC), 5.76–5.93 (m, 2 H, CH=CH).

^{13}C NMR (75 MHz, $CDCl_3$): δ = –5.16 [q, $Si(CH_3)_2$], 18.52 [s, $SiC(CH_3)_3$], 26.05 [q, $SiC(CH_3)_3$], 54.87 (q, OCH_3), 62.86 (t, CH_2OSi), 68.02 (t, CH_2OC), 122.96, 135.00 (2 d, CH=CH), 155.77 (s, C=O).

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{12}H_{24}NaO_4Si$: 283.1342; found: 283.1336.

Anal. Calcd for $C_{12}H_{24}O_4Si$: C, 55.35; H, 9.29. Found: C, 55.12; H, 9.34.

(2*E*)-4-(*tert*-Butyldiphenylsiloxy)but-2-enyl Methyl Carbonate (1b)

Following general procedure 1 using (2*E*)-4-(*tert*-butyldiphenylsiloxy)but-2-en-1-ol[17b] gave **1b** as a colorless oil; yield: 95%; TLC: R_f = 0.33 [(2*E*)-4-(*tert*-butyldiphenylsiloxy)but-2-en-1-ol], 0.57 (**1b**) (PE–EtOAc, 3:1, $KMnO_4$).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.07 [s, 9 H, $SiC(CH_3)_3$], 3.80 (s, 3 H, OCH_3), 4.21–4.23 (m, 2 H, CH_2OSi), 4.64–4.66 (m, 2 H, CH_2OC), 5.84–5.99 (m, 2 H, CH=CH), 7.36–7.47 (m, 6 H, Ph), 7.65–7.70 (m, 4 H, Ph).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 19.39 [s, $SiC(CH_3)_3$], 26.96 [q, $SiC(CH_3)_3$], 54.88 (q, OCH_3), 63.54 (t, CH_2OSi), 68.06 (t, CH_2OC), 122.97 (d, CH=), 127.84, 129.85 (2 d, Ph), 133.61 (s, Ph), 134.51 (d, CH=), 135.66 (d, Ph), 155.77 (s, C=O).

HRMS (EI): *m*/*z* [M – *t*-C_4H_9]$^+$ calcd for $C_{18}H_{19}O_4Si$: 327.1021; found: 327.1032.

Anal. Calcd for $C_{22}H_{28}O_4Si$: C, 68.71; H, 7.34. Found: C, 68.70; H, 7.31.

Methyl (2*E*)-4-(Trityloxy)but-2-enyl Carbonate (1c)

Following general procedure 1 using (2*E*)-4-(trityloxy)but-2-en-1-ol[18] gave **1c** as a white powder; yield: 97%; mp 64–65 °C; TLC: R_f = 0.17 [(2*E*)-4-(trityloxy)but-2-en-1-ol], 0.45 (**1c**) (PE–EtOAc, 4:1, $KMnO_4$).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.66 (dd, *J* = 4.3 Hz, *J* = 1.3 Hz, 2 H, CH_2OCO_2), 3.80 (s, 3 H, OCH_3), 4.67 (dd, *J* = 5.7 Hz, *J* = 0.9 Hz, 2 H, C*H*$_2$OCPh$_3$), 5.90 (dt, *J* = 15.6 Hz, *J* = 4.3 Hz, 1 H, C*H*CH$_2$OCO$_2$), 6.01 (dtt, *J* = 15.5 Hz, *J* = 5.8 Hz, *J* = 1.3 Hz, 1 H, C*H*CH$_2$OCPh$_3$), 7.21–7.34 (m, 9 H, Ph), 7.44–7.48 (m, 6 H, Ph).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 54.91 (q, OCH_3), 63.78 (t, *C*H$_2$OCPh$_3$), 68.15 (t, *C*H$_2$OCO$_2$), 87.03 (s, *C*Ph$_3$), 124.05 (d, CH=), 127.16, 127.98, 128.71 (3 d, Ph), 132.51 (d, CH=), 144.13 (s, Ph), 155.74 (s, CO_2).

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{25}H_{24}NaO_4$: 411.1572; found: 411.1567.

Anal. Calcd for $C_{25}H_{24}O_4$: C, 77.30; H, 6.23. Found: C, 77.29; H, 6.19.

(2*E*)-4-Hydroxybut-2-enyl Methyl Carbonate (1d)

Following general procedure 1 using (2*E*)-but-2-ene-1,4-diol[19] gave **1d** as a colorless oil; yield: 46%; TLC: R_f = 0.02 [(2*E*)-but-2-ene-1,4-diol], 0.21 (**1d**), 0.53 [(2*E*)-but-2-ene-1,4-diyl dimethyl biscarbonate] (PE–EtOAc, 3:1, $KMnO_4$). In addition (2*E*)-but-2-ene-1,4-diyl dimethyl biscarbonate[22] (31%) was obtained as side product.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.75 (s, 1 H, OH), 3.78 (s, 3 H, OCH_3), 4.17 (dd, *J* = 4.8 Hz, *J* = 1.3 Hz, 2 H, C*H*$_2$OH), 4.63 (dd, *J* = 5.8 Hz, *J* = 1.0 Hz, 2 H, CH$_2$OC), 5.83 (dtt, *J* = 15.5 Hz, *J* = 5.9 Hz, *J* = 1.4 Hz, 1 H, C*H*CH$_2$OC), 5.96 (dtt, *J* = 15.5 Hz, *J* = 4.8 Hz, *J* = 0.9 Hz, 1 H, C*H*CH$_2$OH).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 54.96 (t, CH_2OH), 62.67 (t, *C*H$_2$OC), 67.74 (q, OCH_3), 124.35 (d, *C*HCH$_2$OH), 134.50 (d, *C*HCH$_2$OC), 155.73 (s, CO_2).

HRMS (EI): *m*/*z* [M]$^+$ calcd for $C_6H_{10}O_4$: 146.0579; found: 146.0587.

Anal. Calcd for $C_6H_{10}O_4$: C, 49.31; H, 6.90. Found: C, 49.11; H, 6.83.

Methyl (2*E*)-5-(Trityloxy)pent-2-enyl Carbonate (1e)

5-(Trityloxy)pent-2-yn-1-ol

A soln of 1.6 M *n*-BuLi in *n*-hexane (19.0 mL, 30.0 mmol) was added dropwise to a soln of 1-(trityloxy)but-3-yne[20] (9.5 g, 30.0 mmol) in THF (60 mL) at –40 °C. The mixture was stirred at this temperature for 15 min and transferred through a Teflon tube into a suspension of paraformaldehyde (2.7 g, 90.0 mmol) in THF (30 mL) at –45 °C. The resultant mixture was allowed to warm up to r.t. and stirred until complete conversion (1 h) [TLC: R_f = 0.49 [1-(trityloxy)but-3-yne], 0.16 [5-(trityloxy)pent-2-yn-1-ol] (PE–EtOAc, 4:1, $KMnO_4$)]. Et_2O (100 mL) was added. The organic phase was separated and washed with brine (50 mL), dried (Na_2SO_4), and concentrated in vacuo. The crude product was subjected to flash chromatography (silica gel, 90 g, PE–EtOAc, 4:1) to yield 5-(trityloxy)pent-2-yn-1-ol (6.8 g, 66%) as a colorless powder; mp 98–99 °C.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.64 (br s, OH), 2.53 (tt, *J* = 7.1 Hz, *J* = 2.1 Hz, 2 H, C*H*$_2$CH$_2$O), 3.24 (t, *J* = 7.1 Hz, 2 H, CH$_2$OCPh$_3$), 4.23 (s, 2 H, C*H*$_2$OH), 7.22–7.35 (m, 9 H, Ph), 7.46–7.49 (m, 6 H, Ph).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 20.41 (t, *C*H$_2$CH$_2$O), 51.45 (t, CH$_2$OH), 62.29 (t, *C*H$_2$OCPh$_3$), 79.49, 83.64 (2 s, C≡C), 86.82 (s, CPh$_3$), 127.15, 127.94, 128.77 (3 d, Ph), 144.11 (s, Ph).

HRMS (ESI): *m*/*z* [M + K]$^+$ calcd for $C_{24}H_{22}KO_2$: 381.1251; found: 381.1251.

Anal. Calcd for $C_{24}H_{22}O_2$: C, 84.18; H, 6.48. Found: C, 83.88; H, 6.55.

(2*E*)-5-(Trityloxy)pent-2-en-1-ol

A soln of 5-(trityloxy)pent-2-yn-1-ol (6.16 g, 18.0 mmol) in anhyd THF (25 mL) was added dropwise, over a period of 15 min, to a cooled (0 °C) suspension of $LiAlH_4$ (0.85 g, 22.5 mmol) in anhyd THF (25 mL). The mixture was heated at reflux for 2 h [TLC: R_f = 0.16 [5-(trityloxy)pent-2-yn-1-ol], 0.11 [(2*E*)-5-(trityloxy)pent-2-en-1-ol] (PE–EtOAc, 4:1, $KMnO_4$)]. After cooling to r.t., H_2O (20 mL) was added dropwise. After stirring for 10 min, the resulting suspension was extracted with Et_2O (3 × 50 mL). The combined organic layers were dried (Na_2SO_4), filtered, and concentrated in vacuo. The crude product was purified by flash chromatography (silica gel, 200 g, PE–Et_2O, 2:1) to yield (2*E*)-5-(trityloxy)pent-2-en-1-ol (5.69 g, 92%) as a colorless powder; mp 61 °C.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.31 (br s, OH), 2.35–2.41 (m, 2 H, C*H*$_2$CH$_2$O), 3.13 (t, *J* = 6.8 Hz, 2 H, CH$_2$OCPh$_3$), 4.08 (d, *J* = 3.6 Hz, 2 H, C*H*$_2$OH), 5.63–5.76 (m, 2 H, CH=CH), 7.21–7.33 (m, 9 H, Ph), 7.44–7.46 (m, 6 H, Ph).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 33.14 (t, *C*H$_2$CH$_2$O), 63.38 (t, *C*H$_2$OCPh$_3$), 63.80 (t, CH_2OH), 86.64 (s, CPh$_3$), 127.04, 127.87, 128.81 (3 d, Ph), 129.75, 130.98 (2 d, CH=), 144.43 (s, Ph).

HRMS (ESI): *m*/*z* [M + K]$^+$ calcd for $C_{24}H_{24}KO_2$: 383.1408; found: 383.1408.

Anal. Calcd for $C_{24}H_{24}O_2$: C, 83.69; H, 7.02. Found: C, 83.57; H, 7.16.

Methyl (2*E*)-5-(Trityloxy)pent-2-enyl Carbonate (1e)

Following general procedure 1 using (2*E*)-5-(trityloxy)pent-2-en-1-ol gave **1e** as a colorless oil; yield: 93%; TLC: R_f = 0.11 [(2*E*)-5-(trityloxy)pent-2-en-1-ol], 0.40 (**1e**) (PE–EtOAc, 4:1, $KMnO_4$)].

^{1}H NMR (300 MHz, $CDCl_3$): δ = 2.39 (dt, *J* = 6.6 Hz, *J* = 6.6 Hz, 2 H, C*H*$_2$CH$_2$O), 3.15 (t, *J* = 6.7 Hz, 2 H, CH$_2$OCPh$_3$), 3.77 (s, 3 H, OCH_3), 4.59 (dd, *J* = 6.2 Hz, *J* = 0.8 Hz, 2 H, C*H*$_2$OCO$_2$), 5.66 (dtt, *J* = 15.4 Hz, *J* = 6.5 Hz, *J* = 0.9 Hz, 1 H, C*H*CH$_2$OCO$_2$), 5.86 (dt, *J* = 15.3 Hz, *J* = 6.9 Hz, 1 H, C*H*CH$_2$CH$_2$), 7.21–7.34 (m, 9 H, Ph), 7.44–7.47 (m, 6 H, Ph).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 33.17 (t, *C*H$_2$CH$_2$O), 54.82 (q, OCH_3), 62.97 (t, *C*H$_2$OCPh$_3$), 68.54 (t, *C*H$_2$OCO$_2$), 86.63 (s, CPh$_3$), 125.27 (d, *C*HCH$_2$OCO$_2$), 127.04, 127.88, 128.79 (3 d, Ph), 133.88 (d, *C*HCH$_2$CH$_2$), 144.36 (s, Ph), 155.78 (s, CO_2).

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{26}H_{26}NaO_4$: 425.1723; found: 425.1725.

Anal. Calcd for $C_{26}H_{26}O_4$: C, 77.59; H, 6.51. Found: C, 77.68; H, 6.53.

Methyl (4*E*)-6-[(Methoxycarbonyl)oxy]hex-4-enoate (1f)

Following general procedure 1 using methyl (4*E*)-6-hydroxyhex-4-enoate (**32**) gave **1f** as a colorless oil; yield: 98%; TLC: R_f = 0.04 (**32**), 0.20 (**1f**) (PE–EtOAc, 4:1, $KMnO_4$).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 2.33–2.43 (m, 4 H, CH_2CH_2), 3.65 (s, 3 H, CO_2CH_3), 3.76 (s, 3 H, OCO_2CH_3), 4.55 (d, *J* = 6.2 Hz, 2 H, CH$_2$OCO$_2$), 5.61 (dt, *J* = 15.4 Hz, *J* = 6.3 Hz, 1 H, C*H*CH$_2$OCO$_2$), 5.75–5.85 (m, 1 H, C*H*CH$_2$CH$_2$).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 27.50 (t, *C*H$_2$CH$_2$CO$_2$), 33.29 (t, *C*H$_2$CO$_2$), 51.71 (q, CO_2CH_3), 54.83 (q, OCO_2CH_3), 68.29 (t, *C*H$_2$OCO$_2$), 124.63 (d, *C*HCH$_2$OCO$_2$), 134.71 (d, *C*HCH$_2$CH$_2$), 155.69 (s, O*C*O$_2$CH$_3$), 173.28 (s, *C*O$_2$CH$_3$).

HRMS (FAB): *m*/*z* [M + H]$^+$ calcd for $C_9H_{15}O_5$: 203.0919; found: 203.0923.

Anal. Calcd for $C_9H_{14}O_5$: C, 53.46; H, 6.98. Found: C, 53.69; H, 7.04.

Methyl (2*E*,4*E*)-6-(Trityloxy)hexa-2,4-dienyl Carbonate (1g)
(2*E*)-4-(Trityloxy)but-2-enal

In a flame-dried 500-mL 3-necked flask under argon, PCC (5.6 g, 26.0 mmol) and Celite (35.0 g) were suspended in anhyd CH_2Cl_2 (170 mL). A soln of (2*Z*)-4-(trityloxy)but-2-en-1-ol[21] (5.6 g, 17.0 mmol) in anhyd CH_2Cl_2 (15 mL) was added and the brown mixture was stirred at r.t. for 2 h until complete consumption of the alcohol [TLC: R_f = 0.24 (educt), 0.40 (product) (PE–EtOAc, 3:1, UV)]. CH_2Cl_2 (170 mL) was added, the mixture was filtered through a pad of Celite–Florisil (1:1, 100 g), which was washed with CH_2Cl_2 (4 × 70 mL). The filtrate was concentrated in vacuo to give the crude product as a green solid (5.0 g, 89%). This was subjected to flash column chromatography (silica gel, 250 g, PE–EtOAc, 3:1) to yield pure (2*E*)-4-(trityloxy)but-2-enal (4.8 g, 86%) as colorless needles; mp 137–138 °C.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.95 (dd, *J* = 3.5 Hz, *J* = 1.9 Hz, 2 H, CH_2), 6.64 (ddt, *J* = 15.7 Hz, *J* = 7.8 Hz, *J* = 1.9 Hz, 1 H, C*H*CHO), 6.80 (dt, *J* = 15.7 Hz, *J* = 3.5 Hz, 1 H, C*H*CH_2), 7.23–7.35 (m, 9 H, Ph), 7.42–7.47 (m, 6 H, Ph), 9.58 (d, *J* = 7.8 Hz, 1 H, CHO).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 63.27 (t, CH_2), 87.35 (s, CPh_3), 127.45 (d, Ph), 128.16, 128.62 (2 d, Ph), 131.26 (d, *C*HCHO), 143.63 (s, Ph), 153.89 (d, *C*HCH_2), 193.67 (d, CHO).

HRMS (FAB): *m*/*z* [M + Na]$^+$ calcd for $C_{23}H_{20}O_2Na$: 351.1361; found: 351.1374.

Anal. Calcd for $C_{23}H_{20}O_2$: C, 84.12; H, 6.14. Found: C, 83.83; H, 6.11.

Ethyl (2*E*,4*E*)-6-(Trityloxy)hexa-2,4-dienoate

In a flame-dried 250-mL 3-neck flask under argon, triethyl phosphonoacetate (13.2 mL, 66.1 mmol) was added dropwise to a suspension of NaH (1.45 g, 60.42 mmol) in anhyd THF (70 mL) at r.t. The mixture was stirred for 30 min and then cooled to –78 °C. (2*E*)-4-(Trityloxy)but-2-enal (16.70 g, 50.89 mmol) was added dropwise and the mixture was allowed to warm to r.t. overnight and complete consumption of the aldehyde was indicated [TLC: R_f = 0.28 (educt), 0.41 (product) (PE–EtOAc, 9:1, $KMnO_4$)]. The mixture was cooled to –40 °C and Et_2O (200 mL) and sat. NH_4Cl soln (200 mL) were added. The mixture was allowed to warm to r.t., the phases were separated, and the aqueous phase was extracted with Et_2O (2 × 90 mL). The combined organic phases were washed with sat. aq NH_4Cl soln (2 × 160 mL) and brine (100 mL), dried (Na_2SO_4), and concentrated in vacuo to afford a colorless oil. This was subjected to flash column chromatography (silica gel, 300 g, PE–EtOAc, 20:1) to yield pure ethyl (2*E*,4*E*)-6-(trityloxy)hexa-2,4-dienoate (16.90 g, 83%) as a white solid; mp 72–73 °C.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.33 (t, *J* = 7.1 Hz, 3 H, CH_3), 3.80 (d, *J* = 3.8 Hz, 2 H, CH_2CH), 4.25 (q, *J* = 7.2 Hz, 2 H, C$H_2$$CH_3$), 5.97 (d, *J* = 15.3 Hz, 1 H, $CHCO_2$), 6.18 (dt, *J* = 15.3 Hz, *J* = 4.7 Hz, 1 H, C*H*CH_2), 6.57–6.66 (m, 1 H, C*H*$CHCH_2$), 7.23–7.39 (m, 10 H, C*H*$CHCO_2$, Ph), 7.48–7.52 (m, 6 H, Ph).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.40 (q, CH_3), 60.35 (t, *C*H_2CH_3), 64.03 (t, *C*H_2CH), 87.15 (s, CPh_3), 121.14 (d, *C*HCO_2), 127.22 (d, Ph), 127.93 (d, *C*$HCHCH_2$), 128.00, 128.64 (2 d, Ph), 139.39 (d, *C*HCH_2), 143.96 (s, Ph), 144.21 (d, *C*$HCHCO_2$), 167.12 (s, CO_2).

HRMS (FAB): *m*/*z* [M + H]$^+$ calcd for $C_{27}H_{27}O_3$: 399.1960; found: 399.1957.

Anal. Calcd for $C_{27}H_{26}O_3$: C, 81.38; H, 6.58. Found: C, 81.66; H, 6.53.

(2*E*,4*E*)-6-(Trityloxy)hexa-2,4-dien-1-ol

Under argon, a soln of ethyl (2*E*,4*E*)-6-(trityloxy)hexa-2,4-dienoate (16.8 g, 42.2 mmol) in anhyd Et_2O (200 mL) was cooled to –78 °C. 1 M DIBAL-H in *n*-hexane (92.8 mL, 92.8 mmol) was added over a period of 1 h through a dropping funnel. After 2 h, consumption of the substrate was complete [TLC: R_f = 0.57 (educt), 0.21 (product) (PE–EtOAc, 3:1, UV)]. The mixture was allowed to warm to r.t. Sat. aq NH_4Cl soln (40 mL) and sat. aq potassium sodium tartrate soln (50 mL) were added, and the mixture was stirred for 1 h in order to dissolve the salts. Then, Et_2O (100 mL) was added, the phases were separated, and the aqueous phase was extracted with Et_2O (2 × 100 mL). The organic phases were combined and washed with sat. aq NH_4Cl soln (2 × 50 mL), dried (Na_2SO_4), and concentrated in vacuo. Flash column chromatography (silica gel, 300 g, PE–EtOAc, 3:1) afforded (2*E*,4*E*)-6-(trityloxy)hexa-2,4-dien-1-ol (14.96 g, >99%) as a colorless oil.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.38 (br s, 1 H, OH), 3.66 (d, *J* = 5.1 Hz, 2 H, C$H_2$$OCPh_3$), 4.21 (d, *J* = 5.8 Hz, 2 H, CH_2OH), 5.80 (dt, *J* = 14.8 Hz, *J* = 5.2 Hz, 1 H, C*H*CH_2), 5.86 (dt, *J* = 14.7 Hz, *J* = 5.8 Hz, 1 H, C*H*CH_2), 6.24–6.44 (m, 2 H, C*H*$CHCH_2$), 7.21–7.34 (m, 9 H, Ph), 7.44–7.48 (m, 6 H, Ph).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 63.52 (t, CH_2OH), 64.48 (t, *C*$H_2$$OCPh_3$), 87.02 (s, CPh_3), 127.13, 127.97, 128.76 (3 d, Ph), 130.20 (d, *C*HCH_2), 130.92 (d, *C*$HCHCH_2$), 131.27 (d, *C*HCH_2), 131.80 (d, *C*$HCHCH_2$), 144.27 (s, Ph).

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{25}H_{24}NaO_2$: 379.1674; found: 379.1669.

Anal. Calcd for $C_{25}H_{24}O_2$: C, 84.24; H, 6.79. Found: C, 83.95; H, 6.76.

Methyl (2*E*,4*E*)-6-(Trityloxy)hexa-2,4-dienyl Carbonate (1g)

Following general procedure 1 using (2*E*,4*E*)-6-(trityloxy)hexa-2,4-dien-1-ol gave **1g** as a white solid; yield: 83%; mp 82–84 °C; TLC: R_f = 0.13 (educt), 0.50 (**1g**) (PE–EtOAc, 5:1, UV).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.67 (d, *J* = 5.0 Hz, 2 H, C$H_2$$OCPh_3$), 3.80 (s, 3 H, CH_3), 4.68 (d, *J* = 6.6 Hz, 2 H, C$H_2$$OCO_2$), 5.75–5.89 (m, 2 H, C*H*CH_2), 6.30–6.44 (m, 2 H, C*H*$CHCH_2$), 7.21–7.33 (m, 9 H, Ph), 7.43–7.47 (m, 6 H, Ph).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 54.94 (q, CH_3), 64.29 (t, *C*$H_2$$OCO_2$), 68.25 (t, *C*$H_2$$OCPh_3$), 87.03 (s, CPh_3), 125.32 (d, *C*HCH_2), 127.16, 127.98, 128.74 (3 d, Ph), 129.49 (d, *C*$HCHCH_2$), 132.49 (d, *C*HCH_2), 134.80 (d, *C*$HCHCH_2$), 144.21 (s, Ph), 155.80 (s, O*C*O_2CH_3).

HRMS (FAB): *m*/*z* [M + Na]$^+$ calcd for $C_{27}H_{26}NaO_4$: 437.1729; found: 437.1712.

Anal. Calcd for $C_{27}H_{26}O_4$: C, 78.24; H, 6.32. Found: C, 78.17; H, 6.34.

Ethyl (2*E*)-4-Hydroxybut-2-enyl Carbonate (2d)

Following general procedure 1 using (2*E*)-but-2-ene-1,4-diol[19] gave **2d** as a colorless oil; yield: 48%; TLC: R_f = 0.54 (**2d**), 0.74 [(2*E*)-but-2-ene-1,4-diyl diethyl biscarbonate] (PE–EtOAc, 3:2, $KMnO_4$). The reaction yielded (2*E*)-but-2-ene-1,4-diyl diethyl biscarbonate[23] as colorless oil, in 25% yield as side product.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.30 (t, *J* = 7.0 Hz, 3 H, CH_2C*H*$_3$), 1.70 (br s, 1 H, OH), 4.14–4.19 (m, 2 H, CH_2OH), 4.19 (q, *J* = 7.1 Hz, 2 H, C$H_2$$CH_3$), 4.62 (dd, *J* = 5.9 Hz, *J* = 1.1 Hz, 2 H, CH_2OC), 5.83 (dtt, *J* = 15.6 Hz, *J* = 5.8 Hz, *J* = 1.3 Hz, 1 H, C*H*CH_2OC), 5.96 (dtt, *J* = 15.6 Hz, *J* = 4.8 Hz, *J* = 1.1 Hz, 1 H, C*H*CH_2OH).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.37 (q, CH_2CH_3), 62.71 (t, *C*$H_2$$CH_3$), 64.20 (t, CH_2OH), 67.50 (t, *C*H_2OC), 124.52, 134.40 (2 d, CH=CH), 155.12 (CO_2).

HRMS (EI): *m/z* [M]$^+$ calcd for $C_7H_{12}O_4$: 160.0736; found: 160.0756.

Anal. Calcd for $C_7H_{12}O_4$: C, 52.49; H, 7.55. Found: C, 52.31; H, 7.82.

Iridium-Catalyzed Allylic Amination; General Procedure 2

A Schlenk tube was dried under argon with a heat gun and charged with a soln of $[Ir(COD)Cl]_2$ (13.4 mg, 0.02 mmol) and **L*** (0.04 mmol) in anhyd THF (1.0 mL, content of H_2O <30 mg/L, Karl–Fischer titration). Anhyd TBD (11.1 mg, 0.08 mmol) was added and the mixture stirred for 5 min (**L2**) or 1 h (**L1**, **L3**). Then the carbonate (1 mmol), the nucleophile or pronucleophile (1.0–1.5 mmol) and additives (Et_3N or THT) were added. In case of low solubility of the (pro)nucleophile, anhyd THF (up to 4 mL) was added, and the soln was stirred for the time and at the temperature stated. Conversion was monitored by TLC or GC. The solvent was removed under reduced pressure and the residue was analyzed with respect to the ratio of branched and linear product by ^{1}H NMR. Pure reaction products were obtained by flash column chromatography.

(+)-(2*S*)-*N*-Benzyl-1-(*tert*-butyldimethylsiloxy)but-3-en-2-amine[24] [(+)-(*S*)-3a] and (2*E*)-*N*-Benzyl-4-(*tert*-butyldimethylsiloxy)but-2-en-1-amine (4a)

Following general procedure 2 using **1a** (Table 1, entries 1–3) and isolation by flash column chromatography (silica gel, PE–EtOAc, 2:1); TLC: R_f = 0.51 (**1a**), 0.48 (**3a**), 0.09 (**4a**) (PE–EtOAc, 5:1, $KMnO_4$). HPLC [Daicel Chiralcel OD-H, 250 × 4.6 mm, 5 μm, with guard cartridge 10 × 4 mm, 5 μm, *n*-hexane–*i*-PrOH, 90:10, flow = 0.5 mL min^{-1}, r.t., 210 nm]: t_R = 6.3 [(–)-(*R*)-**3a**], 7.4 [(+)-(*S*)-**3a**], 8.9 min (**4a**).

(+)-(2*S*)-*N*-Benzyl-1-(*tert*-butyldimethylsiloxy)but-3-en-2-amine[24] [(+)-(*S*)-3a]

Colorless oil.

$[\alpha]_D^{20}$ +19.0 [*c* 0.97, $CHCl_3$, 97% ee (*S*)].[24]

^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.04, 0.05 [2 s, 6 H, $Si(CH_3)_2$], 0.89 [s, 9 H, $SiC(CH_3)_3$], 2.06 (br s, 1 H, NH), 3.20–3.24 (m, 1 H, NCH), 3.52 (dd, *J* = 9.7 Hz, *J* = 8.4 Hz, 1 H, C*H*$_a$H$_b$O), 3.61 (dd, *J* = 10.0 Hz, *J* = 4.0 Hz, 1 H, CH$_a$*H*$_b$O), 3.66 (d, *J* = 13.4 Hz, 1 H, NC*H*$_a$H$_b$), 3.88 (d, *J* = 13.4 Hz, 1 H, NCH$_a$*H*$_b$), 5.20 (dd, *J* = 10.4 Hz, *J* = 1.7 Hz, 1 H, CH=C*H*$_E$H$_Z$), 5.25 (dd, *J* = 17.7 Hz, *J* = 1.7 Hz, 1 H, CH=CH$_E$*H*$_Z$), 5.66 (ddd, *J* = 17.6 Hz, *J* = 9.9 Hz, *J* = 7.9 Hz, 1 H, C*H*=CH$_2$), 7.22–7.33 (m, 5 H, Ph).

^{13}C NMR (125 MHz, $CDCl_3$): δ = –5.28, –5.20 [2 q, $Si(CH_3)_2$], 18.40 [s, Si*C*$(CH_3)_3$], 26.03 [q, SiC(*C*$H_3)_3$], 51.20 (t, NCH_2), 62.61 (d, NCH), 66.33 (t, CH_2O), 117.86 (t, CH=*C*H_2), 126.86, 128.16, 128.50 (3 d, Ph), 138.05 (d, *C*H=CH$_2$), 140.83 (s, Ph).

HRMS (FAB): *m/z* [M + H]$^+$ calcd for $C_{17}H_{30}NOSi$: 292.2097; found: 292.2072.

Anal. Calcd for $C_{17}H_{29}NOSi$: C, 70.04; H, 10.03; N, 4.80. Found: C, 69.88; H, 10.10; N, 4.98.

(2*E*)-*N*-Benzyl-4-(*tert*-butyldimethylsiloxy)but-2-en-1-amine (4a)

Colorless oil.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.07 [s, 6 H, $Si(CH_3)_2$], 0.91 [s, 9 H, $SiC(CH_3)_3$], 1.50 (br s, 1 H, NH), 3.27 (d, *J* = 5.5 Hz, 2 H, NC*H*$_2$CH), 3.79 (s, 2 H, NCH_2Ph), 4.16–4.18 (m, 2 H, CH_2O), 5.71 (dt, *J* = 15.4 Hz, *J* = 4.2 Hz, 1 H, C*H*CH$_2$O), 5.80 (dt, *J* = 15.7 Hz, *J* = 5.5 Hz, 1 H, C*H*CH$_2$N), 7.22–7.36 (m, 5 H, Ph).

^{13}C NMR (75 MHz, $CDCl_3$): δ = –5.03 [q, $Si(CH_3)_2$], 18.58 [s, Si*C*$(CH_3)_3$], 26.13 [q, SiC(*C*$H_3)_3$], 50.76 (t, N*C*H$_2$CH), 53.50 (t, NCH_2Ph), 63.64 (t, CH_2O), 127.07, 128.32, 128.54, 128.79 (4 d, NCH$_2$*C*H, Ph), 131.38 (d, *C*HCH$_2$O), 140.48 (s, Ph).

HRMS (FAB): *m/z* [M + H]$^+$ calcd for $C_{17}H_{30}NOSi$: 292.2097; found: 292.2073.

Anal. Calcd for $C_{17}H_{29}NOSi$: C, 70.04; H, 10.03; N, 4.80. Found: C, 70.13; H, 10.05; N, 4.95.

(+)-(2*S*)-*N*-Benzyl-1-(*tert*-butyldiphenylsiloxy)but-3-en-2-amine [(+)-(*S*)-3b] and (2*E*)-*N*-Benzyl-4-(*tert*-butyldiphenylsiloxy)but-2-en-1-amine (4b)

Following general procedure 2 using **1b** (Table 1, entries 4–6) and separation by flash column chromatography (silica gel, PE–Et_2O, 15:1); TLC: R_f = 0.51 (**1b**), 0.48 (**3b**), 0.09 (**4b**) (PE–EtOAc, 5:1, $KMnO_4$). HPLC [Daicel Chiralcel OD-H, 250 × 4.6 mm, 5 μm, with guard cartridge 10 × 4 mm, 5 μm, *n*-hexane–*i*-PrOH, 90:10, flow = 0.5 mL min^{-1}, r.t., 210 nm]: t_R = 7.6 [(–)-(*R*)-**3b**], 8.7 [(+)-(*S*)-**3b**], 9.8 min (**4b**).

(+)-(2*S*)-*N*-Benzyl-1-(*tert*-butyldiphenylsiloxy)but-3-en-2-amine [(+)-(*S*)-3b]

Colorless oil.

$[\alpha]_D^{24}$ +20.7 (*c* 1.13, $CHCl_3$, 98% ee).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.06 [s, 9 H, $SiC(CH_3)_3$], 2.14 (br s, 1 H, NH), 3.28 (ddd, *J* = 6.8 Hz, *J* = 6.7 Hz, *J* = 6.7 Hz, 1 H, NCH), 3.65 (d, *J* = 6.2 Hz, 2 H, CH_2O), 3.68 (d, *J* = 13.6 Hz, 1 H, NC*H*$_a$H$_b$), 3.91 (d, *J* = 13.6 Hz, 1 H, NCH$_a$*H*$_b$), 5.17 (d, *J* = 9.7 Hz, 1 H, CH=C*H*$_E$H$_Z$), 5.19 (dd, *J* = 17.5 Hz, *J* = 1.4 Hz, 1 H, CH=CH$_E$*H*$_Z$), 5.64 (ddd, *J* = 17.4 Hz, *J* = 10.1 Hz, *J* = 7.7 Hz, 1 H, C*H*=CH$_2$), 7.24–7.46 (m, 11 H, Ph), 7.62–7.68 (m, 4 H, Ph).

^{13}C (75 MHz, $CDCl_3$): δ = 19.37 [s, Si*C*$(CH_3)_3$], 26.97 [q, SiC(*C*$H_3)_3$], 51.10 (t, NCH_2), 62.30 (d, NCH), 66.98 (t, CH_2O), 118.00 (t, CH=*C*H_2), 126.91, 127.82, 128.22, 128.54, 129.82 (5 d, Ph), 133.46, 133.63 (2 s, Ph), 135.72 (d, Ph), 137.78 (d, *C*H=CH$_2$), 140.77 (s, Ph).

HRMS (FAB): *m/z* [M + H]$^+$ calcd for $C_{27}H_{34}NOSi$: 416.2410; found: 416.2479.

Anal. Calcd for $C_{27}H_{33}NOSi$: C, 78.02; H, 8.00; N, 3.37. Found: C, 78.03; H, 7.98; N, 3.49.

(2*E*)-*N*-Benzyl-4-(*tert*-butyldiphenylsiloxy)but-2-en-1-amine (4b)

Colorless oil.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.07 [s, 9 H, $SiC(CH_3)_3$], 1.46 (br s, 1 H, NH), 3.28 (dd, *J* = 5.8 Hz, *J* = 1.1 Hz, 2 H, NC*H*$_2$CH), 3.79 (s, 2 H, NCH_2Ph), 4.21–4.22 (m, 2 H, CH_2O), 5.72 (dt, *J* = 15.4 Hz, *J* = 4.5 Hz, 1 H, C*H*CH$_2$O), 5.84 (dtt, *J* = 15.3 Hz, *J* = 5.9 Hz, *J* = 1.3 Hz, 1 H, C*H*CH$_2$N), 7.23–7.45 (m, 11 H, Ph), 7.68–7.71 (m, 4 H, Ph).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 19.38 [s, Si*C*$(CH_3)_3$], 26.99 [q, SiC(*C*$H_3)_3$], 50.74 (t, N*C*H$_2$CH), 64.26 (t, CH_2O), 127.08, 127.79, 128.36, 128.54, 128.63, 129.76 (6 d, Ph, NCH$_2$C*H*), 130.95 (d, C*H*CH$_2$O), 133.89 (s, Ph), 135.70 (d, Ph), 140.43 (s, Ph).

HRMS (FAB): *m/z* [M + H]$^+$ calcd for $C_{27}H_{34}NOSi$: 416.2410; found: 416.2396.

Anal. Calcd for $C_{27}H_{33}NOSi$: C, 78.02; H, 8.00; N, 3.37. Found: C, 77.82; H, 8.18; N, 3.42.

(+)-(2*S*)-*N*-Benzyl-1-(trityloxy)but-3-en-2-amine [(+)-(*S*)-3c] and (2*E*)-*N*-Benzyl-4-(trityloxy)-*N*-[(2*E*)-4-(trityloxy)but-2-enyl]but-2-en-1-amine (4c′)

Following general procedure 2 using **1c** (Table 1, entries 7–9) and separation by flash column chromatography (silica gel, PE–EtOAc, 20:1); TLC: R_f = 0.42 (**1c**), 0.45 (**3c**), 0.30 (**4c′**) (PE–EtOAc, 2:1, $KMnO_4$). HPLC [Daicel Chiralpak AD-H, 250 × 4.6 mm, 5 μm, with guard cartridge 10 × 4 mm, 5 μm, *n*-hexane–*i*-PrOH, 98:2,

flow = 0.5 mL min^{-1}, r.t., 230 nm]: t_R = 10.7 [(+)-(*S*)-**3c**], 12.9 [(–)-(*R*)-**3c**], 9.2 min [**4c′**].

(+)-(2*S*)-*N*-Benzyl-1-(trityloxy)but-3-en-2-amine [(+)-(*S*)-3c]
Colorless oil.

$[\alpha]_D^{20}$ +15.4 (*c* 0.98, $CHCl_3$, 97% ee).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.95 (br s, 1 H, NH), 3.12–3.23 (m, 2 H, CH_2O), 3.25–3.32 (m, 1 H, CHN), 3.65 (d, *J* = 13.5 Hz, 1 H, NC*H*$_a$H$_b$Ph), 3.85 (d, *J* = 13.5 Hz, 1 H, NCH$_a$*H*$_b$Ph), 5.17 (dd, *J* = 10.2 Hz, *J* = 1.6 Hz, 1 H, CH=C*H*$_E$H$_Z$), 5.19 (ddd, *J* = 17.2 Hz, *J* = 1.6 Hz, *J* = 0.8 Hz, 1 H, CH=CH$_E$*H*$_Z$), 5.67 (ddd, *J* = 17.4 Hz, *J* = 10.0 Hz, *J* = 7.5 Hz, 1 H, C*H*=CH$_2$), 7.21–7.35 (m, 14 H, Ph), 7.41–7.45 (m, 6 H, Ph).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 51.14 (t, NCH_2Ph), 60.89 (d, CHN), 66.62 (t, CH_2O), 86.76 (s, CPh_3), 117.61 (t, CH=*C*H$_2$), 126.94, 127.12, 127.92, 128.22, 128.52, 128.84 (6 d, Ph), 138.24 (d, *C*H=CH$_2$), 140.82, 144.17 (2 s, Ph).

HRMS (FAB): *m*/*z* [M + H]$^+$ calcd for $C_{30}H_{30}NO$: 420.2328; found: 420.2321.

Anal. Calcd for $C_{30}H_{29}NO$: C, 85.88; H, 6.97; N, 3.34. Found: C, 85.70; H, 6.97; N, 3.33.

(2*E*)-*N*-Benzyl-4-(trityloxy)-*N*-[(2*E*)-4-(trityloxy)but-2-enyl]but-2-en-1-amine (4c′)
Colorless oil.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.15 (d, *J* = 5.9 Hz, 4 H, CH_2), 3.62–3.65 (m, 6 H, CH_2, CH_2Ph), 5.77 (dt, *J* = 15.6 Hz, *J* = 4.9 Hz, 2 H, CH=), 5.90 (dt, *J* = 15.5 Hz, *J* = 6.2 Hz, 2 H, CH=), 7.21–7.39 (m, 23 H, Ph), 7.47–7.50 (m, 12 H, Ph).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 55.31 (t, CH_2), 57.54 (t, CH_2Ph), 64.51 (t, CH_2), 86.82 (s, CPh_3), 126.81, 126.91, 127.77, 128.16, 128.61, 128.85, 129.02 (7 d, =CH, Ph), 130.14 (d, CH=), 139.32, 144.22 (2 s, Ph).

HRMS (FAB): *m*/*z* [M + H]$^+$ calcd for $C_{53}H_{50}NO_2$: 732.3841; found: 732.3815.

Anal. Calcd. for $C_{53}H_{49}NO_2$: C, 86.97; H, 6.75; N, 1.91. Found: C, 86.78; H, 6.99; N, 1.82.

(+)-(2*S*)-2-(Benzylamino)but-3-en-1-ol [(+)-(*S*)-3d] and (2*E*)-4-(Benzylamino)but-2-en-1-ol (4d)
Following general procedure 2 using **1d** or **2d** (Table 1, entries 13–16) with separation by flash column chromatography (silica gel, PE–EtOAc, 4:3 to 1:3); TLC: R_f = 0.47 (**2d**), 0.39 (**3d**), 0.10 (**4d**) (EtOAc, $KMnO_4$). HPLC [Daicel Chiralcel OD-H, 250 × 4.6 mm, 5 μm, with guard cartridge 10 × 4 mm, 5 μm, *n*-hexane–*i*-PrOH, 85:15, flow = 0.5 mL min^{-1}, r.t., 210 nm]: t_R = 11.0 [(–)-(*R*)-**3d**], 12.7 [(+)-(*S*)-**3d**], 15.8 min (**4d**).

(+)-(2*S*)-2-(Benzylamino)but-3-en-1-ol [(+)-(*S*)-3d]
Colorless solid; mp 57–58 °C.

$[\alpha]_D^{20}$ +18.1 (*c* 0.98, $CHCl_3$, 93% ee).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 2.00 (br s, 2 H, NH, OH), 3.23 (ddd, *J* = 7.6 Hz, *J* = 7.6 Hz, *J* = 4.5 Hz, 1 H, NCH), 3.39 (dd, *J* = 10.5 Hz, *J* = 7.9 Hz, 1 H, C*H*$_a$H$_b$O), 3.62 (dd, *J* = 10.5 Hz, *J* = 4.5 Hz, 1 H, CH$_a$*H*$_b$O), 3.68 (d, *J* = 12.9 Hz, 1 H, NC*H*$_a$H$_b$Ph), 3.89 (d, *J* = 13.0 Hz, 1 H, NCH$_a$*H*$_b$Ph), 5.21–5.27 (m, 2 H, CH=C*H*$_2$), 5.62–5.76 (m, 1 H, C*H*=CH$_2$), 7.22–7.34 (m, 5 H, Ph).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 51.06 (t, NCH_2Ph), 62.17 (d, NCH), 64.74 (t, CH_2O), 117.95 (t, CH=*C*H$_2$), 127.24, 128.36, 128.61 (3 d, Ph), 128.95 (s, Ph), 137.40 (d, *C*H=CH$_2$), 140.20 (s, Ph).

HRMS (FAB): *m*/*z* [M]$^+$ calcd for $C_{11}H_{15}NO$: 177.1154; found: 177.1141.

Anal. Calcd for $C_{11}H_{15}NO$: C, 74.54; H, 8.53; N, 7.90. Found: C, 74.21; H, 8.59; N, 7.69.

(2*E*)-4-(Benzylamino)but-2-en-1-ol (4d)
Colorless oil.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.88–1.95 (m, 2 H, NH, OH), 3.26–3.28 (m, 2 H, NC*H*$_2$CH), 3.79 (s, 2 H, NCH_2Ph), 4.11–4.12 (m, 2 H, CH_2O), 5.74–5.87 (m, 2 H, CH=CH), 7.22–7.35 (m, 5 H, Ph).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 50.55 (t, NCH_2), 53.46 (NCH_2Ph), 63.20 (t, CH_2O), 127.19, 128.35, 128.57, 129.97, 131.39 (5 d, Ph, CH=CH), 140.03 (s, Ph).

HRMS (FAB): *m*/*z* [M]$^+$ calcd for $C_{11}H_{15}NO$: 177.1154; found: 177.1104.

Anal. Calcd for $C_{11}H_{15}NO$: C, 74.54; H, 8.53; N, 7.90. Found: C, 74.80; H, 8.59; N, 7.87.

(–)-(2*S*)-*N*-(4-Methoxyphenyl)-1-(trityloxy)but-3-en-2-amine [(–)-(*S*)-5c] and (2*E*)-*N*-(4-Methoxyphenyl)-4-(trityloxy)but-2-en-1-amine (6c)
Following general procedure 2 using **1c** (Table 1, entries 10–12) with separation by flash column chromatography (silica gel, PE–EtOAc, 20:1); TLC: R_f = 0.42 (**1c**), 0.46 (**5c**), 0.34 (**6c**) (PE–EtOAc, 5:1, $KMnO_4$). HPLC [Daicel Chiralpak AD-H, 250 × 4.6 mm, 5 μm, with guard cartridge 10 × 4 mm, 5 μm, *n*-hexane–*i*-PrOH, 98:2, flow = 0.5 mL min^{-1}, r.t., 210 nm]: t_R = 18.2 [(+)-(*R*)-**5c**], 22.6 min [(–)-(*S*)-**5c**].

(–)-(2*S*)-*N*-(4-Methoxyphenyl)-1-(trityloxy)but-3-en-2-amine [(–)-(*S*)-5c]
Colorless oil.

$[\alpha]_D^{20}$ –15.8 (*c* 1.02, $CHCl_3$, 96% ee).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.24 (dd, *J* = 9.2 Hz, *J* = 6.2 Hz, 1 H, C*H*$_a$H$_b$O), 3.32 (dd, *J* = 9.2 Hz, *J* = 4.7 Hz, 1 H, CH$_a$*H*$_b$O), 3.75 (s, 3 H, CH_3), 3.88–3.94 (m, 1 H, NCH), 5.19 (ddd, *J* = 10.4 Hz, *J* = 1.3 Hz, *J* = 1.3 Hz, 1 H, CH=C*H*$_E$H$_Z$), 5.29 (ddd, *J* = 17.2 Hz, *J* = 1.4 Hz, *J* = 1.4 Hz, 1 H, CH=CH$_E$*H*$_Z$), 5.87 (ddd, *J* = 17.3 Hz, *J* = 10.4 Hz, *J* = 5.9 Hz, 1 H, C*H*=CH$_2$), 6.56–6.60 (m, 2 H, Ph), 6.74–6.78 (m, 2 H, Ph), 7.22–7.34 (m, 9 H, Ph), 7.43–7.47 (m, 6 H, Ph).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 55.93 (q, CH_3), 57.55 (d, NCH), 66.11 (t, CH_2O), 86.83 (s, CPh_3), 114.86, 115.39 (2 d, Ph), 116.63 (t, CH=*C*H$_2$), 127.21, 127.99, 128.81 (3 d, Ph), 138.09 (d, *C*H=CH$_2$), 141.83 (s, Ar), 144.00 (s, Ph), 152.40 (s, Ar).

HRMS (FAB): *m*/*z* [M]$^+$ calcd for $C_{30}H_{29}NO_2$: 435.2198; found: 435.2170.

Anal. Calcd. for $C_{30}H_{29}NO_2$: C, 82.73; H, 6.71; N, 3.22. Found: C, 82.96; H, 6.81; N, 3.05.

(2*E*)-*N*-(4-Methoxyphenyl)-4-(trityloxy)but-2-en-1-amine (6c)
Colorless oil.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.28 (br s, 1 H, NH), 3.66 (dd, *J* = 4.8 Hz, *J* = 1.3 Hz, 2 H, NCH_2), 3.75–3.77 (m, 2 H, CH_2O), 3.77 (s, 3 H, CH_3), 5.83 (dt, *J* = 15.6 Hz, *J* = 4.9 Hz, 1 H, =CH), 5.97 (dt, *J* = 15.5 Hz, *J* = 5.5 Hz, 1 H, =CH), 6.61–6.66 (m, 2 H, Ph), 6.78–6.84 (m, 2 H, Ph), 7.23–7.35 (m, 9 H, Ph), 7.47–7.50 (m, 6 H, Ph).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 46.89 (t, CH_2O), 55.91 (q, CH_3), 64.41 (t, NCH_2), 86.99 (s, CPh_3), 114.56, 114.97 (2 d, Ar), 127.10, 127.94, 128.04, 128.73, 129.09 (5 d, Ph, CH=CH), 142.37 (s, Ar), 144.27 (s, Ph), 152.38 (s, Ar).

HRMS (FAB): *m/z* [M]$^+$ calcd for $C_{30}H_{29}NO_2$: 435.2198; found: 435.2227.

Anal. Calcd for $C_{30}H_{29}NO_2$: C, 82.73; H, 6.71; N, 3.22. Found: C, 82.80; H, 6.82; N, 3.16.

(+)-(2*S*)-2-[(4-Methoxyphenyl)amino]but-3-en-1-ol [(+)-(*S*)-5d]

Following general procedure 2 using **1d** (Table 1, entries 17–19) with purification by flash column chromatography (silica gel, PE–EtOAc, 10:1) gave **5d** as a yellow oil; TLC: R_f = 0.42 (**1d**), 0.46 (**5d**) (EtOAc, $KMnO_4$). HPLC [Daicel Chiralcel OD-H, 250 × 4.6 mm, 5 μm, with guard cartridge 10 × 4 mm, 5 μm, *n*-hexane–*i*-PrOH, 85:15, flow = 0.5 mL min^{-1}, r.t., 210 nm]: t_R = 18.3 [(+)-(*S*)-**5d**], 20.1 min [(–)-(*R*)-**5d**].

$[\alpha]_D^{20}$ +20.1 (*c* 1.02, $CHCl_3$, 82.5% ee).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 2.72 (br s, 2 H, NH, OH), 3.59 (dd, *J* = 10.8 Hz, *J* = 6.8 Hz, 1 H, CH_aH$_b$O), 3.74 (s, 3 H, CH_3), 3.77 (dd, *J* = 11.1 Hz, *J* = 4.4 Hz, 1 H, CH$_a$$H_b$O), 3.91–3.98 (m, 1 H, NCH), 5.23 (ddd, *J* = 10.4 Hz, *J* = 1.3 Hz, *J* = 1.3 Hz, 1 H, CH=CH_EH$_Z$), 5.29 (ddd, *J* = 17.2 Hz, *J* = 1.4 Hz, *J* = 1.4 Hz, 1 H, CH=CH$_E$$H_Z$), 5.79 (ddd, *J* = 17.4 Hz, *J* = 10.4 Hz, *J* = 5.7 Hz, 1 H, C*H*=CH$_2$), 6.62–6.67 (m, 2 H, Ar), 6.73–6.80 (m, 2 H, Ar).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 55.87 (q, CH_3), 59.02 (d, NCH), 65.06 (t, CH_2O), 114.94 (d, Ar), 115.78 (d, Ar), 117.49 (t, CH=*C*H$_2$), 136.78 (d, *C*H=CH$_2$), 141.35 (s, Ar), 152.76 (s, Ar).

HRMS (FAB): *m/z* [M]$^+$ calcd for $C_{11}H_{15}NO_2$: 193.1103; found: 193.1118.

Anal. Calcd for $C_{11}H_{15}NO_2$: C, 68.37; H, 7.82; N, 7.25. Found: C, 68.28; H, 7.84; N, 7.20.

(2*E*)-4-[(4-Methoxyphenyl)amino]but-2-en-1-ol (6d)

A soln of (2*E*)-4-(*tert*-butyldiphenylsiloxy)-*N*-(4-methoxyphenyl)but-2-en-1-amine[25] (250 mg, 0.579 mmol) in anhyd MeOH (1 mL) was added dropwise to methanolic HCl prepared by dropping AcCl (0.4 mL, 5.8 mmol, 10 equiv) into anhyd MeOH (8 mL). After 3 d [TLC: R_f = 0.17 (**6d**) (PE–EtOAc, 3:1, $KMnO_4$)] the soln was diluted with Et_2O (20 mL) and washed with sat. aq $NaHCO_3$ soln (20 mL). The aqueous layer was separated and extracted with Et_2O (5 × 20 mL). The combined organic layers were dried (Na_2SO_4), filtered, and concentrated in vacuo. Purification by flash column chromatography (silica gel, PE–EtOAc, 4:1) yielded **6d** (81 mg, 72%) as a colorless solid; mp 72–73 °C; HPLC [Daicel Chiralcel OD-H, 250 × 4.6 mm, 5 μm, with guard cartridge 10 × 4 mm, 5 μm, *n*-hexane–*i*-PrOH, 85:15, flow = 0.5 mL min^{-1}, r.t., 210 nm] t_R = 37.0 min (**6d**).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 2.55 (br s, 2 H, NH, OH), 3.71–3.75 (m, 2 H, NCH_2), 3.74 (s, 3 H, CH_3), 4.12–4.14 (m, 2 H, CH_2O), 5.77–5.92 (m, 2 H, CH=CH), 6.57–6.64 (m, 2 H, Ar), 6.75–6.81 (m, 2 H, Ar).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 46.55 (t, NCH_2), 55.93 (q, CH_3), 63.18 (t, CH_2O), 114.57, 115.03 (2 d, Ar), 129.23 (d, NCH_2*C*H), 131.16 (d, *C*HCH$_2$O), 142.21, 152.45 (2 s, Ar).

HRMS (FAB): *m/z* [M]$^+$ calcd for $C_{11}H_{15}NO_2$: 193.1103; found: 193.1111.

Anal. Calcd for $C_{11}H_{15}NO_2$: C, 68.37; H, 7.82; N, 7.25. Found: C, 68.16; H, 7.76; N, 7.23.

***tert*-Butyl Formyl{(1*S*)-1-[(trityloxy)methyl]prop-2-enyl}carbamate [(+)-(*S*)-7] and *tert*-Butyl Formyl[(2*E*)-4-(trityloxy)but-2-enyl]carbamate (8)**

Following general procedure 2 using **1c** (Table 2, entries 1–4) with separation by flash column chromatography (silica gel, PE–Et_2O, 10:1 to 5:1); TLC: R_f = 0.44 (**1c**), 0.50 (**7**), 0.44 (**8**) (PE–EtOAc, 3:1, $KMnO_4$). HPLC [Daicel Chiralpak AD-H, 250 × 4.6 mm, 5 μm, with guard cartridge 10 × 4 mm, 5 μm, *n*-hexane–*i*-PrOH, 99.5:0.5, flow = 0.5 mL min^{-1}, r.t., 210 nm]: t_R = 22.1 [(–)-(*R*)-**7**], 27.1 min [(+)-(*S*)-**7**].

***tert*-Butyl Formyl{(1*S*)-1-[(trityloxy)methyl]prop-2-enyl}carbamate [(+)-(*S*)-7]**

Colorless oil.

$[\alpha]_D^{20}$ +39.0 (*c* 1.08, $CHCl_3$, 97% ee).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.42 [s, 9 H, C(CH$_3$)$_3$], 3.36 (dd, *J* = 8.9 Hz, *J* = 5.9 Hz, 1 H, CH_aH$_b$O), 3.48 (dd, *J* = 9.0 Hz, *J* = 9.0 Hz, 1 H, CH$_a$$H_b$), 5.14 (ddd, *J* = 10.4 Hz, *J* = 1.2 Hz, *J* = 1.2 Hz, 1 H, CH=CH_EH$_Z$), 5.17 (ddd, *J* = 17.4 Hz, *J* = 1.3 Hz, *J* = 1.3 Hz, 1 H, CH=CH$_E$$H_Z$), 5.34 (ddd, *J* = 7.3 Hz, *J* = 7.2 Hz, *J* = 7.0 Hz, 1 H, NCH), 5.91 (ddd, *J* = 17.3 Hz, *J* = 10.4 Hz, *J* = 6.7 Hz, 1 H, C*H*=CH$_2$), 7.20–7.33 (m, 9 H, Ph), 7.39–7.43 (m, 6 H, Ph), 9.29 (s, 1 H, CHO).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 28.07 [q, C(*C*H$_3$)$_3$], 54.17 (d, NCH), 63.21 (t, CH_2O), 84.15 [s, *C*(CH$_3$)$_3$], 86.65 (s, CPh_3), 118.24 (t, CH=*C*H$_2$), 127.14, 127.94, 128.75 (3 d, Ph), 133.84 (d, *C*H=CH$_2$), 143.94 (s, Ph), 152.55 (s, CO_2), 163.41 (d, CHO).

HRMS (FAB): *m/z* [M + Na]$^+$ calcd for $C_{29}H_{31}NNaO_4$: 480.2151; found: 480.2089.

Anal. Calcd for $C_{29}H_{31}NO_4$: C, 76.12; H, 6.83; N, 3.06. Found: C, 76.19; H, 6.92; N, 3.07.

The enantiomeric excess of carbamate **7** was determined after cleavage of the formyl protecting group. A soln of **7** (1.10 g, 2.40 mmol) in anhyd MeOH (20.0 mL) was treated with KOH (202 mg, 3.61 mmol) at r.t. for 7 h (complete conversion) [TLC: R_f = 0.19 (**7**), 0.15 (**7′**) (PE–Et_2O, 4:1)]. Acidic ion exchange resin (Amberlite IR-120, Merck) was added in portions until pH 7 was reached. The mixture was filtered, the filtrate concentrated in vacuo, and the residue subjected to flash column chromatography (silica gel, PE–Et_2O, 9:1) to give *tert*-butyl {(1*S*)-1-[(trityloxy)methyl]prop-2-enyl}carbamate (**7′**) (1.03 g, quantitative yield) as a colorless solid; mp 93–95 °C. HPLC [Daicel Chiralpak AD-H, 250 × 4.6 mm, 5 μm, with guard cartridge 10 × 4 mm, 5 μm, *n*-hexane–*i*-PrOH, 99:1, flow = 0.5 mL min^{-1}, r.t., 210 nm] t_R = 34.1 [(+)-(*R*)-**7′**], 47.0 min [(–)-(*S*)-**7′**].

***tert*-Butyl Formyl[(2*E*)-4-(trityloxy)but-2-enyl]carbamate (8)**

Colorless solid; mp 89–91 °C.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.56 [s, 9 H, C(CH$_3$)$_3$], 3.58–3.59 (m, 2 H, CH_2O), 4.21 (dd, *J* = 3.3 Hz, *J* = 1.2 Hz, 2 H, NCH_2), 5.70–5.84 (m, 2 H, CH=CH), 7.20–7.32 (m, 9 H, Ph), 7.41–7.45 (m, 6 H, Ph), 9.20 (s, 1 H, CHO).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 28.20 [q, C(*C*H$_3$)$_3$], 41.95 (t, CH_2N), 64.09 (t, CH_2O), 84.14 [s, *C*(CH$_3$)$_3$], 86.99 (s, CPh_3), 125.15 (d, CH=), 127.13 127.95, 128.73 (3 d, Ph) 130.78 (d, CH=), 144.22 (s, Ph), 152.57 (s, CO_2), 162.81 (d, CHO).

HRMS (FAB): *m/z* [M]$^+$ calcd for $C_{29}H_{31}NO_4$: 457.2253; found: 457.2228.

Anal. Calcd for $C_{29}H_{31}NO_4$: C, 76.12; H, 6.83; N, 3.06. Found: C, 76.11; H, 7.01; N, 3.18.

(+)-Di-*tert*-butyl {(1*S*)-1-[(Trityloxy)methyl]prop-2-enyl}imidodicarbonate [(+)-(*S*)-9] and Di-*tert*-butyl [(2*E*)-4-(Trityloxy)but-2-enyl]imidodicarbonate (10)

Following general procedure 2 using **1c** (Table 2, entries 5–10) with separation by flash column chromatography (silica gel, PE–Et_2O, 19:1 to 9:1); TLC: R_f = 0.24 (**1c**), 0.31 (**9**), 0.40 (**10**) (PE–EtOAc, 10:1, $KMnO_4$). HPLC [Daicel Chiralcel OD-H, 250 × 4.6 mm, 5 μm, with guard cartridge 10 × 4 mm, 5 μm, *n*-hexane–*i*-PrOH, 99.5:0.5, flow = 0.5 mL min^{-1}, r.t., 210 nm]: t_R = 8.4 [(+)-(*S*)-**9**], 17.8 min [(–)-(*R*)-**9**].

(+)-Di-*tert*-butyl {(1*S*)-1-[(Trityloxy)methyl]prop-2-enyl}imidodicarbonate [(+)-(*S*)-9]

Colorless rhombic plates; mp 143–146 °C.

$[\alpha]_D^{20}$ +25.7 (*c* 0.97, $CHCl_3$, 97% ee).

^{1}H NMR (500 MHz, $CDCl_3$): δ = 1.46 [s, 18 H, $C(CH_3)_3$], 3.22 (dd, *J* = 8.9 Hz, *J* = 5.6 Hz, 1 H, CH_aH_bO), 3.56 (dd, *J* = 8.9 Hz, *J* = 8.8 Hz, 1 H, CH_aH_bO), 5.09–5.16 (m, 1 H, NCH), 5.11 (d, *J* = 10.1 Hz, 1 H, $CH{=}CH_EH_Z$), 5.16 (d, *J* = 17.4 Hz, 1 H, $CH{=}CH_EH_Z$), 5.87 (ddd, *J* = 17.2 Hz, *J* = 10.7 Hz, *J* = 6.3 Hz, 1 H, $CH{=}CH_2$), 7.21–7.24 (m, 3 H, Ph), 7.27–7.30 (m, 6 H, Ph), 7.44–7.46 (m, 6 H, Ph).

^{13}C (125 MHz, $CDCl_3$): δ = 28.17 [q, $C(CH_3)_3$], 58.86 (d, NCH), 64.62 (t, CH_2O), 82.33 [s, $C(CH_3)_3$], 86.59 (s, CPh_3), 117.34 (t, $CH{=}CH_2$), 127.05, 127.84, 128.89 (3 d, Ph), 135.01 (d, $CH{=}CH_2$), 144.18 (s, Ph), 153.00 (CO_2).

HRMS (FAB): *m*/*z* [M + H]$^+$ calcd for $C_{33}H_{40}NO_5$: 530.2907; found: 530.2882.

Anal. Calcd for $C_{33}H_{39}NO_5$: C, 74.83; H, 7.42; N, 2.64. Found: C, 74.83; H, 7.41; N, 2.68.

Di-*tert*-butyl [(2*E*)-4-(Trityloxy)but-2-enyl]imidodicarbonate (10)

Colorless oil.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.53 [s, 18 H, $C(CH_3)_3$], 3.60 (d, *J* = 4.7 Hz, 2 H, CH_2O), 4.21 (d, *J* = 5.7 Hz, 2 H, CH_2N), 5.76 (dt, *J* = 15.7 Hz, *J* = 4.5 Hz, 1 H, $CHCH_2O$), 5.87 (dt, *J* = 15.5 Hz, *J* = 5.7 Hz, 1 H, $CHCH_2N$), 7.27–7.33 (m, 9 H, Ph), 7.42–7.44 (m, 6 H, Ph).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 28.23 [q, $C(CH_3)_3$], 47.83 (t, CH_2O), 64.24 (t, CH_2N), 82.40 [s, $C(CH_3)_3$], 86.93 (s, CPh_3), 126.86 (d, $CHCH_2N$), 127.10, 127.92, 128.73 (3 d, Ph), 129.68 (d, $CHCH_2O$), 144.28 (s, Ph), 152.39 (s, CO_2).

HRMS (FAB): *m*/*z* [M + H]$^+$ calcd for $C_{33}H_{40}NO_5$: 530.2907; found: 530.2953.

Anal. Calcd for $C_{33}H_{39}NO_5$: C, 74.83; H, 7.42; N, 2.64. Found: C, 74.54; H, 7.58; N, 2.44.

(+)-2-{(1*S*)-1-[(Trityloxy)methyl]prop-2-enyl}-1*H*-isoindole-1,3(2*H*)-dione [(+)-(*S*)-11] and 2-[(2*E*)-4-(Trityloxy)but-2-enyl]-1*H*-isoindole-1,3(2*H*)-dione (12)

Following general procedure 2 using **1c** (Table 2, entries 11–13) with separation by flash column chromatography (silica gel, PE–Et_2O, 9:1); TLC: R_f = 0.42 (**1c**), 0.37 (**11**), 0.32 (**12**) (PE–EtOAc, 4:1, $KMnO_4$). HPLC [Daicel Chiralpak AD-H, 250 × 4.6 mm, 5 µm, with guard cartridge 10 × 4 mm, 5 µm, *n*-hexane–*i*-PrOH, 98.5:1.5, flow = 0.5 mL min^{-1}, r.t., 210 nm]: t_R = 60.4 [(+)-(*S*)-**11**], 67.6 min [(–)-(*R*)-**11**].

(+)-2-{(1*S*)-1-[(Trityloxy)methyl]prop-2-enyl}-1*H*-isoindole-1,3(2*H*)-dione [(+)-(*S*)-11]

Colorless microcrystals; mp 98–99 °C.

$[\alpha]_D^{20}$ +30.5 (*c* 0.97, $CHCl_3$, 96% ee).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.49 (dd, *J* = 9.4 Hz, *J* = 5.4 Hz, 1 H, CH_aH_bO), 3.73 (dd, *J* = 9.3 Hz, *J* = 9.3 Hz, 1 H, CH_aH_bO), 5.04–5.12 (m, 1 H, NCH), 5.21 (ddd, *J* = 10.4 Hz, *J* = 1.1 Hz, *J* = 1.1 Hz, 1 H, $CH{=}CH_EH_Z$), 5.27 (ddd, *J* = 17.3 Hz, *J* = 1.2 Hz, *J* = 1.2 Hz, 1 H, $CH{=}CH_EH_Z$), 6.16 (ddd, *J* = 17.4 Hz, *J* = 10.3 Hz, *J* = 7.3 Hz, 1 H, $CH{=}CH_2$), 7.17–7.27 (m, 9 H, Ph), 7.34–7.39 (m, 6 H, Ph), 7.68–7.74 (m, 2 H, Ar), 7.82–7.88 (m, 2 H, Ar).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 54.15 (d, NCH), 63.16 (t, CH_2O), 86.76 (s, CPh_3), 119.07 (t, $CH{=}CH_2$), 123.29 (d, Ar), 127.10 (d, Ph), 127.88, 128.68 (2 d, Ph), 132.12 (s, Ar), 132.57 (d, $CH{=}CH_2$), 133.99 (d, Ar), 143.82 (s, Ph), 168.02 (s, C=O).

HRMS (FAB): *m*/*z* [M + Na]$^+$ calcd for $C_{31}H_{25}NNaO_3$: 482.1732; found: 482.1729.

Anal. Calcd for $C_{31}H_{25}NO_3$: C, 81.02; H, 5.48; N, 3.05. Found: C, 80.78; H, 5.44; N, 3.02.

2-[(2*E*)-4-(Trityloxy)but-2-enyl]-1*H*-isoindole-1,3(2*H*)-dione (12)

White solid; mp 117–118 °C.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 3.59 (d, *J* = 3.3 Hz, 2 H, CH_2O), 4.30 (d, *J* = 4.9 Hz, 2 H, CH_2N), 5.77 (dt, *J* = 15.4 Hz, *J* = 4.0 Hz, 1 H, $CHCH_2O$), 5.89 (dt, *J* = 15.6 Hz, *J* = 5.0 Hz, 1 H, $CHCH_2N$), 7.14–7.30 (m, 9 H, Ph), 7.37–7.43 (m, 6 H, Ph), 7.65–7.74 (m, 2 H, Ar), 7.80–7.89 (m, 2 H, Ar).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 39.36 (t, OCH_2), 63.98 (t, NCH_2), 87.01 (s, CPh_3), 123.40 (d, Ar), 124.27 (d, NCH_2CH), 127.08 (d, Ph), 127.93, 128.71 (2 d, Ar), 131.10 (d, OCH_2CH), 132.31 (s, Ar), 134.06 (d, Ar), 144.16 (s, Ph), 168.04 (s, C=O).

HRMS (FAB): *m*/*z* [M + Na]$^+$ calcd for $C_{31}H_{25}NNaO_3$: 482.1732; found: 482.1747.

Anal. Calcd for $C_{31}H_{25}NO_3$: C, 81.02; H, 5.48; N, 3.05. Found: C, 80.85; H, 5.49; N, 3.05.

(–)-2-Nitro-*N*-{(1*S*)-1-[(trityloxy)methyl]prop-2-enyl}benzenesulfonamide [(–)-(*S*)-13] and 2-Nitro-*N*-[(2*E*)-4-(trityloxy)but-2-enyl]benzenesulfonamide (14)

Following general procedure 2 using **1c** (Table 2, entries 14–16) with separation by flash column chromatography (silica gel, PE–EtOAc, 4:1); TLC: R_f = 0.49 (**1c**), 0.32 (**13**), 0.28 (**14**) (PE–EtOAc, 4:1, $KMnO_4$). HPLC [Daicel Chiralpak AD-H, 250 × 4.6 mm, 5 µm, with guard cartridge 10 × 4 mm, 5 µm, *n*-hexane–*i*-PrOH, 95:5, flow = 0.5 mL min^{-1}, r.t., 210 nm]: t_R = 43.3 [(+)-(*R*)-**13**], 49.1 min [(–)-(*S*)-**13**].

(–)-2-Nitro-*N*-{(1*S*)-1-[(trityloxy)methyl]prop-2-enyl}benzenesulfonamide [(–)-(*S*)-13]

White solid; mp 58–59 °C.

$[\alpha]_D^{20}$ –5.85 (*c* 1.08, $CHCl_3$, 95% ee).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.17 (dd, *J* = 9.4 Hz, *J* = 4.1 Hz, 1 H, CH_aH_bO), 3.25 (dd, *J* = 9.4 Hz, *J* = 5.1 Hz, 1 H, CH_aH_bO), 4.07 (dddd, *J* = 5.8 Hz, *J* = 5.8 Hz, *J* = 5.8 Hz, *J* = 5.7 Hz, 1 H, NCH), 5.09 (d, *J* = 10.4 Hz, 1 H, $CH{=}CH_EH_Z$), 5.19 (d, *J* = 17.1 Hz, 1 H, $CH{=}CH_EH_Z$), 5.80 (ddd, *J* = 17.1 Hz, *J* = 10.4 Hz, *J* = 6.6 Hz, 1 H, $CH{=}CH_2$), 5.97 (d, *J* = 7.5 Hz, 1 H, NH), 7.20–7.30 (m, 9 H, Ph), 7.33–7.42 (m, 6 H, Ph), 7.62–7.70 (m, 2 H, Ar), 7.80–7.85 (m, 1 H, Ar), 8.01–8.06 (m, 1 H, Ar).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 57.50 (d, NCH), 65.81 (t, CH_2O), 87.07 (s, CPh_3), 117.63 (t, $CH{=}CH_2$), 125.46 (d, Ar), 127.29, 127.97, 128.63 (3 d, Ph), 131.01, 132.80, 133.42 (3 d, Ar), 134.81 (s, Ar), 135.23 (d, $CH{=}CH_2$), 143.37 (s, Ph), 147.82 (s, Ar).

HRMS (FAB): *m*/*z* [(^{32}S)M]$^+$ calcd for $C_{29}H_{26}N_2O_5{}^{32}S$: 514.1562; found: 514.1553.

Anal. Calcd for $C_{29}H_{26}N_2O_5S$: C, 67.69; H, 5.09; N, 5.44; S, 6.23. Found: C, 67.59; H, 5.19; N, 5.18; S, 6.00.

2-Nitro-*N*-[(2*E*)-4-(trityloxy)but-2-enyl]benzenesulfonamide (14)

White solid; mp 50–53 °C.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 3.51–3.52 (m, 2 H, CH_2O), 3.77–3.82 (m, 2 H, CH_2N), 5.38 (t, *J* = 6.1 Hz, 1 H, NH), 5.61–5.81 (m, 2 H, CH=CH), 7.20–7.40 (m, 15 H, Ph), 7.59–7.72 (m, 2 H, Ar), 7.77–7.86 (m, 1 H, Ar), 8.09–8.18 (m, 1 H, Ar).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 45.73 (t, CH_2N), 63.65 (t, CH_2O), 87.00 (s, CPh_3), 124.86 (d, =CH), 125.47 (d, Ar), 127.23, 127.98,

128.66 (3 d, Ph), 131.26 (d, Ar), 131.47 (d, =CH), 132.90, 133.66 (2 d, Ar), 134.34 (s, Ar), 144.03 (s, Ph), 148.14 (s, Ar).

HRMS (FAB): *m/z* [(^{32}S)M]$^+$ calcd for $C_{29}H_{26}N_2O_5{}^{32}S$: 514.1562; found: 514.1565.

Anal. Calcd for $C_{29}H_{26}N_2O_5S$: C, 67.69; H, 5.09; N, 5.44; S, 6.23. Found: C, 67.74; H, 5.23; N, 5.16; S, 5.97.

tert-Butyl [(1*S*)-1-(Hydroxymethyl)prop-2-enyl]carbamate [(*S*)-15]

Following general procedure 2 using **1d** (Table 3, entries 1–3) with purification by flash column chromatography (silica gel, PE–EtOAc, 2:1 to 1:1 to 0:1). The ^{1}H NMR data as well as the optical rotation of this compound were in excellent agreement with reported data.[26] The ^{13}C NMR data have not been reported and, therefore, is given below.

^{13}C NMR (75 MHz, $CDCl_3$): δ = 28.50 [q, C(CH_3)$_3$], 54.87 (d, NCH), 65.40 (t, CH_2O), 80.01 [s, $C(CH_3)_3$], 116.75 (t, $=CH_2$), 135.57 (d, =CH), 156.13 (s, CO_2).

For determination of the enantiomeric purity of **15**, a sample was benzylated to give the known *tert*-butyl {(1*S*)-1-[(benzyloxy)methyl]prop-2-enyl}carbamate (**15′**).[27] HPLC [Daicel Chiralcel OJ-H, 250 × 4.6 mm, 5 μm, with guard cartridge 10 × 4 mm, 5 μm, *n*-hexane–*i*-PrOH, 99:1, flow = 0.5 mL min^{-1}, r.t., 210 nm]: t_R = 31.3 [(–)-(*R*)-**15′**], 36.1 min [(+)-(*S*)-**15′**].

Synthesis of Linear Allylic Amides from Allylic Bromides by Nucleophilic Substitution; General Procedure 3

K_2CO_3 (2.0 mmol) and HN(CHO)Boc, $NaNBoc_2$, or phthalimide (1.0 mmol) were added to a soln of (2*E*)-4-bromobut-2-en-1-ol (1.0 mmol) in anhyd DMF (10 mL) and the mixture was stirred at r.t. until complete conversion was reached. H_2O (10 mL) was added, and the mixture was extracted with EtOAc (2 × 20 mL). The combined organic layers were washed with H_2O, dried (anhyd Na_2SO_4), and concentrated in vacuo. Pure products were obtained by flash column chromatography (silica gel, PE–EtOAc, detection: UV and $KMnO_4$).

tert-Butyl Formyl[(2*E*)-4-hydroxybut-2-enyl]carbamate (16)

Following general procedure 3 using (2*E*)-4-bromobut-2-en-1-ol gave **16** as a colorless oil; TLC: R_f = 0.61 [(2*E*)-4-bromobut-2-en-1-ol], 0.32 (**16**) (PE–EtOAc, 1:1, $KMnO_4$).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.48 (t, *J* = 5.8 Hz, 1 H, OH), 1.54 [s, 9 H, C(CH_3)$_3$], 4.12 (dd, *J* = 4.9 Hz, *J* = 4.9 Hz, 2 H, CH_2O), 4.19 (dd, *J* = 5.8 Hz, *J* = 1.1 Hz, 2 H, CH_2N), 5.66 (dtt, *J* = 15.5 Hz, *J* = 5.7 Hz, *J* = 1.3 Hz, 1 H, C*H*CH_2N), 5.80 (dtt, *J* = 15.5 Hz, *J* = 5.1 Hz, *J* = 1.0 Hz, 1 H, C*H*CH_2O), 9.17 (s, 1 H, CHO).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 28.19 [q, C(CH_3)$_3$], 41.70 (t, CH_2N), 62.93 (t, CH_2O), 84.32 [s, $C(CH_3)_3$], 125.40 (d, *C*HCH_2N), 132.65 (d, *C*HCH_2O), 152.34 (s, CO_2), 162.81 (d, CHO).

HRMS (EI): *m/z* [M]$^+$ calcd for $C_{10}H_{17}NO_4$: 215.1158; found: 215.1147.

Anal. Calcd for $C_{10}H_{17}NO_4$: C, 55.80; H, 7.96; N, 6.51. Found: C, 55.85; H, 8.04; N, 6.45.

(–)-(2*S*)-2-[(*tert*-Butoxycarbonyl)amino]but-3-enyl *tert*-Butyl Carbonate [(–)-(*S*)-17]

Following general procedure 2 using **1d** with $NaNBoc_2$ (Table 3, entries 4–6) with purification by flash column chromatography (silica gel, PE–EtOAc, 9:1 to EtOAc) to give **17** as a colorless oil; TLC: R_f = 0.29 (**1d**), 0.63 (**17**), 0.28 (*tert*-butyl 2-oxo-4-vinyloxazolidinone-3-carboxylate) (PE–EtOAc, 1:1, $KMnO_4$). GC [Chrompack permethyl-β-cyclodextrin, 25 m × 0.25 mm, temperature 130 °C, injector temperature 200 °C]: t_R = 60.7 [(+)-(*R*)-**17**], 62.7 min [(–)-(*S*)-**17**].

$[\alpha]_D^{20}$ –31.1 (*c* 1.53, $CHCl_3$, 93% ee).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.44, 1.47 [2 s, 18 H, C(CH_3)$_3$], 4.09 (dd, *J* = 11.0 Hz, *J* = 4.6 Hz, 1 H, CH_aH_bO), 4.15 (dd, *J* = 11.3 Hz, *J* = 5.5 Hz, 1 H, CH_aH_bO), 4.42 (br s, 1 H, NCH), 4.83 (br s, 1 H, NH), 5.20 (ddd, *J* = 10.5 Hz, *J* = 1.2 Hz, *J* = 1.2 Hz, 1 H, CH=CH_EH_Z), 5.27 (ddd, *J* = 17.2 Hz, *J* = 1.6 Hz, *J* = 1.1 Hz, 1 H, CH=CH_EH_Z), 5.80 (ddd, *J* = 17.2 Hz, *J* = 10.5 Hz, *J* = 5.3 Hz, 1 H, C*H*=CH_2).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 27.86, 28.49 [2 q, C(CH_3)$_3$], 52.07 (d, NCH), 68.25 (t, CH_2O), 79.84, 82.61 [2 s, $C(CH_3)_3$], 116.80 (t, $=CH_2$), 134.94 (d, =CH), 153.58, 155.30 (2 s, CO_2).

HRMS (FAB): *m/z* [M + H]$^+$ calcd for $C_{14}H_{26}NO_5$: 288.1811; found: 288.1763.

Anal. Calcd for $C_{14}H_{25}NO_5$: C, 58.52; H, 8.77; N, 4.87. Found: C, 58.35; H, 8.68; N, 5.02.

Di-*tert*-Butyl [(2*E*)-4-Hydroxybut-2-enyl]imidodicarbonate (18)

Following general procedure 3 using (2*E*)-4-bromobut-2-en-1-ol gave **18** as a colorless oil; TLC: R_f = 0.61 [(2*E*)-4-bromobut-2-en-1-ol], 0.39 (**18**) (PE–EtOAc, 1:1, $KMnO_4$).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.49 [s, 18 H, C(CH_3)$_3$], 1.54 (t, *J* = 5.9 Hz, 1 H, OH), 4.13 (dd, *J* = 5.0 Hz, *J* = 5.0 Hz, 2 H, CH_2O), 4.17 (d, *J* = 4.7 Hz, 2 H, CH_2N), 5.72 (dt, *J* = 15.4 Hz, *J* = 4.6 Hz, 1 H, C*H*CH_2N), 5.79 (dt, *J* = 15.4 Hz, *J* = 4.4 Hz, 1 H, C*H*CH_2O).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 28.23 [q, C(CH_3)$_3$], 47.49 (t, CH_2N), 63.15 (t, CH_2O), 82.54 [s, $C(CH_3)_3$], 127.20 (d, *C*HCH_2N), 131.66 (d, *C*HCH_2O), 152.52 (s, CO_2).

HRMS (FAB): *m/z* [M + H]$^+$ calcd for $C_{14}H_{26}NO_5$: 288.1811; found: 288.1833.

Anal. Calcd for $C_{14}H_{25}NO_5$: C, 58.52; H, 8.77; N, 4.87. Found: C, 58.29; H, 8.75; N, 4.94.

(–)-2-[(1*S*)-1-(Hydroxymethyl)prop-2-enyl]-1*H*-isoindole-1,3(2*H*)-dione [(–)-(*S*)-19]

Following general procedure 2 using **1d** (Table 3, entries 7–9). The spectroscopic data was in full agreement with that reported.[13] HPLC [Daicel Chiralcel OJ-H, 250 × 4.6 mm, 5 μm, with guard cartridge 10 × 4 mm, 5 μm, *n*-hexane–*i*-PrOH, 90:10, flow = 0.5 mL min^{-1}, r.t., 210 nm]: t_R = 39.2 [(–)-(*S*)-**19**], 42.1 min [(+)-(*R*)-**19**].

2-[(2*E*)-4-Hydroxybut-2-enyl]-1*H*-isoindole-1,3(2*H*)-dione (20)

Following general procedure 3 using (2*E*)-4-bromobut-2-en-1-ol (Table 3, entries 7–9) except for purification after extractive workup. Prior to chromatography, the crude product was extracted with PE–CH_2Cl_2 (1:2, 3 ×) in order to remove phthalimide. The resulting soln was concentrated in vacuo and the residue subjected to flash column chromatography; TLC: R_f = 0.61 [(2*E*)-4-bromobut-2-en-1-ol], 0.40 (**20**) (PE–EtOAc, 1:1, $KMnO_4$). The spectroscopic data for this compound was in full agreement with that reported.[21,28]

(+)-(5*S*)-1-Benzyl-5-vinylpyrrolidin-2-one [(+)-(*S*)-21f′] and Methyl (4*E*)-6-(Benzylamino)hex-4-enoate (22f)

Following general procedure 2 using **1f** (Table 4, entry 10) and *ent*-**L2** as ligand; separation was by flash column chromatography (silica gel, PE–EtOAc, 1:1 to 1:2); TLC: R_f = 0.47 (**1f**), 0.14 (**21f′**), 0.02 (**22f**) (PE–EtOAc, 1:1, $KMnO_4$). HPLC [Daicel Chiralpak AD-H, 250 × 4.6 mm, 5 μm, with guard cartridge 10 × 4 mm, 5 μm, *n*-hexane–*i*-PrOH, 97:3, flow = 0.5 mL min^{-1}, r.t., 210 nm]: t_R = 42.3 [(+)-(*S*)-**21f′**], 44.2 min [(–)-(*R*)-**21f′**].

(+)-(5*S*)-1-Benzyl-5-vinylpyrrolidin-2-one [(+)-(*S*)-21f′]

Pale brown oil.

$[\alpha]_D^{20}$ +164 [*c* 0.85, MeOH, 93% ee (*S*)].

^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.69–1.81 (m, 1 H, NCHCH_aH$_b$), 2.10–2.23 (m, 1 H, NCHCH$_a$$H_b$), 2.32–2.55 (m, 2 H, CH_2CO), 3.83–3.90 (m, 1 H, NCH), 3.84 (d, *J* = 14.8 Hz, 1 H, PhCH_aH$_b$), 4.98 (d, *J* = 14.6 Hz, 1 H, PhCH$_a$$H_b$), 5.13 (dd, *J* = 17.2 Hz, *J* = 0.7 Hz, 1 H, CH=CH$_E$$H_Z$), 5.21 (dd, *J* = 10.1 Hz, *J* = 1.2 Hz, 1 H, CH=CH$_E$H$_Z$), 5.64 (ddd, *J* = 17.0 Hz, *J* = 10.0 Hz, *J* = 8.4 Hz, 1 H, C*H*=CH$_2$), 7.20–7.33 (m, 5 H, Ph).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 25.40 (t, NCH*C*H$_2$), 30.10 (t, *C*H$_2$CO), 44.27 (t, PhCH$_2$), 60.49 (d, NCH), 118.31 (t, CH=*C*H$_2$), 127.49, 128.44, 128.65 (3 d, Ph), 136.86 (s, Ph), 137.59 (d, *C*H=CH$_2$), 174.98 (s, CO).

HRMS (EI): *m*/*z* [M]$^+$ calcd for $C_{13}H_{15}NO$: 201.1154; found: 201.1167.

Methyl (4*E*)-6-(Benzylamino)hex-4-enoate (22f)
Pale brown oil.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.44 (br s, 1 H, NH), 2.35–2.42 (m, 4 H, CH_2CH_2), 3.20–3.22 (m, 2 H, NCH_2), 3.67 (s, 3 H, OCH_3), 3.76 (s, 2 H, $PhCH_2$), 5.59–5.61 (m, 2 H, CH=CH), 7.22–7.29 (m, 5 H, Ph).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 27.75 (t, C*H*$_2$CH$_2$CO$_2$), 33.91 (t, *C*H$_2$CO$_2$), 51.04 (t, N*C*H$_2$CH), 51.68 (q, CH_3), 53.40 (t, $PhCH_2$), 127.05, 128.31, 128.52, 129.73, 130.49 (5 d, Ph, CH=), 140.44 (s, Ph), 173.64 (s, CO_2).

HRMS (EI): *m*/*z* [M]$^+$ calcd for $C_{14}H_{19}NO_2$: 233.1416; found: 233.1411.

Anal. Calcd for $C_{14}H_{19}NO_2$: C, 72.07; H, 8.21; N, 6.00. Found: C, 71.78; H, 8.06; N, 5.94.

(+)-Methyl (4*S*)-4-[(4-Methoxyphenyl)amino]hex-5-enoate [(+)-(*S*)-23f] and Methyl (4*E*)-6-[(4-Methoxyphenyl)amino]hex-4-enoate (24f)
Following general procedure 2 using **1f** (Table 4, entries 11–13) with separation by flash column chromatography (silica gel, PE–EtOAc, 10:1); TLC: R_f = 0.34 (**1f**), 0.29 (**23f**), 0.19 (**24f**) (PE–Et_2O, 1:1, $KMnO_4$). HPLC [Daicel Chiralcel OD-H, 250 × 4.6 mm, 5 µm, with guard cartridge 10 × 4 mm, 5 µm, *n*-hexane–*i*-PrOH, 9:1, flow = 0.5 mL min^{-1}, r.t., 254 nm]: t_R = 22.8 [(–)-(*R*)-**23f**], 38.8 min [(+)-(*S*)-**23f**].

(+)-Methyl (4*S*-)4-[(4-Methoxyphenyl)amino]hex-5-enoate [(+)-(*S*)-23f]
Colorless oil.

$[\alpha]_D^{20}$ +9.6 [*c* 0.96, MeOH, 90% ee (*S*)].

^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.90 (dt, *J* = 7.1 Hz, *J* = 7.1 Hz, 2 H, C*H*$_2$CH$_2$CO$_2$), 2.46 (t, *J* = 7.3 Hz, 2 H, CH_2CO_2), 3.42 (br s, 1 H, NH), 3.67 (s, 3 H, CO_2CH_3), 3.73 (s, 3 H, OCH_3), 3.79 (ddd, *J* = 6.7 Hz, *J* = 6.7 Hz, *J* = 6.6 Hz, 1 H, NCH), 5.14 (ddd, *J* = 10.3 Hz, *J* = 1.2 Hz, *J* = 1.2 Hz, 1 H, CH=CH$_E$H$_Z$), 5.20 (ddd, *J* = 17.2 Hz, *J* = 1.3 Hz, *J* = 1.3 Hz, 1 H, CH=CH$_E$$H_Z$), 5.72 (ddd, *J* = 17.1 Hz, *J* = 10.4 Hz, *J* = 6.4 Hz, 1 H, C*H*=CH$_2$), 6.54–6.59 (m, 2 H, Ar), 6.73–6.78 (m, 2 H, Ar).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 30.51 (t, *C*H$_2$CO$_2$), 30.78 (t, C*H*$_2$CH$_2$CO$_2$), 51.74 (q, CO_2CH_3), 55.88 (q, OCH_3), 56.57 (d, NCH), 114.92, 114.98 (2 d, Ar), 115.93 (t, CH=*C*H$_2$), 139.68 (d, *C*H=CH$_2$), 141.57, 152.22 (2 s, Ar), 174.13 (s, CO_2).

HRMS (EI): *m*/*z* [M]$^+$ calcd for $C_{14}H_{19}NO_3$: 249.1365; found: 249.1378.

Anal. Calcd. for $C_{14}H_{19}NO_3$: C, 67.45; H, 7.68; N, 5.62. Found: C, 67.42; H, 7.68; N, 5.66.

Methyl (4*E*)-6-[(4-Methoxyphenyl)amino]hex-4-enoate (24f)
Colorless oil.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 2.36–2.43 (m, 4 H, CH_2CH_2), 3.43 (br s, 1 H, NH), 3.65–3.69 (m, 2 H, NCH_2), 3.67 (s, 3 H, CO_2CH_3), 3.75 (s, 3 H, OCH_3), 5.57–5.76 (m, 2 H, CH=CH), 6.55–6.61 (m, 2 H, Ar), 6.74–6.80 (m, 2 H, Ar).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 27.68, 33.81 (2 t, CH_2CH_2), 46.97 (t, NCH_2), 51.70 (q, CO_2CH_3), 55.92 (q, OCH_3), 114.47, 114.97 (2 d, Ar), 128.71, 130.75 (2 d, CH=CH), 142.46, 152.32 (2 s, Ar), 173.56 (s, CO_2).

HRMS (EI): *m*/*z* [M]$^+$ calcd for $C_{14}H_{19}NO_3$: 249.1365; found: 249.1375.

(–)-*tert*-Butyl Formyl{(1*S*)-1-[2-(trityloxy)ethyl]prop-2-enyl}carbamate [(–)-(*S*)-25e] and *tert*-Butyl Formyl[(2*E*)-5-(trityloxy)pent-2-enyl]carbamate (26e)
Following general procedure 2 using **1e** (Table 4, entry 2) and *ent*-**L2** as ligand; separation was by flash column chromatography (silica gel, PE–Et_2O 10:1); TLC: R_f = 0.40 (**1e**), 0.47 (**25e**), 0.44 (**26e**) (PE–EtOAc, 4:1, $KMnO_4$). HPLC [Daicel Chiralpak AD-H, 250 × 4.6 mm, 5 µm, with guard cartridge 10 × 4 mm, 5 µm, *n*-hexane–*i*-PrOH, 95:5, flow = 0.5 mL min^{-1}, r.t., 220 nm]: t_R = 11.6 [(–)-(*S*)-**25e**], 13.2 min [(+)-(*R*)-**25e**].

(–)-*tert*-Butyl Formyl{(1*S*)-1-[2-(trityloxy)ethyl]prop-2-enyl}carbamate [(–)-(*S*)-25e]
Colorless solid; mp 89–90 °C.

$[\alpha]_D^{20}$ –12.6 [*c* 1.20, $CHCl_3$, 92% ee (*S*)].

^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.47 [s, 9 H, C(CH_3)$_3$], 2.06–2.28 (m, 2 H, NCHCH_2), 2.98–3.11 (m, 2 H, CH_2O), 5.06 (dd, *J* = 10.1 Hz, *J* = 1.0 Hz, 1 H, CH=CH$_E$$H_Z$), 5.11 (dd, *J* = 17.0 Hz, *J* = 1.2 Hz, 1 H, CH=CH$_E$$H_Z$), 5.17 (ddd, *J* = 7.1 Hz, *J* = 7.1 Hz, *J* = 7.1 Hz, 1 H, CHN), 5.97 (ddd, *J* = 17.2 Hz, *J* = 10.2 Hz, *J* = 6.9 Hz, 1 H, C*H*=CH$_2$), 7.19–7.31 (m, 9 H, Ph), 7.41–7.44 (m, 6 H, Ph), 9.10 (s, 1 H, CHO).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 28.16 [q, C(*C*H$_3$)$_3$], 32.50 (t, NCH*C*H$_2$), 52.12 (d, NCH), 60.53 (t, CH_2O), 84.03 [s, *C*(CH$_3$)$_3$], 86.75 (s, CPh_3), 117.15 (t, CH=*C*H$_2$), 127.04, 127.85, 128.82 (3 d, Ph), 136.46 (d, *C*H=CH$_2$), 144.26 (s, Ph), 152.48 (s, CO_2), 163.30 (d, CHO).

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{30}H_{33}NNaO_4$: 494.2302; found: 494.2303.

Anal. Calcd for $C_{30}H_{33}NO_4$: C, 76.41; H, 7.05; N, 2.97. Found: C, 76.67; H, 7.14; N, 2.89.

***tert*-Butyl Formyl[(2*E*)-5-(trityloxy)pent-2-enyl]carbamate (26e)**
Colorless oil.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.43 [s, 9 H, C(CH_3)$_3$], 2.27 (dt, *J* = 6.7 Hz, *J* = 6.7 Hz, 2 H, C*H*$_2$CH$_2$O), 3.02 (t, *J* = 6.8 Hz, 2 H, CH_2O), 4.07 (d, *J* = 6.0 Hz, 2 H, NCH_2), 5.41 (dt, *J* = 15.4 Hz, *J* = 6.2 Hz, 1 H, C*H*CH$_2$N), 5.62 (dt, *J* = 15.1 Hz, *J* = 7.2 Hz, 1 H, C*H*=CHCH$_2$O), 7.16–7.26 (m, 9 H, Ph), 7.35–7.38 (m, 6 H, Ph), 9.11 (s, 1 H, CHO).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 28.16 [q, C(*C*H$_3$)$_3$], 33.15 (t, *C*H$_2$CH$_2$O), 42.20 (t, CH_2N), 63.19 (t, CH_2O), 83.98 [s, *C*(CH$_3$)$_3$], 86.58 (s, CPh_3), 125.85 (d, CH=), 127.01 127.87, 128.79 (3 d, Ph), 131.28 (d, CH=), 144.38 (s, Ph), 152.49 (s, CO_2), 162.79 (d, CHO).

HRMS (ESI): *m*/*z* [M + K]$^+$ calcd for $C_{30}H_{33}KNO_4$: 510.2041; found: 510.2048.

Anal. Calcd for $C_{30}H_{33}NO_4$: C, 76.41; H, 7.05; N, 2.97. Found: C, 76.63; H, 6.99; N, 2.86.

(+)-Di-*tert*-butyl {(1*R*)-[2-(Trityloxy)ethyl]prop-2-enyl}imidodicarbonate [(+)-(*R*)-27e] and Di-*tert*-butyl [(2*E*)-5-(Trityloxy)pent-2-enyl]imidodicarbonate (28e)

Following general procedure 2 using **1e** (Table 4, entries 4–6) with separation by flash column chromatography (silica gel, PE–Et_2O, 15:1); TLC: R_f = 0.38 (**1e**), 0.47 (**27e**), 0.44 (**28e**) (PE–EtOAc, 4:1, $KMnO_4$). HPLC [Daicel Chiralpak AD-H, 250 × 4.6 mm, 5 μm, with guard cartridge 10 × 4 mm, 5 μm, *n*-hexane–*i*-PrOH, 96:4, flow = 0.5 mL min^{-1}, r.t., 210 nm] t_R = 8.1 [(–)-(*S*)-**27e**], 8.8 min [(+)-(*R*)-**27e**].

(+)-Di-*tert*-butyl {(1*R*)-[2-(Trityloxy)ethyl]prop-2-enyl}imidodicarbonate [(+)-(*R*)-27e]

Colorless powder; mp 85–86 °C.

$[\alpha]_D^{20}$ +3.2 [*c* 1.42, $CHCl_3$, 98% ee (*R*)].

^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.47 [s, 18 H, $C(CH_3)_3$], 2.08 (dddd, *J* = 13.8 Hz, *J* = 6.8 Hz, *J* = 6.8 Hz *J* = 6.7 Hz, 1 H, NCH-CH_aH$_b$), 2.22 (dddd, *J* = 13.7 Hz, *J* = 7.1 Hz, *J* = 7.0 Hz *J* = 6.9 Hz, 1 H, NCHCH$_a$*H*$_b$), 3.04–3.18 (m, 2 H, CH_2O), 4.94 (ddd, *J* = 7.2 Hz, *J* = 7.2 Hz, *J* = 7.1 Hz, 1 H, NCH), 5.08 (ddd, *J* = 10.3 Hz, *J* = 1.2 Hz, *J* = 1.2 Hz, 1 H, CH=CH_EH$_Z$), 5.14 (ddd, *J* = 17.3 Hz, *J* = 1.4 Hz, *J* = 1.4 Hz, 1 H, CH=CH$_E$*H*$_Z$), 5.98 (ddd, *J* = 17.2 Hz, *J* = 10.4 Hz, *J* = 6.7 Hz, 1 H, C*H*=CH_2), 7.21–7.34 (m, 9 H, Ph), 7.44–7.48 (m, 6 H, Ph).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 28.16 [q, $C(CH_3)_3$], 33.35 (t, NCH*C*H$_2$), 56.50 (d, NCH), 60.67 (t, CH_2O), 82.21 [s, *C*$(CH_3)_3$], 86.67 (s, CPh_3), 116.46 (t, CH=*C*H$_2$), 126.97, 127.84, 128.83 (3 d, Ph), 137.52 (d, *C*H=CH_2), 144.43 (s, Ph), 152.97 (CO_2).

HRMS (ESI): *m*/*z* [M + K]$^+$ calcd for $C_{34}H_{41}KNO_5$: 582.2616; found: 582.2624.

Anal. Calcd for $C_{34}H_{41}NO_5$: C, 75.11; H, 7.60; N, 2.58. Found: C, 74.89; H, 7.54; N, 2.52.

Di-*tert*-butyl [(2*E*)-5-(Trityloxy)pent-2-enyl]imidodicarbonate (28e)

Colorless oil.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.45 [s, 18 H, $C(CH_3)_3$], 2.35 (dt, *J* = 6.8 Hz, *J* = 6.7 Hz, 2 H, C*H*$_2$CH$_2$O), 3.08 (t, *J* = 6.9 Hz, 2 H, CH_2O), 4.09 (d, *J* = 5.7 Hz, 2 H, CH_2N), 5.51 (dt, *J* = 15.6 Hz, *J* = 5.7 Hz, 1 H, C*H*CH$_2$N), 5.63 (dt, *J* = 15.4 Hz, *J* = 6.5 Hz, 1 H, C*H*CH$_2$CH$_2$O), 7.19–7.31 (m, 9 H, Ph), 7.40–7.44 (m, 6 H, Ph).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 28.21 [q, $C(CH_3)_3$], 33.19 (t, *C*H$_2$CH$_2$O), 48.04 (t, CH_2O), 63.47 (t, CH_2N), 82.25 [s, *C*$(CH_3)_3$], 86.60 (s, CPh_3), 126.99 (d, Ph), 127.34 (d, CH=), 127.86, 128.79 (2 d, Ph), 130.15 (d, CH=), 144.41 (s, Ph), 152.47 (s, CO_2).

HRMS (ESI): *m*/*z* [M + K]$^+$ calcd for $C_{34}H_{41}KNO_5$: 582.2616; found: 582.2618.

Anal. Calcd for $C_{34}H_{41}NO_5$: C, 75.11; H, 7.60; N, 2.58. Found: C, 74.94; H, 7.39; N, 2.35.

(–)-Methyl (4*S*)-4-[Bis(*tert*-butoxycarbonyl)amino]hex-5-enoate [(–)-(*S*)-27f] and Methyl (4*E*)-6-[Bis(*tert*-butoxycarbonyl)amino]hex-4-enoate (28f)

Following general procedure 2 using **1f** (Table 4, entry 17) and *ent*-**L2** as ligand; separation was by flash column chromatography (silica gel, PE–EtOAc, 15:1); TLC: R_f = 0.16 (**1f**), 0.29 (**27f**), 0.21 (**28f**) (PE–EtOAc, 4:1, $KMnO_4$).

(–)-Methyl (4*S*)-4-[Bis(*tert*-butoxycarbonyl)amino]hex-5-enoate [(–)-(*S*)-27f]

Colorless oil.

$[\alpha]_D^{20}$ –5.70 [*c* 1.28, MeOH, 98% ee (*S*)].

^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.48 [s, 18 H, $C(CH_3)_3$], 2.01–2.26 (m, 2 H, CH_2CH$_2$CO$_2$), 2.33 (t, *J* = 7.8 Hz, 2 H, CH_2CO_2), 3.66 (s, 3 H, OCH_3), 4.63–4.70 (m, 1 H, NCH), 5.13 (ddd, *J* = 10.7 Hz. *J* = 1.3 Hz, *J* = 1.3 Hz, 1 H, CH=CH_EH$_Z$), 5.18 (ddd, 17.5 Hz, *J* = 1.4 Hz, *J* = 1.4 Hz, 1 H, CH=CH$_E$*H*$_Z$), 5.97 (ddd, *J* = 17.2 Hz, *J* = 10.5 Hz, *J* = 6.7 Hz, 1 H, C*H*=CH_2).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 27.81 (t, CH_2CH$_2$CO$_2$), 28.15 [q, $C(CH_3)_3$], 31.08 (t, *C*H$_2$CO$_2$), 51.73 (q, OCH_3), 58.47 (d, NCH), 82.52 [s, *C*$(CH_3)_3$], 117.03 (t, CH=*C*H$_2$), 137.16 (d, *C*H=CH_2), 153.02 (s, NCO_2), 173.53 (s, *C*O$_2$CH$_3$).

HRMS (FAB): *m*/*z* [M + Na]$^+$ calcd for $C_{17}H_{29}NNaO_6$: 366.1893; found: 366.1869.

Anal. Calcd for $C_{17}H_{29}NO_6$: C, 59.46; H, 8.51; N, 4.08. Found: C, 59.49; H, 8.47; N, 4.24.

The enantiomeric excess of this compound was determined after the removal of one Boc group as follows. A soln of carbamate **27f** (46.2 mg, 0.13 mmol) in CH_2Cl_2 (1 mL) was treated with TFA (18 mg, 0.16 mmol) at 0 °C. The resulting soln was stirred at r.t. for 6 h until complete conversion (TLC). The solvent was evaporated in vacuo, and the crude product was subjected to flash chromatography (silica gel, PE–EtOAc, 4:1) to yield methyl (4*S*)-4-[(*tert*-butoxycarbonyl)amino]hex-5-enoate (**27f′**) (30.7 mg, 97%) as a colorless powder; mp 53–54 °C. HPLC [Daicel Chiralpak AD-H, 250 × 4.6 mm, 5 μm, with guard cartridge 10 × 4 mm, 5 μm, *n*-hexane–*i*-PrOH, 95:5, flow = 0.5 mL min^{-1}, r.t., 210 nm]: t_R = 21.6 [(–)-(*S*)-**27f′**], 23.1 min [(+)-(*R*)-**27f′**].

Methyl (4*E*)-6-[Bis(*tert*-butoxycarbonyl)amino]hex-4-enoate (28f)

Colorless oil.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.48 [s, 18 H, $C(CH_3)_3$], 2.30–2.40 (m, 4 H, CH_2CH_2), 3.65 (s, 3 H, OCH_3), 4.08 (d, *J* = 5.3 Hz, 2 H, NCH_2), 5.44–5.65 (m, 2 H, CH=CH).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 27.59 (t, *C*H$_2$CH$_2$CO$_2$), 28.19 [q, $C(CH_3)_3$], 33.77 (t, *C*H$_2$CO$_2$), 47.88 (t, NCH_2), 51.67 (q, OCH_3), 82.33 [s, *C*$(CH_3)_3$], 126.69 (d, NCH$_2$*C*H), 131.36 (d, CH$_2$CH$_2$*C*H), 152.44 (s, NCO_2), 173.47 (s, *C*O$_2$CH$_3$).

HRMS (FAB): *m*/*z* [M + H]$^+$ calcd for $C_{17}H_{30}NO_6$: 344.2073; found: 344.2072.

Anal. Calcd for $C_{17}H_{29}NO_6$: C, 59.46; H, 8.51; N, 4.08. Found: C, 59.55; H, 8.56; N, 4.07.

(+)-Di-*tert*-butyl [(1*S*,2*E*)-4-(Trityloxy)-1-vinylbut-2-enyl]imidodicarbonate [(+)-(*S*)-27g] and Di-*tert*-butyl [(2*E*,4*E*)-6-(Trityloxy)hexa-2,4-dienyl]imidodicarbonate (28g)

Following general procedure 2 using **1g** (Table 4, entries 19, 20) with separation by flash column chromatography (silica gel, *n*-pentane–*i*-PrOH, 20:1); TLC: R_f = 0.35 (**1g**), 0.44 (**27g**), 0.39 (**28g**) (PE–EtOAc, 5:1, $KMnO_4$). HPLC [Daicel Chiralcel OD-H, 250 × 4.6 mm, 5 μm, with guard cartridge 10 × 4 mm, 5 μm, *n*-hexane–*i*-PrOH, 99.1:0.1, flow = 0.5 mL min^{-1}, r.t., 220 nm]: t_R = 29.8 [(–)-(*R*)-**27g**], 32.0 min [(+)-(*S*)-**27g**].

(+)-Di-*tert*-butyl [(1*S*,2*E*)-4-(Trityloxy)-1-vinylbut-2-enyl]imidodicarbonate [(+)-(*S*)-27g]

Colorless oil.

$[\alpha]_D^{20}$ +1.27 [*c* 0.99, $CHCl_3$, >99% ee (*S*)].

^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.51 (s, 18 H, CH_3), 3.63 (d, *J* = 4.7 Hz, 2 H, CH_2OCPh$_3$), 5.19 (dt, *J* = 10.3 Hz, *J* = 1.4 Hz, 1 H, CH=CH_EH$_Z$), 5.22 (dt, *J* = 17.3 Hz, *J* = 1.4 Hz, 1 H, CH=CH$_E$*H*$_Z$), 5.29–5.33 (m, 1 H, CHN), 5.75 (ddt, *J* = 15.7 Hz, *J* = 4.8 Hz, *J* = 1.2 Hz, 1 H, C*H*CH$_2$O), 6.02–6.14 (m, 2 H, C*H*=CH_2, C*H*CHCH$_2$), 7.20–7.33 (m, 9 H, Ph), 7.44–7.48 (m, 6 H, Ph).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 28.21 (q, CH_3), 60.23 (d, *C*HN), 64.18 (t, CH_2O), 82.56 (s, *C*CH_3), 86.96 (s, CPh_3), 116.71 (t, =CH_2), 127.10, 127.92, 128.75 (3 d, Ph), 129.26 (d, *C*HCHCH$_2$), 130.14 (d, *C*HCH$_2$), 137.28 (d, *C*H=CH$_2$), 144.29 (s, Ph), 152.54 (s, CO_2).

HRMS (FAB): *m*/*z* [M + Na]$^+$ calcd for $C_{35}H_{41}NNaO_5$: 578.2882; found: 578.2907.

Anal. Calcd for $C_{35}H_{41}NO_5$: C, 75.65; H, 7.44; N, 2.52. Found: C, 75.65; H, 7.49; N, 2.51.

Di-*tert*-butyl [(2*E*,4*E*)-6-(Trityloxy)hexa-2,4-dienyl]imidodicarbonate (28g)

Colorless plates.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.51 (s, 18 H, CH_3), 3.65 (d, *J* = 5.0 Hz, 2 H, C*H*$_2$OCPh$_3$), 4.21 (d, *J* = 6.2 Hz, 2 H, CH_2N), 5.66–5.79 (m, 2 H, C*H*CH$_2$), 6.15–6.39 (m, 2 H, C*H*CHCH$_2$), 7.20–7.33 (m, 9 H, Ph), 7.43–7.47 (m, 6 H, Ph).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 28.25 (q, CH_3), 47.95 (t, CH_2N), 64.49 (t, *C*H$_2$OCPh$_3$), 82.47 [s, *C*(CH$_3$)$_3$], 87.00 (s, CPh_3), 127.11, 127.95 (2 d, Ph), 128.40 (d, *C*HCH$_2$N), 128.77 (d, Ph), 130.27 (d, *C*HCH$_2$O), 130.42 (d, *C*HCHCH$_2$O), 132.33 (d, *C*HCHCH$_2$N), 144.28 (s, Ph), 152.52 (s, NCO_2).

HRMS (FAB): *m*/*z* [M + Na]$^+$ calcd for $C_{35}H_{41}NNaO_5$: 578.2882; found: 578.2928.

Anal. Calcd for $C_{35}H_{41}NO_5$: C, 75.65; H, 7.44; N, 2.52. Found: C, 75.58; H, 7.51; N, 2.50.

(+)-2-{(1*S*)-1-[2-(Trityloxy)ethyl]prop-2-enyl}-1*H*-isoindole-1,3(2*H*)-dione [(+)-(*S*)-29e] and 2-[(2*E*)-5-(Trityloxy)pent-2-enyl]-1*H*-isoindole-1,3(2*H*)-dione (30e)

Following general procedure 2 using **1e** (Table 4, entry 8) and *ent*-**L2** as ligand; separation was by flash column chromatography (silica gel, PE–Et_2O, 10:1); TLC: R_f = 0.36 (**1e**), 0.31 (**29e**), 0.26 (**30e**) (PE–EtOAc, 4:1, $KMnO_4$). HPLC [Daicel Chiralpak AD-H, 250 × 4.6 mm, 5 μm, with guard cartridge 10 × 4 mm, 5 μm, *n*-hexane–*i*-PrOH, 95:5, flow = 0.5 mL min^{-1}, r.t., 220 nm]: t_R = 19.9 [(+)-(*S*)-**29e**], 28.5 min [(–)-(*R*)-**29e**].

(+)-2-{(1*S*)-1-[2-(Trityloxy)ethyl]prop-2-enyl}-1*H*-isoindole-1,3(2*H*)-dione [(+)-(*S*)-29e]

Colorless foam; mp 42–43 °C.

$[\alpha]_D^{20}$ +36.3 [*c* 1.40, $CHCl_3$, 93% ee (*S*)].

^{1}H NMR (300 MHz, $CDCl_3$): δ = 2.19–2.30 (m, 1 H, NCHCH_aH_b), 2.47–2.58 (m, 1 H, NCHCH$_a$$H_b$), 3.06–3.19 (m, 2 H, CH_2O), 5.12 (ddd, *J* = 7.8 Hz, *J* = 7.6 Hz, *J* = 7.1 Hz, 1 H, NCH), 5.16 (dd, *J* = 10.2 Hz, *J* = 0.9 Hz, 1 H, CH=CH_EH_Z), 5.23 (dd, *J* = 17.1 Hz, *J* = 1.1 Hz, 1 H, CH=CH$_E$$H_Z$), 6.16 (dddd, *J* = 17.2 Hz, *J* = 10.2 Hz, *J* = 7.2 Hz, *J* = 0.9 Hz, 1 H, C*H*=CH$_2$), 7.15–7.30 (m, 9 H, Ph), 7.39–7.42 (m, 6 H, Ph), 7.70–7.75 (m, 2 H, Ar), 7.79–7.83 (m, 2 H, Ar).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 32.15 (t, NCH*C*H$_2$), 51.44 (d, NCH), 60.32 (t, CH_2O), 86.68 (s, CPh_3), 117.29 (t, CH=*C*H$_2$), 123.21 (d, Ar), 126.89, 127.77, 128.71 (3 d, Ph), 132.11 (s, Ar), 133.85 (d, *C*H=CH$_2$), 135.68 (d, Ar), 144.06 (s, Ph), 168.10 (s, C=O).

HRMS (ESI): *m*/*z* [M + K]$^+$ calcd for $C_{32}H_{27}KNO_3$: 512.1623; found: 512.1623.

Anal. Calcd for $C_{32}H_{27}NO_3$: C, 81.16; H, 5.75; N, 2.96. Found: C, 81.09; H, 5.91; N, 2.82.

2-[(2*E*)-5-(Trityloxy)pent-2-enyl]-1*H*-isoindole-1,3(2*H*)-dione (30e)

Colorless solid; mp 108–109 °C.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 2.32 (dt, *J* = 6.5 Hz, *J* = 6.5 Hz, 2 H, C*H*$_2$CH$_2$O), 3.07 (t, *J* = 6.7 Hz, 2 H, CH_2O), 4.24 (dd, *J* = 6.0 Hz, *J* = 0.8 Hz, 2 H, CH_2N), 5.58 (dt, *J* = 15.3 Hz, *J* = 6.1 Hz, 1 H, C*H*CH$_2$N), 5.77 (dt, *J* = 15.1 Hz, *J* = 6.9 Hz, 1 H, C*H*CH$_2$CH$_2$O), 7.17–7.30 (m, 9 H, Ph), 7.36–7.41 (m, 6 H, Ph), 7.67–7.72 (m, 2 H, Ar), 7.81–7.84 (m, 2 H, Ar).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 33.10 (t, *C*H$_2$CH$_2$O), 39.60 (t, OCH$_2$), 62.96 (t, NCH$_2$), 86.53 (s, CPh_3), 123.37 (d, Ar), 125.27 (d, NCH$_2$*C*H), 126.97, 127.85, 128.79 (3 d, Ph), 131.70 (d, CH$_2$CH$_2$*C*H), 132.34 (s, Ar), 134.00 (d, Ar), 144.37 (s, Ph), 168.08 (s, C=O).

HRMS (ESI): *m*/*z* [M + K]$^+$ calcd for $C_{32}H_{27}KNO_3$: 512.1622; found: 512.1627.

Anal. Calcd for $C_{32}H_{27}NO_3$: C, 81.16; H, 5.75; N, 2.96. Found: C, 81.19; H, 5.92; N, 2.82.

(+)-2-[(1*R*,2*E*)-4-(Trityloxy)-1-vinylbut-2-enyl]-1*H*-isoindole-1,3(2*H*)-dione [(+)-(*R*)-29g] and 2-[(2*E*,4*E*)-6-(Trityloxy)hexa-2,4-dienyl]-1*H*-isoindole-1,3(2*H*)-dione (30g)

Following general procedure 2 using **1g** (Table 4, entries 21, 22) and *ent*-**L1** and *ent*-**L2** as ligands; separation was by flash column chromatography (silica gel, PE–EtOAc, 9:1); TLC: R_f = 0.35 (**1g**), 0.27 (**29g**), 0.21 (**30g**) (PE–EtOAc, 5:1, $KMnO_4$). HPLC [Daicel Chiralcel OD-H, 250 × 4.6 mm, 5 μm, with guard cartridge 10 × 4 mm, 5 μm, *n*-hexane–*i*-PrOH, 98:2, flow = 0.5 mL min^{-1}, r.t., 220 nm]: t_R = 21.2 [(+)-(*R*)-**29g**], 23.5 min [(–)-(*S*)-**29g**].

(+)-2-[(1*R*,2*E*)-4-(Trityloxy)-1-vinylbut-2-enyl]-1*H*-isoindole-1,3(2*H*)-dione [(+)-(*R*)-29g]

Colorless solid; mp 47–49 °C.

$[\alpha]_D^{20}$ +0.73 [*c* 1.01, $CHCl_3$, >99% ee (*R*)].

^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.64 (d, *J* = 5.1 Hz, 2 H, OCH_2), 5.23–5.33 (m, 2 H, =C*H*$_2$), 5.34–5.39 (m, 1 H, C*H*N), 5.85 (ddt, *J* = 15.5 Hz, *J* = 5.1 Hz, *J* = 1.0 Hz, 1 H, C*H*CH$_2$O), 6.15–6.28 (m, 2 H, C*H*CHCH$_2$, C*H*=CH$_2$), 7.18–7.30 (m, 9 H, Ph), 7.41–7.45 (m, 6 H, Ph), 7.68–7.74 (m, 2 H, Ar), 7.81–7.87 (m, 2 H, Ar).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 55.03 (d, NCH), 64.28 (t, *C*H$_2$OCPh$_3$), 87.10 (s, CPh_3), 117.91 (t, =CH_2), 123.40 (d, Ar), 127.11 (d, Ph), 127.37 (d, *C*HCHCH$_2$), 127.95, 128.75 (2 d, Ph), 131.23 (d, *C*HCH$_2$), 132.17 (s, Ar), 134.10 (d, Ar), 134.93 (d, *C*H=CH$_2$), 144.17 (s, Ph), 167.69 (s, C=O).

HRMS (FAB): *m*/*z* [M + Na]$^+$ calcd for $C_{33}H_{27}NO_3Na$: 508.1888; found: 508.1921.

Anal. Calcd for $C_{33}H_{27}NO_3$: C, 81.63; H, 5.60; N, 2.88. Found: C, 81.36; H, 5.60; N, 2.94.

2-[(2*E*,4*E*)-6-(Trityloxy)hexa-2,4-dienyl]-1*H*-isoindole-1,3(2*H*)-dione (30g)

Colorless, rectangular plates; mp 179–181 °C.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.59 (d, *J* = 5.1 Hz, 2 H, C*H*$_2$OCPh$_3$), 4.31 (d, *J* = 6.2 Hz, 2 H, CH_2N), 5.68–5.82 (m, 2 H, C*H*CH$_2$), 6.23–6.37 (m, 2 H, C*H*CHCH$_2$), 7.16–7.29 (m, 9 H, Ph), 7.38–7.42 (m, 6 H, Ph), 7.66–7.72 (m, 2 H, Ar), 7.80–7.86 (m, 2 H, Ar).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 39.43 (t, CH_2N), 64.29 (t, *C*H$_2$OCPh$_3$), 86.95 (s, CPh_3), 123.44 (d, Ar), 125.90 (d, *C*HCH$_2$N), 127.10, 127.95, 128.73 (3 d, Ph), 129.61 (d, *C*HCHCH$_2$O), 131.55 (d, *C*HCH$_2$O), 132.33 (s, Ar), 133.61 (d, *C*HCHCH$_2$N), 134.09 (d, Ar), 144.23 (s, Ph), 168.07 (s, C=O).

HRMS (FAB): *m*/*z* [M + Na]$^+$ calcd for $C_{33}H_{27}NO_3Na$: 508.1888; found: 508.1932.

Anal. Calcd for $C_{33}H_{27}NO_3$: C, 81.63; H, 5.60; N, 2.88. Found: C, 81.38; H, 5.64; N, 2.94.

Dimethyl [(2*E*)-4-Hydroxybut-2-enyl]malonate (31)

2-Vinyloxirane (1.77 g, 25.4 mmol) was added dropwise to a soln of dimethyl malonate (2.23 g, 16.9 mmol), $Pd(PPh_3)_4$ (97 mg, 84 μmol), and dppe (33 mg, 84 μmol) in anhyd THF (30 mL) under an argon atmosphere at –78 °C. The mixture was stirred for 3 h until complete consumption of the substrate [TLC: R_f = 0.42 (dimethyl malonate), 0.15 (**31**) (PE–Et_2O, 1:1, $KMnO_4$)]. The mixture was allowed to warm to r.t. and the solvent was removed in vacuo. The residual oil (*E*/*Z* ratio of 15:1, determined by ^1H NMR) was purified by flash chromatography (silica gel, 150 g, PE–EtOAc, 1:1) to yield pure **31** (2.67 g, 78%) as a colorless oil. The spectroscopic data for **31** was in full agreement with that reported.[15]

Methyl (4*E*)-6-Hydroxyhex-4-enoate (32)

A flame-dried Schlenk tube under argon was charged with NaCl (1.75 g, 30.0 mmol), **31** (3.03 g, 15.0 mmol), H_2O (1.62 g, 90.0 mmol), a small amount (<0.1 mg) of 2,6-di-*tert*-butyl-4-methylphenol as radical inhibitor, and DMSO (10 mL). The mixture was stirred at 150 °C for 15 h until complete conversion of the starting material [TLC and GC/MS monitoring: R_f = 0.20 (**32**), 0.15 (**31**) (PE–Et_2O, 1:2, $KMnO_4$)]. Then H_2O (75 mL) was added and the aqueous phase was extracted with Et_2O (4 × 150 mL). The combined organic phases were washed with H_2O (1 × 60 mL) and brine (1 × 60 mL), dried (Na_2SO_4), filtered, and concentrated in vacuo. The residue was subjected by flash chromatography [silica gel, 120 g, PE–Et_2O, 1:2, R_f = 0.2 (**32**) ($KMnO_4$)] to give **32** (1.82 g, 84%) as a colorless oil.

^1H NMR (300 MHz, $CDCl_3$): δ = 1.88 (br s, 1 H, OH), 2.32–2.42 (m, 4 H, CH_2CH_2), 3.65 (s, 3 H, OCH_3), 4.05 (br s, 2 H, CH_2OH), 5.59–5.72 (m, 2 H, CH=CH).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 27.48 (t, *C*H_2CH_2CH), 33.64 (t, *C*H_2CO_2), 51.68 (q, CH_3), 63.43 (t, CH_2OH), 130.39, 130.49 (2 d, CH=), 173.59 (s, CO_2).

HRMS (EI): *m*/*z* $[M]^+$ calcd for $C_7H_{12}O_3$: 144.0786; found: 144.0816.

Anal. Calcd for $C_7H_{12}O_3$: C, 58.32; H, 8.39. Found: C, 58.05; H, 8.44.

(4*S*)-4-Ammoniohex-5-enoate [(*S*)-Vigabatrin]

A mixture of (–)-(*S*)-**27f** (300 mg, 0.87 mmol), glacial AcOH (2.6 mL) and concd aq HCl (37%, 3.2 mL) was stirred at 60 °C for 12 h. The solvent was removed in vacuo, and the residue was dissolved in H_2O (1 mL). This soln was passed through a column of Dowex 50WX8 ion exchange resin (4 g, 200–400 mesh, H^+ form). The column was eluted with H_2O until the eluant was neutral. Further elution with 0.2 M aq NH_4OH, and removal of the latter in vacuo, afforded (*S*)-vigabatrin (106 mg, 94%) as a colorless solid; mp 169–171 °C. The spectroscopic data for this compound was in full agreement with that reported.[14]

$[\alpha]_D^{20}$ +12.0 [*c* 2.32, H_2O, 98% ee (*S*)].

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