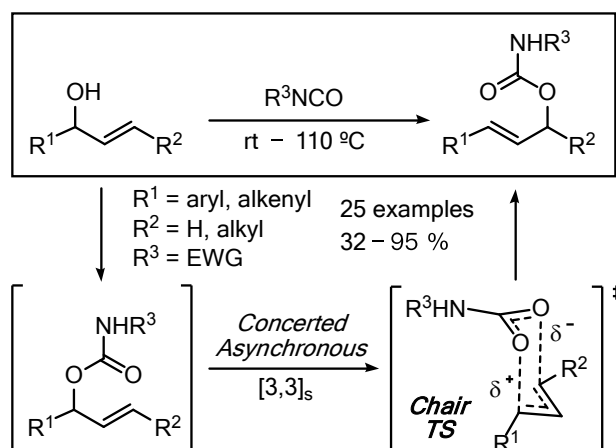


1,3-DIOXA-[3,3]-SIGMATROPIC OXO-REARRANGEMENT OF SUBSTITUTED ALLYLIC CARBAMATES: SCOPE AND MECHANISTIC STUDIES

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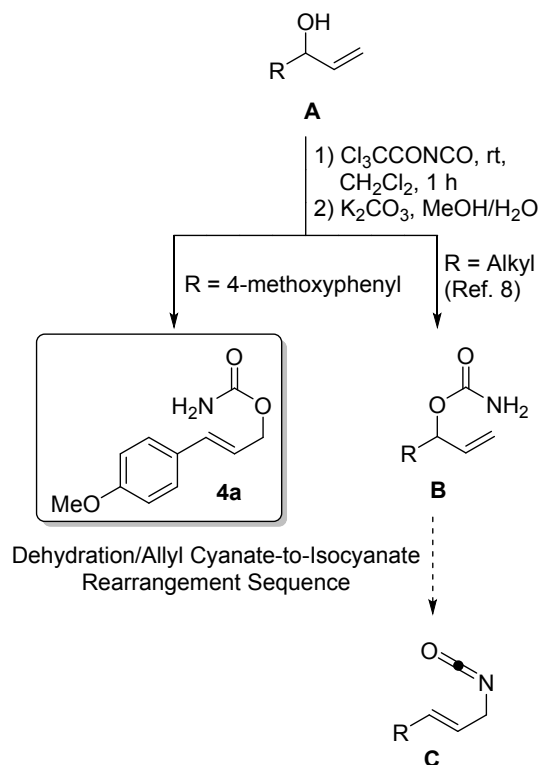


ABSTRACT: An unexpected 1,3-dioxa-[3,3]-sigmatropic rearrangement during the treatment of aryl- and alkenyl-substituted allylic alcohols with activated isocyanates is reported. The reorganization of bonds is highly dependent on the electron density of the aromatic ring and the nature of isocyanate used. This metal-free tandem reaction from branched allyl alcohols initiated by a carbamoylation reaction and followed by a sigmatropic rearrangement thus

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3 offers a new access to (*E*)-cinnamyl and conjugated (*E,E*)-diene carbamates such as *N*-acyl
4 and *N*-sulfonyl derivatives. A computational study was conducted in order to rationalize this
5 phenomenon as well as a rearrangement progress kinetic analysis was performed.
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8 9 INTRODUCTION

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11 Among the plethora of tools at the disposal of synthetic organic chemists, the [3,3]-
12 sigmatropic rearrangements represent very useful methods for the regio and stereoselective
13 formation of carbon-carbon or carbon-heteroatom bonds.¹ Among the C-N bond forming
14 reactions, the sigmatropic rearrangement of allylic trichloroacetimidates, namely the Overman
15 rearrangement,² occupies a place of choice as shown by the number of total synthesis
16 involving this method.³ The decarboxylative [3,3]-rearrangement of allylic carbamates
17 represents also a very useful strategy for the preparation of protected allylic amines from
18 allylic alcohols with an excellent regio- and stereoselectivity.^{4,5} Initially reported by Holm et
19 al. in 1970,⁶ the allyl cyanate/isocyanate rearrangement can be now considered as an attractive
20 alternative method to those above-mentioned, due to the fact that the transposition occurs at or
21 below ambient temperature, under metal-free conditions and with a complete transfer of
22 chirality.⁷ The first step of this process is the formation of the transient allyl cyanate from a
23 carbamate-type **B**, under dehydration conditions, followed by a spontaneous [3,3]-sigmatropic
24 bond reorganization to afford the corresponding allyl isocyanate **C** (Figure 1). This domino
25 dehydration/rearrangement sequence was successfully applied on a wide variety of
26 carbamates coming from alkyl-substituted allylic alcohols such as **A**.⁸ As a continuation of
27 our studies on the use of this methodology for the synthesis of new reagents or original
28 compounds,⁹ we envisaged the formation of branched substituted carbamates of **B**-type in
29 which R would be an aryl group since they have never been employed to date in this kind of
30 rearrangement.^{7b} However, as preliminary result, we observed that treatment of 1-(4-
31 methoxyphenyl)prop-2-en-1-ol with trichloroacetyl isocyanate followed by a basic hydrolysis
32 following a standard sequential process did not provide the expected branched compound
33 (Figure 1). The only product formed was a primary carbamate **4a** with a well-defined
34 stereochemistry of the double bond (*E*). In view of previous works concerning the thermal
35 rearrangement of allylic esters,^{10,11} we envisioned at this stage that the formation of **4a** could
36 be the outcome of a rapid 1,3-dioxa-[3,3]-sigmatropic rearrangement¹² from the branched
37 trichloroacetyl carbamate intermediate before hydrolysis.
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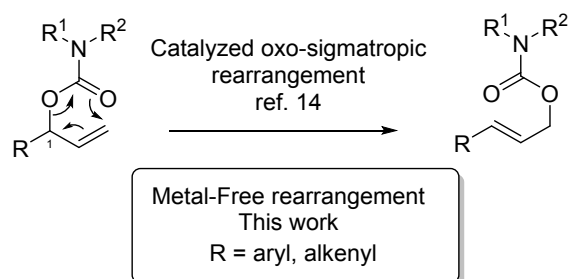


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Figure 1. Observation of the uncatalyzed 1,3-dioxo-[3,3]-sigmatropic rearrangement.

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Surprisingly, this rearrangement does not require any metal catalyst and takes place under neutral conditions.¹³ Indeed, the scarce examples described in literature require catalytic methods based on palladium (II) or mercury (II) salts.¹⁴ Taking into account the important role of molecules bearing a carbamate group as synthetic intermediates¹⁵ as well as in modern drug discovery,¹⁶ and that this one-pot process starting from 2-alken-1-ols (**A**, R = aryl or alkenyl) could constitute a valuable access to linear allyl carbamates (Figure 2),¹⁷ we decided to further explore the substrate scope and limitations of this methodology in order to offer a rationalization of this phenomenon.



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Figure 2. Proposed 1,3-dioxo-[3,3]-sigmatropic rearrangement of *O*-allyl carbamates.

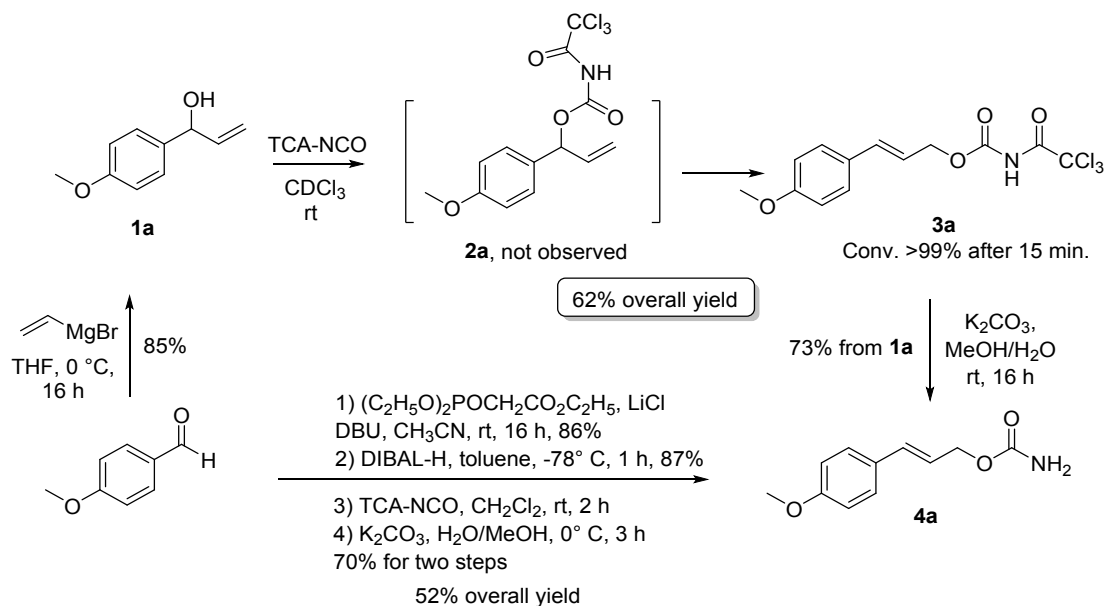
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3 In this paper, we report the results of our study. We show that the rate of the 1,3-
4 dioxo-[3,3] sigmatropic rearrangement depends mainly on the electron density of the aromatic
5 ring. These experimental observations have been confirmed by a kinetic study establishing
6 that the rearrangement is of first kinetic order. The nature of the isocyanate used is also
7 important for the transposition to occur. Activated reagents such as trichloroacetyl or *p*-
8 toluenesulfonyl isocyanates were required. Other substrates, in which an aryl group at the
9 allylic position (C1) was replaced by an alkenyl group, were also examined with success. In
10 addition, a computational study of the mechanism has also been carried out in order to shed
11 some light on the nature of this stereoselective thermal rearrangement.
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20 RESULTS AND DISCUSSION

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22 **Experimental studies.** First of all, we carefully examined the reaction of 1-(4-
23 methoxyphenyl)prop-2-en-1-ol **1a** with trichloroacetyl isocyanate by monitoring the
24 carbamoylation over time by ¹H NMR (Scheme 1). At room temperature, the reaction is
25 complete after 15 minutes in favor of the formation of **3a**, product which may result of a [3,3]
26 sigmatropic rearrangement from intermediate **2a**. At no moment during this NMR study was
27 the branched carbamate **2a** detected indicating the short-lived nature of this reaction
28 intermediate even at lower temperature (-70 °C). In all cases only the linear carbamate **3a** was
29 formed, with (*E*)-stereochemistry of the internal double bond. After evaporation of solvent,¹⁸
30 **3a** could be isolated from the reaction medium by trituration techniques or used without
31 further purification. Treatment of crude mixture under basic conditions in the presence of
32 K₂CO₃ afforded the expected compound **4a** with 73% overall yield from **1a** and 62% from 4-
33 methoxybenzaldehyde. It is noteworthy that this new compound **4a** was also prepared from
34 the same starting material, according to a conventional longer strategy (four steps instead of
35 three) and a poorer overall yield (52%).¹⁹
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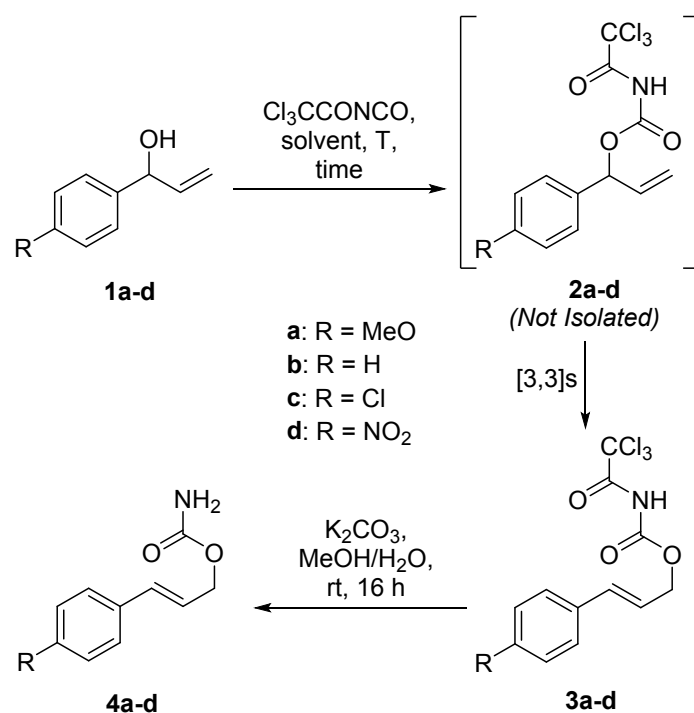
47 **Scheme 1. Synthesis of 4a Using a Rearrangement/Hydrolysis Sequence.**

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In order to determine the main factors that influence this sigmatropic rearrangement, different secondary allylic alcohols bearing both electron withdrawing and electron donating groups at para position on the aromatic ring were tested in the presence of trichloroacetyl isocyanate (TCA-NCO). As summarized in Table 1, the bond reorganization is highly dependent on the nature of the substituent. Except when the mesomeric effect is positive (+M, R = OMe, entry 1), heating the reaction mixture was required for all other cases (entries 2-4). During the NMR study, the formation of intermediates **2b-d** was clearly identified as being the first step before rearrangement can occur. The results obtained confirmed that the rate of this reaction is much slower with electron-deficient aromatic rings. Indeed, conversion of **2c** into **3c** (R = Cl, -I and +M effects) was complete after 20 h at 90 °C (entry 3) while with R = NO₂ (-I and -M effects), the time of reaction was increased sixfold to reach only 50% conversion to **3d** (entry 4). These results suggest a significant electron-deficient character for the allyl moiety along this sigmatropic process. After evaporation of solvent and hydrolysis under basic conditions, all linear carbamates **4** were obtained as single stereoisomer (*E*) and with moderate to good yields.

Table 1. Synthesis of Linear Carbamates 4 from Allyl Alcohols 1 Using Trichloroacetyl Isocyanate.



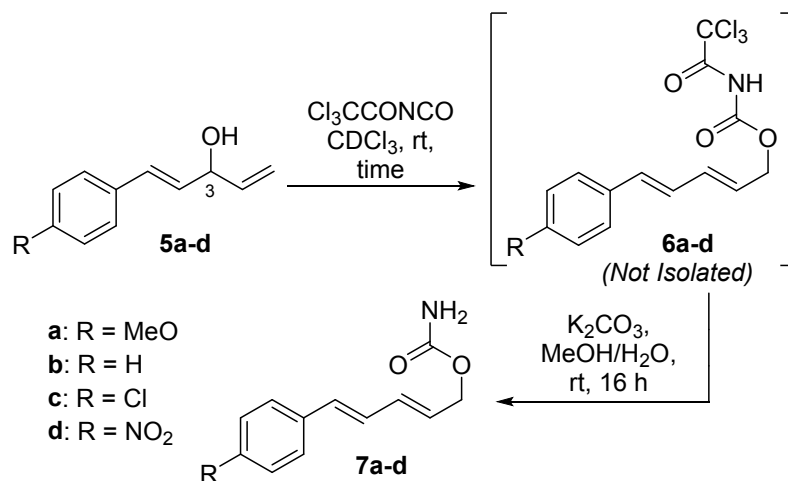
Entry	R	Solvent	T (° C)	Time (h) ^a	Product (Yield, %) ^b
1	MeO	CH ₂ Cl ₂	r.t.	0.25	4a , 73
2	H	Toluene	90	16	4b , 92
3	Cl	Toluene	90	20	4c , 50
4	NO ₂	Toluene	90	120 ^c	4d , 43

^a Reaction was monitored by ¹H-NMR until total consumption of starting material using a deuterated solvent. ^b Isolated yield of pure product. ^c 50% conversion observed.

Considering the potential importance of diene carbamates in the synthesis of natural products,²⁰ the carbamoylation/rearrangement/hydrolysis sequence was also extended to other substrates such as C3-alkenyl-substituted allylic alcohols **5**. The results indicated in Table 2 led to similar conclusions regarding the electronic effects that promote the rearrangement. More the aromatic ring was electron-rich, faster was the sigmatropic process. The difference of reaction rate between starting materials **1** and **5**, both of them possessing the same substitution pattern on the aromatic ring can be in part explained by the generation of a conjugated diene unit acting as the driving force due to the higher stability of products **6**. For instance, the rearrangement took place from **5c** in the presence of trichloroacetyl isocyanate (Table 2, entry 3) without heating, whereas a temperature of 90 °C was required for starting alcohol **1c** (Table 1, entry 3). In the case of nitro group (entry 4, Table 2), the rearranged product **6d** was not observed by NMR analysis even after 7 days of reaction at 90 °C, most likely due to the instability of the corresponding reaction intermediates at this temperature. In all other cases, the linear conjugated diene carbamates **7** were obtained after basic hydrolysis

in good yields, except for R = OMe (Table 2, entry 1), for which the purification on silica gel led to lose of product.

Table 2. Carbamylation/Rearrangement/Hydrolysis Sequence of C3-Alkenyl-Substituted Allyl Alcohols 5.

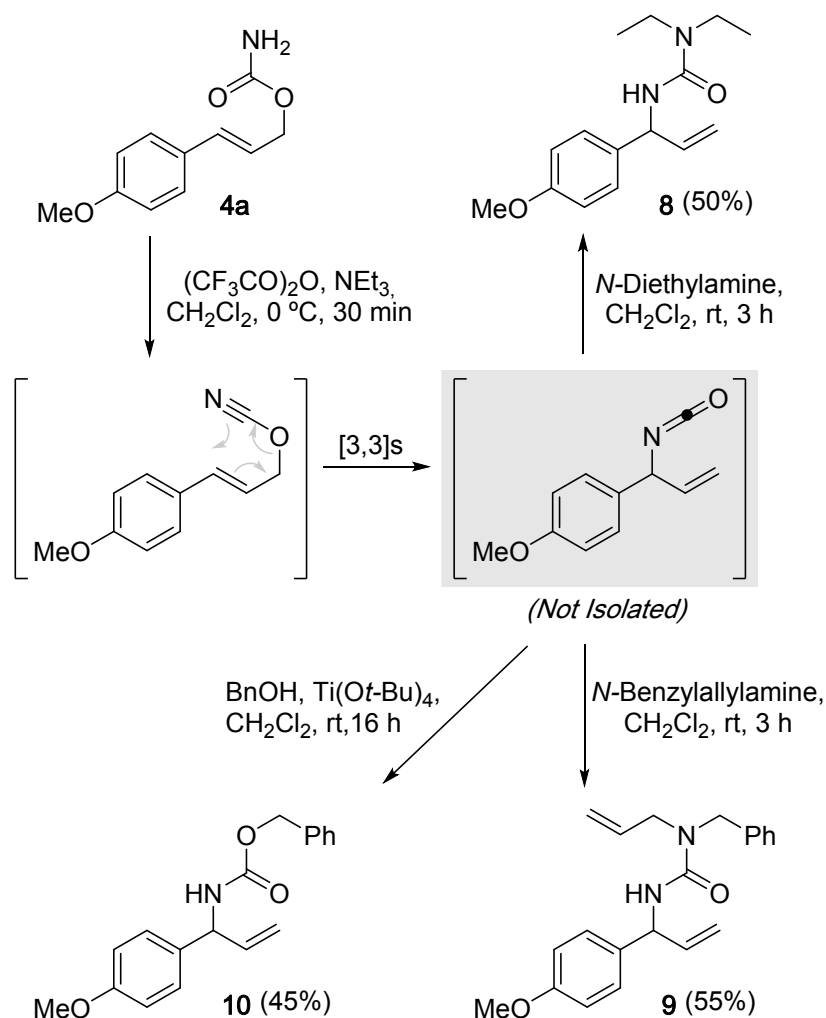


Entry	R	Time (h) ^a	Product (Yield, %) ^b
1	MeO	2	7a , 24(65) ^c
2	H	4	7b , 65
3	Cl	4	7c , 75
4 ^c	NO ₂	178 ^d	-

^a Reactions were monitored by ¹H-NMR until total consumption of starting material. ^b Isolated yield of pure product. ^c Reaction carried out in toluene-*d*8 at 90 °C. ^d No formation of desired product was observed. ^e Determined by ¹H-NMR using 1,3,5-trimethoxybenzene as internal reference.

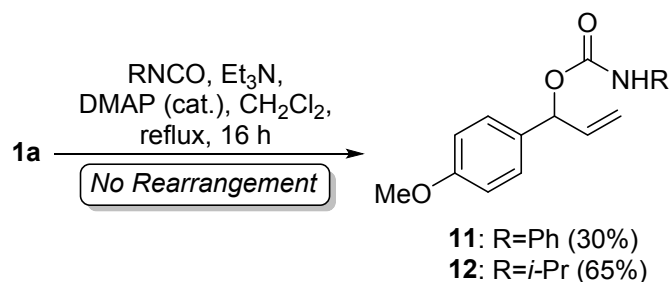
In order to bring to light the utility of this new process, the synthetic interest of linear carbamates such as **4a** was evaluated through a [3,3]-allyl cyanate rearrangement.²¹ Treatment of **4a** with trifluoroacetic anhydride (TFAA, 1.5 equiv) in the presence of a large excess of Et₃N at 0 °C for 30 min. led to the complete formation of isocyanate which can be quenched with various nucleophiles to afford compounds **8**, **9** and **10** in unoptimized yields (Scheme 2). When benzyl alcohol was used as nucleophile, a catalytic amount of Ti(*O**t*-Bu)₄ was required.²²

Scheme 2. Selected In Situ Transformations of Rearranged Carbamate **4a**.



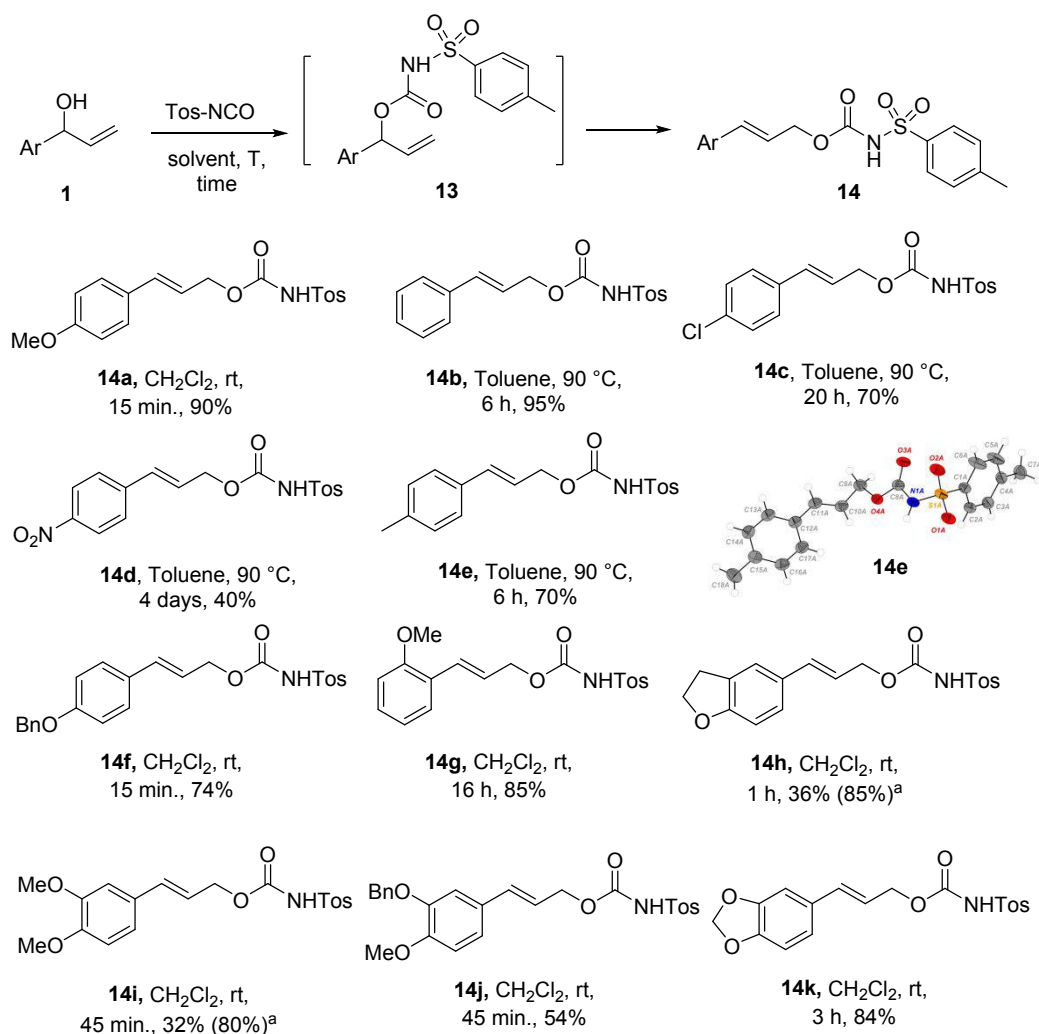
In our quest to determine the parameters influencing this 1,3-dioxo-[3,3]-sigmatropic rearrangement, the nature of the reagent was afterwards examined using deactivated isocyanates. As expected, treatment of **1a** with aliphatic or aromatic isocyanates in the presence of Et₃N and a catalytic amount of DMAP gave rise to the corresponding branched carbamates **11** (R = Ph) and **12** (R = *i*-Pr) with no trace of linear rearranged carbamates, as revealed by NMR analysis of the corresponding crude reaction mixtures (Scheme 3).^{23,24} When the phenyl isocyanate was used, the conversion was incomplete, which justifies the low yield obtained for the isolated compound **11** (30%). From these last results, the presence of the *N*-trichloroacetyl group in carbamates, such as **2a**, appears to be critical for the implementation of the rearrangement, likely by making the NH group less basic.

Scheme 3. No Rearrangement Observed with Deactivated Isocyanates During The Carbamoylation Reaction



In order to validate our hypothesis that the reorganization of branched aryl allyl carbamates could be reliant on the acidity of the carbamate NH, we tried the reaction between the allyl alcohol **1a** and *p*-toluenesulfonyl isocyanate. After 15 minutes at room temperature in CH_2Cl_2 , the conversion into linear *N*-tosyl carbamate **14a** was complete leading exclusively the (*E*)-isomer. In these conditions, the product was obtained after purification with an excellent yield (90%) from **1a** (Table 3). The one-pot reaction was extended to other aryl allyl alcohols **1** with good to high yields of purified products **14**, except for **14h** and **14i** because of their weak stability on silica gel. For substrates with electron-poor aromatic rings (**1b**, **1c**, **1d**, **1e**), heating in toluene solution was required. In all cases, the exclusive *E*-isomer formation of the internal double bond was maintained. Structure of **14e** was determined by X-ray crystallography.

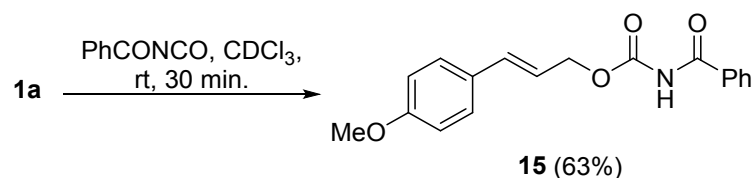
Table 3. 1,3-dioxa-[3,3]-Sigmatropic Rearrangement Using *p*-Toluenesulfonyl Isocyanate as Reagent.



^a Determined by ¹H-NMR using 1,3,5-trimethoxybenzene as internal reference.

Benzoyl isocyanate was also successfully employed to yield the rearranged product **15** from **1a** (Scheme 4). After 30 minutes in CDCl₃, the starting material was completely consumed and the primary carbamate **15** was obtained in 63% yield after purification.

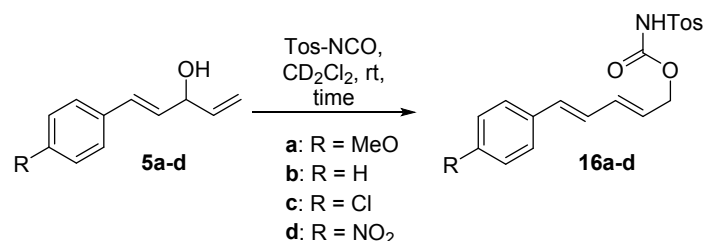
Scheme 4. Carbamylation/Rearrangement Sequence Using Benzoyl Isocyanate.



In the same way, the one-pot process using tosyl isocyanate reagent was carried out successfully from C3-alkenyl-substituted allyl alcohols **5** to afford the corresponding (*E,E*)-

conjugated linear carbamates **16** (Table 4). Nevertheless, compound **16d** (R = NO₂, Table 4, entry 4) was obtained in moderate yield after separation of the unreacted starting material.

Table 4. Carbamoylation/Rearrangement Sequence Using Tosyl Isocyanate From C3-Alkenyl-Substituted Allyl Alcohols 5.

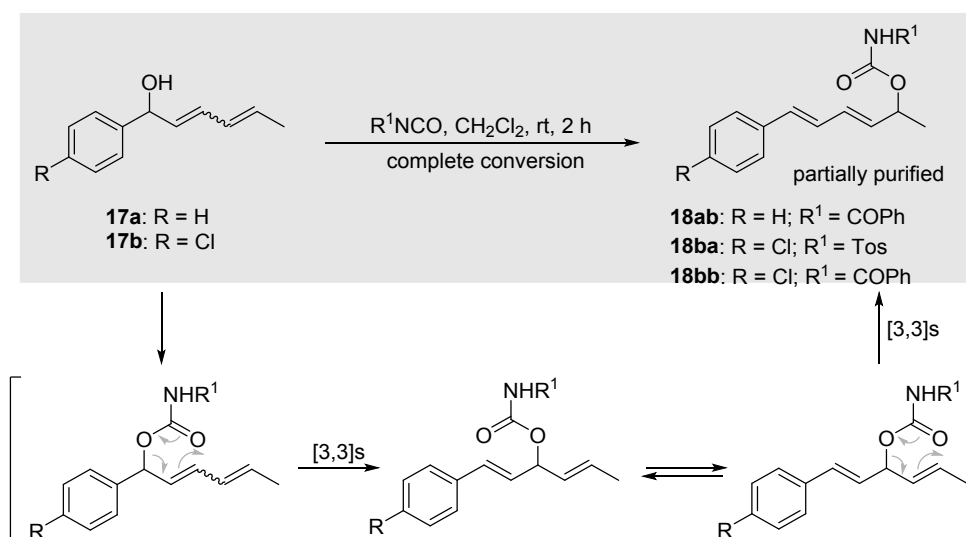


Entry	R	Time (h) ^a	Product (Yield, %) ^b
1	MeO	0.5	16a , 25(85) ^c
2	H	4	16b , 75
3	Cl	4	16c , 68
4 ^c	NO ₂	120 ^d	16d , 36

^a Reactions were monitored by ¹H-NMR until total consumption of starting material. ^b Isolated yield of pure product. ^c Reaction carried out in toluene-*d*8 at 90 °C. ^d 50 % conversion was observed. ^e Determined by ¹H-NMR using 1,3,5-trimethoxybenzene as internal reference.

In order to test whether the carbamoylation reaction could be followed by a sequential double sigmatropic oxo-rearrangement in a one-pot process, 1-aryl-2,4-butadien-1-ols **17** as a mixture of stereoisomers were prepared from hexanedial according to a described procedure (Scheme 5).²⁵ Treatment of **17** with tosyl and benzoyl isocyanates led to the formation of the corresponding rearranged products **18ab**, **18ba** and **18bb** respectively. The reactions took place at room temperature with a complete conversion after 2 h in CH₂Cl₂, but unfortunately the purification of these compounds is difficult due to their instability on silica gel (see Experimental Section). It should be noted, however, that even in the presence of a deactivating group on the aromatic ring, these substrates are prone to undergo this consecutive double rearrangement under mild conditions, as demonstrated with alcohol **17b**.

Scheme 5. Consecutive [3,3]-Sigmatropic Rearrangements from Starting Alcohols 17.



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Finally, we studied the stereoselectivity of the rearrangement in terms of the transfer of chirality when a chiral allyl alcohol is used as starting reactant. To this end, we analyzed the behavior of racemic (*E*)-1-phenylbut-2-en-1-ol **20** and its (*S*)-enantiomer (Figure 3).²⁶ This latter starting alcohol was separated from a racemic mixture by HPLC using a chiral stationary phase (see the Experimental Section). After this chromatographic separation, (*S*)-**20** was obtained with an enantiomeric excess of 98%. Both racemic and (*S*)-**20** were transformed into carbamates **21** (not isolated, see Figure 3) by reaction with (*R*)-[1-(4-fluorophenyl)ethyl]isocyanate (*R*)-**19** in the presence of triethylamine. After two days of reaction at 110 °C in toluene the corresponding rearranged products **22** was obtained. The HPLC profile of the diastereomeric mixture of (*S,R*)+(*R,R*) carbamates **22** showed two well-defined peaks compatible, within the experimental error, with that would be expected for the reaction product stemming from racemic **20**. In the case of the product formed using (*S*)-**20** as reactant, formation of (*S,R*)-**22** was observed with 95% diastereomeric excess, according to the HPLC profile. These results, show that, within the experimental error, most of –if not all– the observed rearrangement takes place *via* a symmetry allowed concerted *supra-supra* mechanism, with virtually complete 1,3-transfer of the chiral information contained in the starting alcohol, together with retention of configuration of the double bond. The mechanistic aspects derived from this observation shall be discussed in the following section.

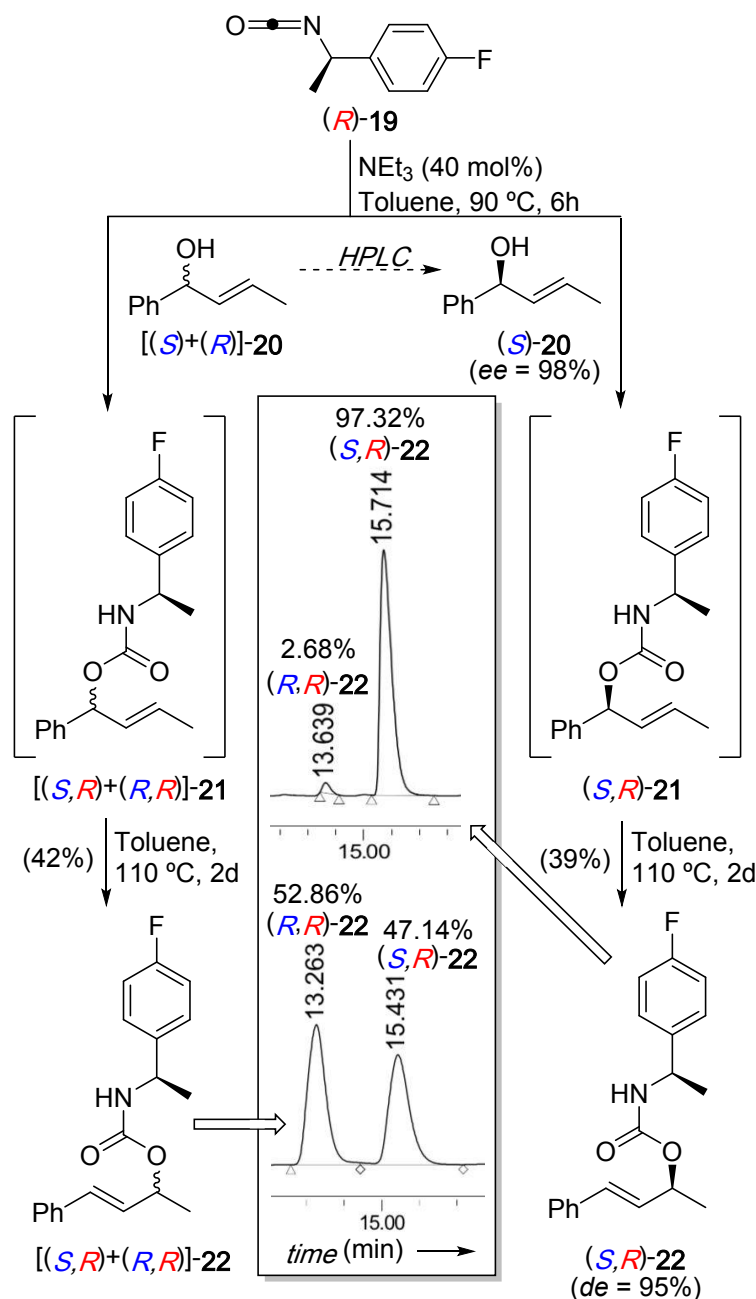


Figure 3. Assessment of the chirality transfer in the reaction between isocyanate **(R)-19** and alcohol **20**. The HPLC chromatograms are also shown.

Mechanistic studies. Conversion of alcohols **1b,c** ($R=H, Cl$, respectively) into the rearranged products **14b,c** in the presence of *p*-toluenesulfonyl isocyanate was monitored by $^1\text{H-NMR}$ in deuterated toluene at 90 °C. A selected ensemble of spectra recorded at different reaction times is gathered in Figure 4. These data indicate that alcohol **1c** is immediately converted into carbamate **13c**, as it can be appreciated by comparison of both spectra. This intermediate

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3 carbamate evolves towards the rearranged product **14c** with no detectable intermediate
4 species. Using these NMR data and applying first-order kinetics in eq 1
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$$6 \quad \ln[\mathbf{13c}]_t - \ln[\mathbf{13c}]_0 = -k_{obs}t \quad (1)$$

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9 we obtained $k_{obs} = 1.08(\pm 0.04) \times 10^{-4} \text{ s}^{-1}$. A similar study for alcohol **1b** (R=H) led to a
10 measured kinetic constant of $k_{obs} = 1.62(\pm 0.06) \times 10^{-4} \text{ s}^{-1}$ (see the Supporting Information).
11 These results were confirmed in a combined experiment using a 1:1 mixture of **1b** and **1c**, to which a
12 50 % of *p*-toluenesulfonyl isocyanate was added. After 5 min. of reaction at room temperature,
13 the ¹H-NMR analysis revealed that ca. 50 % of both alcohols remained unreacted, whereas
14 carbamates **13b** and **13c** were observed in a 1.0:1.2 ratio. After 6h of reaction at 90 °C, a
15 complete **13b**→**14b** (R=H) conversion was observed, whereas for the **13c**→**14c** (R=Cl)
16 rearrangement the conversion was of ca. 40 %. These results showed that the fast formation of
17 carbamates **13** from alcohols **1** is not selective and that the subsequent dioxo-[3,3]-
18 sigmatropic rearrangements occur through a kinetically independent process, not related to the
19 formation of the starting carbamate. In the case of alcohol **1a** (R=OMe) the reaction was too
20 fast to obtain a reliable first-order kinetic under the same experimental conditions used for **1b**
21 and **1c**. However, we could measure the first-order reaction rate until 15 min of reaction at
22 room temperature and obtained $k_{obs} = 1.63(\pm 0.05) \times 10^{-3} \text{ s}^{-1}$, one order of magnitude faster
23 than in the preceding cases. Similar experiments with **1d** (R=NO₂) were not possible because
24 the reaction was too slow. We also examined the efficiency of the reaction in the presence of
25 polar solvents. When alcohol **1b** and tosyl isocyanate were allowed to react in DMSO or
26 DMF no reaction was observed, whereas in acetonitrile only 35 % conversion was observed
27 after three days of reaction at 90 °C. These results are in agreement with those reported in
28 Table 3 (vide supra). We concluded from these data that electron withdrawing groups at the
29 aryl moiety of the starting alcohols result in lower reactivity. On the contrary, electron
30 releasing groups such as methoxy accelerate the sigmatropic rearrangement. This conclusion
31 is compatible with an electron deficient character of the allyl moiety at the corresponding
32 transition state, an aspect (among others) that was analyzed by DFT calculations.
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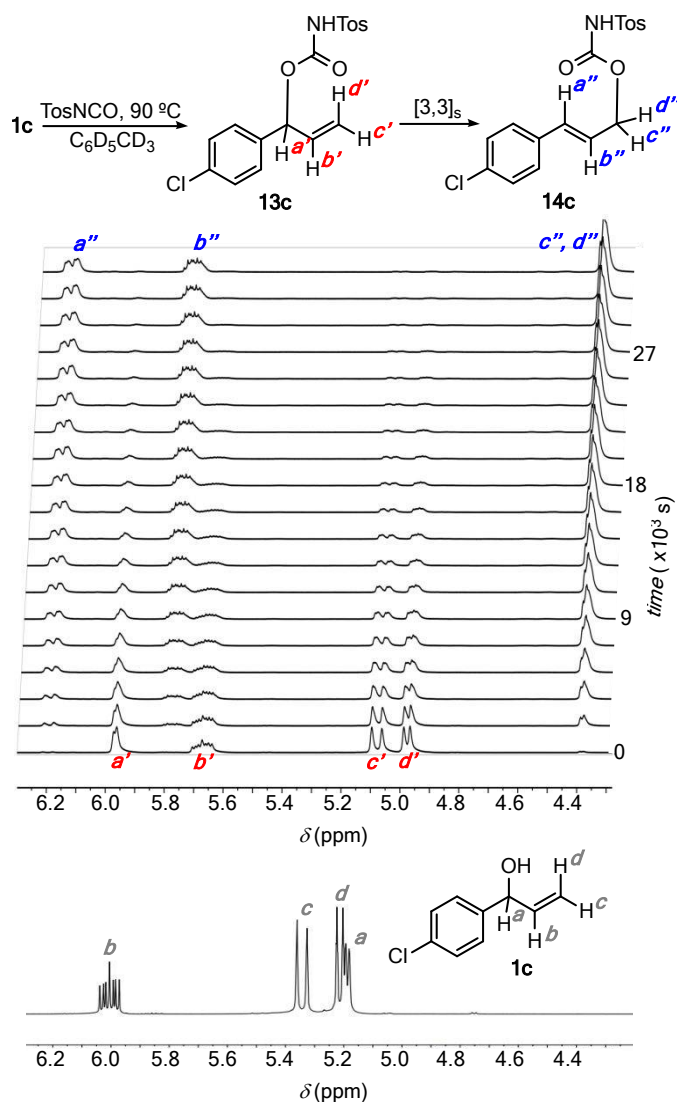


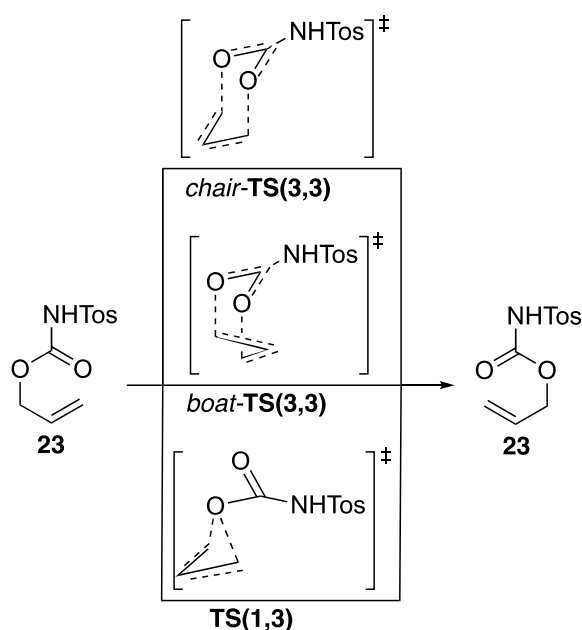
Figure 4. 1H -NMR plots (500 MHz) corresponding to the reaction of 1-(4-chlorophenyl)prop-2-en-1-ol **1c** with *N*-tosyl isocyanate at 90 °C to yield rearranged carbamate **14c** via intermediate **13c**. The successive spectra, recorded at different reaction times, show the evolution of the allylic hydrogens of both carbamates. The spectrum of the allylic region of **1c** is also shown.

Since the 1H -NMR showed that the formation of 1-arylallyl tosylcarbamates **13b,c** from alcohols **1b,c** was not kinetically relevant, we carried out DFT calculations on these transformations. These calculations were performed at the B3LYP-D3(PCM)/6-311G++G(d,p) level of theory. Toluene was used as solvent and the Gibbs energies were calculated at 90 °C (363.15 K).

Previous work on the rearrangement of allyl esters^{10a,b} suggested that both [3,3] and [1,3] mechanisms could occur (Scheme 6). In addition, Birney,^{11,27} Duncan²⁸ and respective co-workers have indicated that in esters and acetimidates both pericyclic and pseudopericyclic mechanisms can compete. In order to elucidate the preference for the [1,3] or [3,3] topologies

associated with these 1,3-dioxa-sigmatropic rearrangements, we studied computationally the degenerate rearrangement of allyl tosylcarbamate **23** via [1,3] or [3,3] sigmatropic shifts. In turn, within the [3,3] reaction path, we considered chair and boat geometries for the corresponding saddle points (Scheme 6) as well as the possible occurrence of pseudopericyclic mechanisms.

Scheme 6. Possible [3,3] and [1,3] Mechanisms for the 1,3-Dioxa Rearrangement of Allyl Tosylcarbamate **23.**



The chief geometric and energetic features of transition structures chair-TS(3,3), boat-TS(3,3) and TS(1,3) are gathered in Figure 5. Our calculations indicate that the dioxa-[3,3]-sigmatropic mechanism is clearly preferred with respect to the [1,3] rearrangement involving only one of the oxygen atoms of the carboxylate moiety. Within the [3,3] mechanism, the chair geometry of the corresponding transition state is 4.6 kcal/mol less energetic than that associated with the boat analogue. These results are in agreement with the empirical observations reported by Lewis and Hill,¹⁰ who established that the [1,3] mechanism is substantially more energetic than the [3,3] reaction path. On the other hand, the dihedral angles calculated for the three transition structures shown in Figure 5 indicate π - π interactions between both reactants, with dihedral angles ω of 85-110 deg. Since the participation of the lone pairs (orbitally disconnected to the C=O π -orbitals) of one or two oxygen atoms should lead to ω values close to 180 deg. (vide infra), we concluded that both

[1,3] and [3,3] geometries shown in Figure 5 correspond to pericyclic and not to pseudopericyclic processes. In addition, these 1,3-dioxa-[3,3]-sigmatropic rearrangements take place via chair geometries and symmetry allowed²⁹ *supra-supra* topologies.

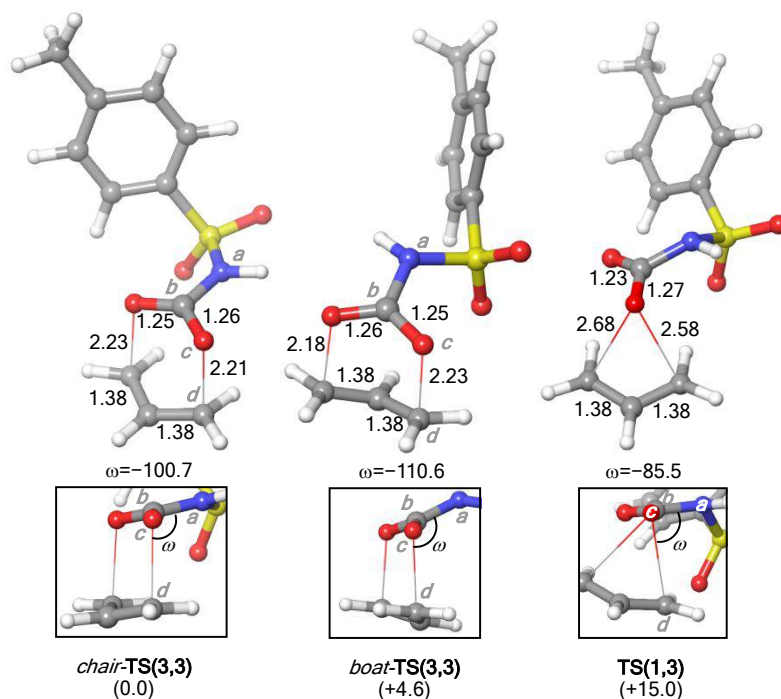


Figure 5. Optimized structures (B3LYP-D3(PCM=toluene)/6-311++G(d,p) level of theory) of transition structures *chair-TS(3,3)*, *boat-TS(3,3)* and *TS(1,3)* depicted in Scheme 6. Bond distances are in Å. Dihedral angle ω (in deg.) is defined by the *a-b-c-d* atoms. Numbers in parenthesis are the relative energies, in kcal/mol.

We also performed isotope labeling NMR experiments in order to verify the previously discussed computational results. These experiments were carried out by using a mixture of 11.1% H_2^{17}O , 29.7% H_2^{18}O and 59.2% H_2^{16}O . Conversion of (trichloromethyl)benzene **24** into doubly labeled benzoic acid **25** under microwave irradiation³⁰ permitted two synthetic routes (Figure 6A). In the first one, we prepared diester **26** following a described procedure.³¹ The ^{17}O -NMR spectrum is shown in Figure 6B. In this spectrum two well separated signals at 340 and 136 ppm can be observed, associated with the sp^2 and sp^3 -hybridized ^{17}O nuclei, respectively. This process permitted us to calibrate the performance of ^{17}O -NMR to distinguish the starting and final resonances associated with the $[^{17}\text{O}_1]\mathbf{13b} \rightarrow [^{17}\text{O}_1]\mathbf{14b}$ transformation.

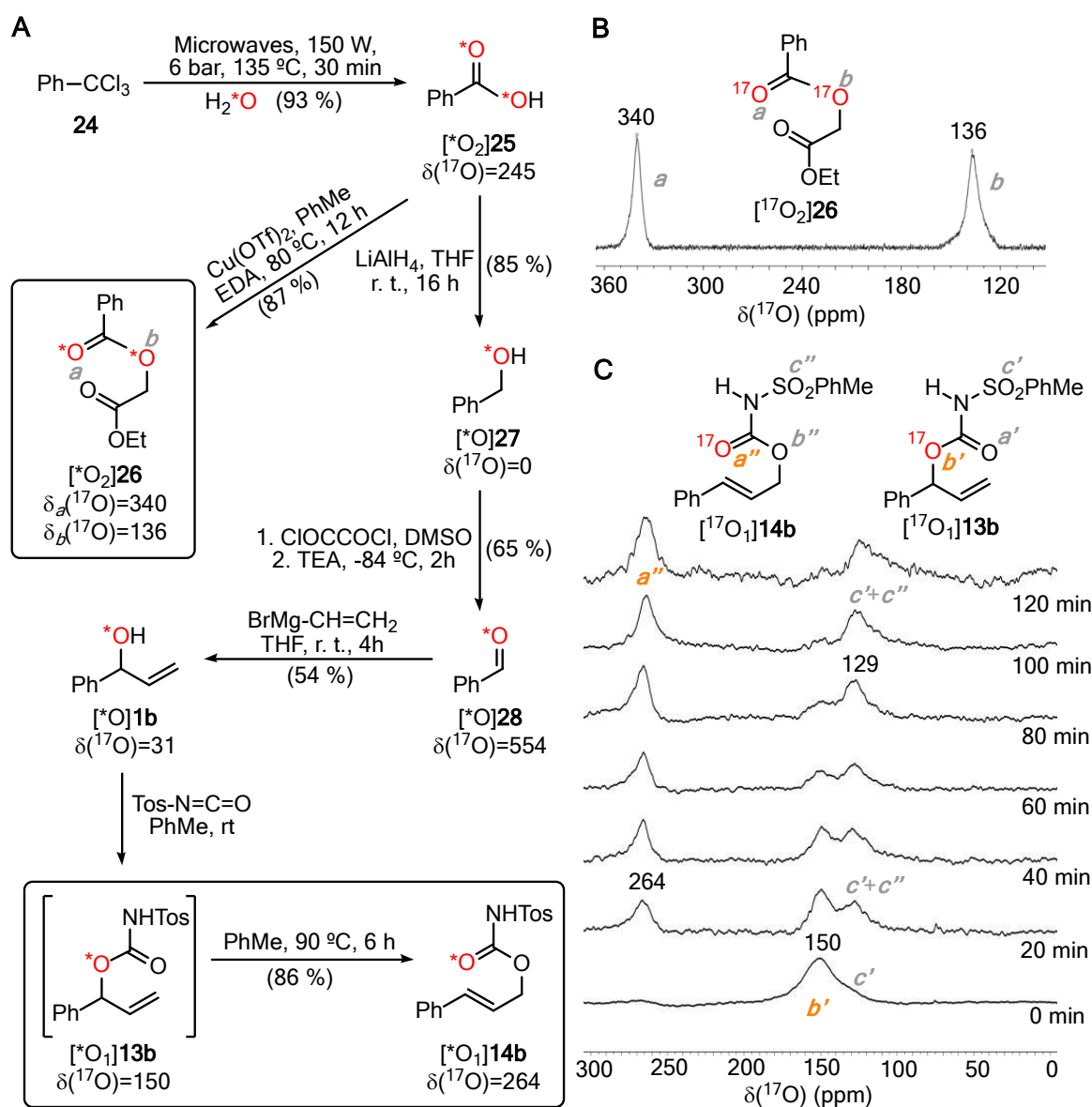


Figure 6. (A) Synthesis of labelled allyl tosylcarbamates [$^{17}\text{O}_1$]**13b** and [$^{17}\text{O}_1$]**14b**, and diester [$^{17}\text{O}_2$]**26**. The [^{17}O]-labelled compounds were synthesized from a mixture of 11.1% H_2^{17}O , together with 29.7% H_2^{18}O and 59.2% H_2^{16}O . The $\delta(^{17}\text{O})$ chemical shifts of the [^{17}O]-labelled compounds are given in ppm. (B) ^{17}O -NMR spectrum of diester [$^{17}\text{O}_2$]**26**, in which the sp^2 and sp^3 -hybridized oxygen atoms can be distinguished. (C) ^{17}O -NMR spectra of the [$^{17}\text{O}_1$]**13b** \rightarrow [$^{17}\text{O}_1$]**14b** transformation recorded in d^8 -PhMe at different reaction times. The signals of sulfone oxygen atoms (c' and c'' , natural abundances) are also given.

The second synthetic route of labeling experiments consisted of the conversion of labeled benzoic acid **25** into allyl alcohol **1b** via a sequence of reduction, oxidation and addition reactions involving O-labeled benzyl alcohol **27** and benzaldehyde **28**, whose diagnostic $\delta(^{17}\text{O})$ chemical shifts are gathered in Figure 6A (see the Supporting Information for further details). Reaction of labeled **1b** with tosyl isocyanate led almost immediately (vide

supra) to labeled **13b**. The ^{17}O -NMR spectrum of labeled $[^{17}\text{O}_1]\mathbf{13b}$ showed a very broad signal at 150 ppm, partially superimposed to the signal associated with the sulfone moiety (natural abundance, see the Supporting Information for further details). Heating of $[^{17}\text{O}_1]\mathbf{13b}$ led us to observe a new signal at 264 ppm (Figure 6C), which was interpreted as associated with the sp^2 -hybridized ^{17}O nucleus of $[^{17}\text{O}_1]\mathbf{14b}$ on the basis of the related signal of $[^{17}\text{O}_2]\mathbf{26}$ shown in Figure 6B. The emergent signal of $[^{17}\text{O}_1]\mathbf{14b}$ was coincident with the decrease of the broad signal of $[^{17}\text{O}_1]\mathbf{13b}$, the broad signals of the SO_2 groups of both tosyl carbamates being of similar chemical shift.³² These results, together with the above described calculations and experiments involving chiral species, led us to the conclusion that, as suggested by Lewis and Hill,¹⁰ the conversion of carbamates **13** into their regioisomers **14** takes place via concerted pericyclic 1,3-dioxa-[3,3]-sigmatropic rearrangements.

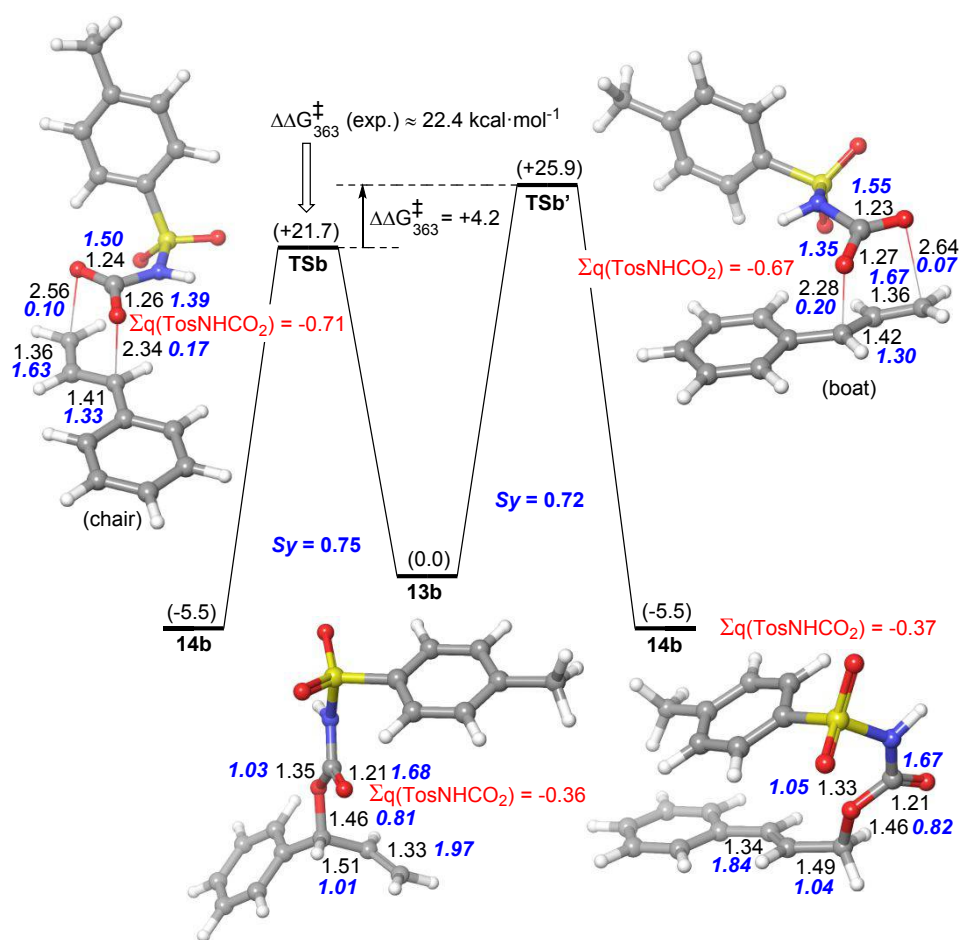


Figure 7. Reaction profiles of the thermal rearrangement of 1-phenylallyl tosylcarbamate **13b** to yield cinnamyl tosylcarbamate **14b**. All stationary points were calculated at the B3LYP-D3(PCM,solvent=toluene)/6-311++G(d,p) level of theory. Numbers in parentheses are the relative free energies, in kcal/mol, calculated at 363.15 K with respect to **13b**. The experimental Gibbs activation energy, estimated at the same temperature, is also provided.

Bond distances are given in Å. $\Sigma q(\text{CO}_2)$ values, displayed in red, correspond to the natural charges of the carboxy moieties and are given in a. u. Numbers in blue correspond to the respective bond orders. The S_y parameter stands for the synchronicity of each elementary process via **TSb** and **TSb'**. For a perfectly synchronous transformation, $S_y=1$ (see text).

The reaction coordinate associated with the [3,3] sigmatropic rearrangement of 1-phenylallyl tosylcarbamate **13b** to yield cinnamyl tosylcarbamate **14b** (R=H) was analyzed first. The chief features of this reaction are gathered in Figure 7. We found two transition structures **TSb** and **TSb'** corresponding to chair and boat geometries, respectively. The former saddle point was found to be ca. 4.2 kcal/mol less energetic than its boat congener, which indicates that only the **13b** → **TSb** → **14b** reaction coordinate is kinetically relevant. The theoretical activation energy was calculated to be 21.7 kcal/mol. From the ¹H-NMR data (vide supra), the experimental Gibbs activation energy at 363.15 K was estimated from the Eyring equation (eq.2) associated with k_{obs} :

$$k_{\text{obs}} = \kappa \frac{k_B \cdot 363.15}{h} \exp \left[- \frac{\Delta G_{363}^\ddagger(\text{exp})}{R \cdot 363.15} \right] \quad (2)$$

Assuming $\kappa \approx 1$, the estimated activation energy was calculated to be 22.4 kcal/mol, in good agreement with the computational value. In addition, using the bond orders associated with the suprafacial [3,3] sigmatropic shift, we computed the earliness of the reaction path via **TSb** as the average of the degree of advancement δB_{AV} of both saddle points, according to the following expression (eq.3):

$$\delta B_{AV} = \frac{1}{6} \sum_{i=1}^6 \delta B_i = \frac{1}{6} \sum_{i=1}^6 \frac{B_i^{TS} - B_i^R}{B_i^P - B_i^R} \quad (3)$$

where B_i is the bond order of the i -th bond involved in the pericyclic reaction at the reactant (R) **13b**, transition state (TS) **TSb** and product (P) **14b**. For the **13b** → **TSb** → **14b** transformation it was found that $\delta B_{AV}=0.42$. Since for an exactly midway transition structure $\delta B_{AV}=0.5$, this result indicates a slightly early saddle point, with $\Delta G_{\text{rxn}}=-5.5$ kcal/mol. We also calculated the synchronicity S_y of the reaction as

$$S_y = 1 - \frac{1}{10} \sum_{i=1}^6 \frac{|\delta B_i - \delta B_{AV}|}{\delta B_{AV}} \quad (4)$$

According to this expression (eq.4), for a perfectly synchronous [3,3] sigmatropic reaction, $\delta B_i = \delta B_{AV}$ for any $i=1,2, \dots, 6$ and therefore $|\delta B_i - \delta B_{AV}| = 0$ and $S_y=1$. In our case, we obtained $S_y=0.75$ for the **13b** → **14b** reaction mediated by **TSb**, which suggests a noticeable

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3 asynchronicity. When the same reaction is mediated by **TSb'**, the reaction was computed to
4 be slightly more asynchronous (see Figure 7). These results are in line with the geometries
5 obtained for both saddle points, with two C...O distances associated with the bonds being
6 broken and formed (see Figure 7). This partially asynchronous but still concerted character of
7 the reaction mechanism agrees with the preservation of the chiral information contained in the
8 starting enantiopure allyl alcohol (see Figure 3). Finally, the charge analysis of the
9 carboxylate moiety along the reaction coordinate showed that this charge was ca. 0.2 e higher
10 in the transition structures than in the reactant and product (Figure 7). This result points to
11 relatively polar transition structures, with an associated positive charge delocalized in the allyl
12 moiety. As a consequence, electron-withdrawing groups in the starting allyl alcohol should
13 destabilize this partial cationic character, thus leading to higher activation energies. Likewise,
14 electron releasing substituents should accelerate the sigmatropic rearrangement, in good
15 agreement with our experimental results (see Tables 1-4).
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26 We also performed the above described DFT study with tosylcarbamate **13c** (R=Cl) to
27 yield 4-chlorocinnamyl tosylcarbamate **14c** (see the Supporting Information for further
28 details). The computed reaction profile for this series was similar to that found for R=H case.
29 As expected, the activation energy computed for the **13c**→**14c** reaction via **TSc** was
30 calculated to be 22.6 kcal/mol, a value slightly higher than that found for the parent **13b**→
31 **14b** reaction. The excellent agreement between this latter computational value and the
32 corresponding experimental estimate (22.7 kcal/mol, see the Supporting Information) reflects
33 the reliability of our calculations and reproduces correctly the lower reaction rate with respect
34 to the parent reaction (R=H) for allyl alcohols when R=Cl.
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42 In order to analyze the reasons for the preference for the chair conformation in **TSb**,
43 we considered applying the distortion/interaction-activation strain model³³ to both saddle
44 points. However, the intramolecular nature of the sigmatropic rearrangement hampered the
45 analysis in terms of interacting molecules. Therefore, we decomposed the activation energy
46 ΔE^\ddagger as the sum of the deformation (FDEF) and interaction (FINT) terms between two
47 carboxylic (C) and allylic (A) fragments at transition structure **TSb**:
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$$53 \Delta E^\ddagger = \Delta E_{FDEF}^\ddagger + \Delta E_{FINT}^\ddagger \quad (5)$$

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55 The deformation of both fragments can be envisaged as the sum of the zwitterionic (ZW) and
56 diradical (DR) contributions of both fragments:
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$$\Delta E_{FDEF}^{\ddagger} = X_{ZW}\Delta E_{ZW}^{\ddagger} + (1 - X_{ZW})\Delta E_{DR}^{\ddagger} \quad (6)$$

where X_{ZW} is the weight of the zwitterionic contribution, the corresponding diradical coefficient X_{DR} satisfying the relation $X_{ZW} + X_{DR} = 1$. Since for the DR structures the charges of both fragments are zero, we approximated the contribution of the ZW form as $X_{ZW} = \delta$, namely the NBO charge of the allylic fragment **A** in **TSb** (Figure 8).

The ΔE_{ZW}^{\ddagger} term was computed as the sum of the single-point energies of isolated carboxylate (**C**⁻) and allyl cation (**A**⁺) fragments at the geometry of **TSb**, with respect to the energy E_0 of the reactant **13b**:

$$\Delta E_{ZW}^{\ddagger} = (\Delta E_{C^-}^{\ddagger} + \Delta E_{A^+}^{\ddagger}) - E_0 \quad (7)$$

The ΔE_{DR}^{\ddagger} term was computed in a similar way, but considering the contributions of the carboxy (**C**[·]) and allyl (**A**[·]) isolated radical fragments, also computed at the geometries of the transition state **TSb**:

$$\Delta E_{DR}^{\ddagger} = (\Delta E_{C^{\cdot}}^{\ddagger} + \Delta E_{A^{\cdot}}^{\ddagger}) - E_0 \quad (8)$$

Our results indicate that both in the chair and boat conformations of **TSb** the contributions of the ZW forms are ca. 1 kcal/mol larger than those associated with the DR forms. Thus, in *chair*-**TSb** the respective values are $\Delta E_{ZW}^{\ddagger} = 73.3$ kcal/mol and $\Delta E_{DR}^{\ddagger} = 72.3$ kcal/mol, whereas the corresponding values for *boat*-**TSb** are $\Delta E_{ZW}^{\ddagger} = 78.4$ kcal/mol and $\Delta E_{DR}^{\ddagger} = 77.6$ kcal/mol. The computed total values of ΔE^{\ddagger} , $\Delta E_{FDEF}^{\ddagger}$ and $\Delta E_{FINT}^{\ddagger}$ terms of eq. (1) are shown in Figure 8. Our calculations indicate that the fragment deformation term $\Delta E_{FDEF}^{\ddagger}$ is 5.1 kcal/mol higher in *boat*-**TSb** than in *chair*-**TSb**, the difference in $\Delta E_{FINT}^{\ddagger}$ being of only 1.2 kcal/mol in favor of *boat*-**TSb**. Therefore, in the boat geometry both the deformation (destabilizing) and interaction (stabilizing) terms between the **C** and **A** fragments are higher in magnitude because of closer steric, Coulombic and electronic contacts in *boat*-**TSb** with respect to its chair congener. We conclude that $\Delta E_{FDEF}^{\ddagger}$ is responsible for the preference for the chair conformation in these pericyclic transition structures, since the more congested boat geometry induces a larger departure of the **C** and **A** fragments from their respective optimal geometries.

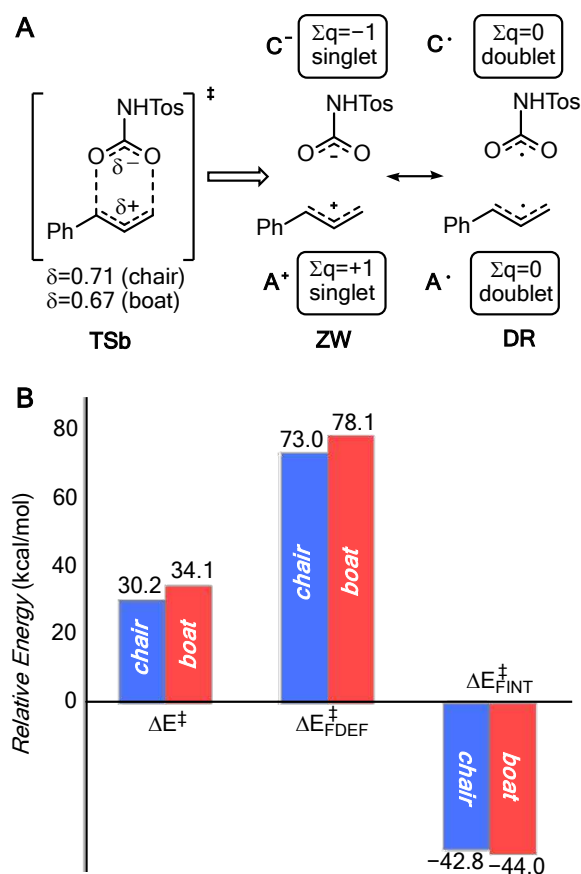


Figure 8. (A) Fragment deformation/interaction analysis (see text) of **TSb** in terms of resonant zwitterionic (**ZW**) and diradical (**DR**) contributions between carboxy (**C**) and allyl (**A**) fragments. Σq is the formal charge of the corresponding fragment. The expected $\langle S^2 \rangle$ values, in atomic units (a.u.) are also given. The sum of NBO charges of each fragment at chair- and boat-**TSb**, in a.u., are denoted as δ . (B) Calculated activation (ΔE^\ddagger), deformation (ΔE_{FDEF}^\ddagger) and interaction energies (ΔE_{FINT}^\ddagger) for the chair and boat conformations of **TSb**, in kcal/mol.

In order to assess whether this relatively polar character of the sigmatropic shift can be extended to other para-substituted allyl alcohol derivatives, we computed at the B3LYP-D3(SCRF,solvent=toluene)/6-311++G(d,p) level the activation free energies associated with different reactants and we plotted these energies with respect to the combined Hammett parameter³⁴ $\langle \sigma \rangle$ of the corresponding substituents in the form

$$\langle \sigma \rangle = Z_W \cdot \sigma_p^+ + (1 - Z_W) \sigma_p \quad (8)$$

where σ_p^+ is the Taft resonance parameter for positive charges and σ_p is the Hammett parameter for a para-substituent (Figure 9). Our results show a moderate linear correlation between the Gibbs activation energies and the combined polar Hammett-Taft parameter $\langle \sigma \rangle$.

However, there is no linear correlation between the ΔG_a and ΔG_{rxn} values,³⁵ as it is shown in Figure 9B. This result does not follow the behavior observed for other pericyclic reactions such as 1,4-dihydrogenations and [4+2] cycloadditions of aromatic molecules,³⁶ thus suggesting that the relationship between activation and reaction energies is not reducible to Marcus-Hammond models. In our opinion, this supports our conclusion that the transition structures of these sigmatropic rearrangements follow a polar-radical carboxy/allyl model not directly connected to the reactants or products. Within this context, it is interesting to note that Houk and Ess³⁷ have shown a departure from the Marcus-Hammond framework in 1,3-dipolar reactions, in which the nature of the different dipoles generates different $\Delta H^\ddagger / \Delta H_{rxn}$ plots.

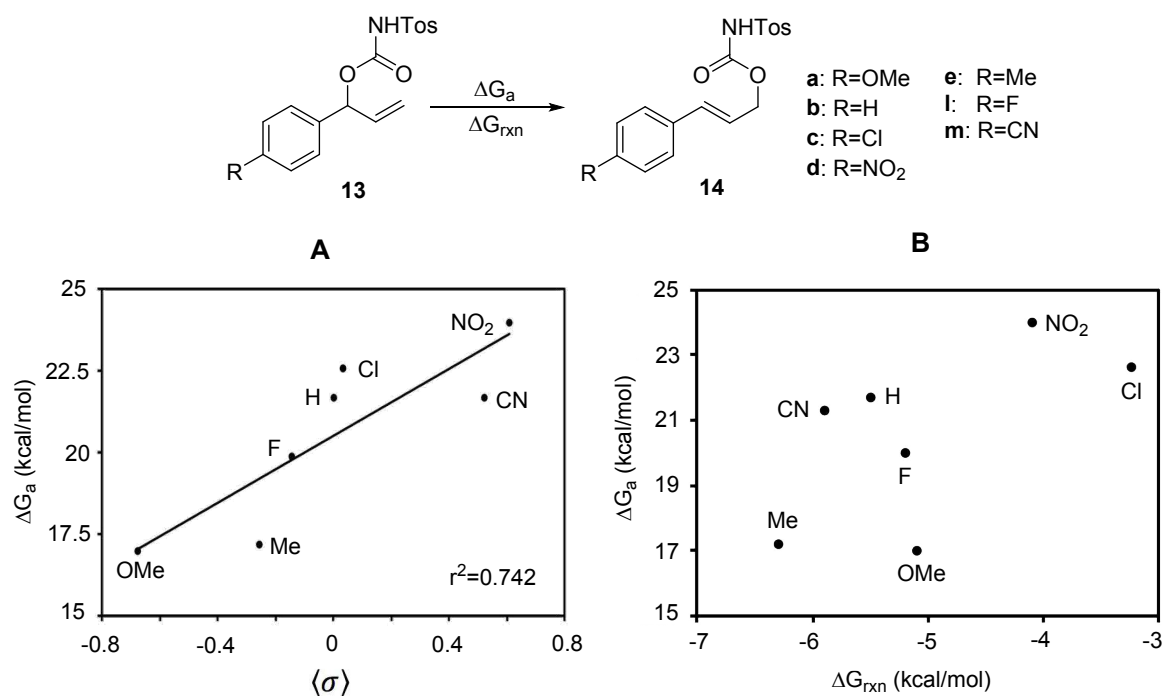


Figure 9. (A) Correlation between the calculated (B3LYP-D3(SCRF, solvent=toluene)/6-311++G(d,p) level of theory) activation energies (ΔG_a) for different *para*-substituents of allyl alcohol derivatives and the composite Hammett parameter $\langle\sigma\rangle$ (see text). (B) Plot of the calculated activation (ΔG_a) and reaction (ΔG_{rxn}) free energies (computed at 363.15 K) for the substituents indicated in (A).

Finally, we explored computationally the conversion of alcohols **17a,b** into carbamates **18ab-bb** (Scheme 5). As a model case, we chose the thermal transformation of (*Z*)-buta-1,3-dien-1-yl formate **29a** into (*E*)- or (*Z*)-**31a** (Figure 10A). From the *s-trans* conformation of (*Z*)-**29a**, the 1,3-dioxa-[3,3]-sigmatropic rearrangement gives rise to

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3 intermediate **30a** via saddle point **TS1a**. This latter intermediate has a novel terminal C=C
4 bond and yields diene (*E*)-**31a** via **TS2a**, which in this model case is identical to **TS1a**. In
5 turn, as we have seen in the previous cases, this model transition structure can adopt chair and
6 boat geometries. Another possibility consists of a degenerate pseudopericyclic reaction^{27,28} —
7 not subjected to the Woodward-Hoffmann²⁹ rules for thermal sigmatropic rearrangements—
8 involving the *s-cis* conformation of (*Z*)-**29a** to yield again (*Z*)-**31a** (Figure 10A). This latter
9 process should occur via C_s -symmetric transition structure **TS3** by through interconversion
10 between C-O σ -bonds, C-C π -bonds and one of the lone pairs of one oxygen of the carboxy
11 group.
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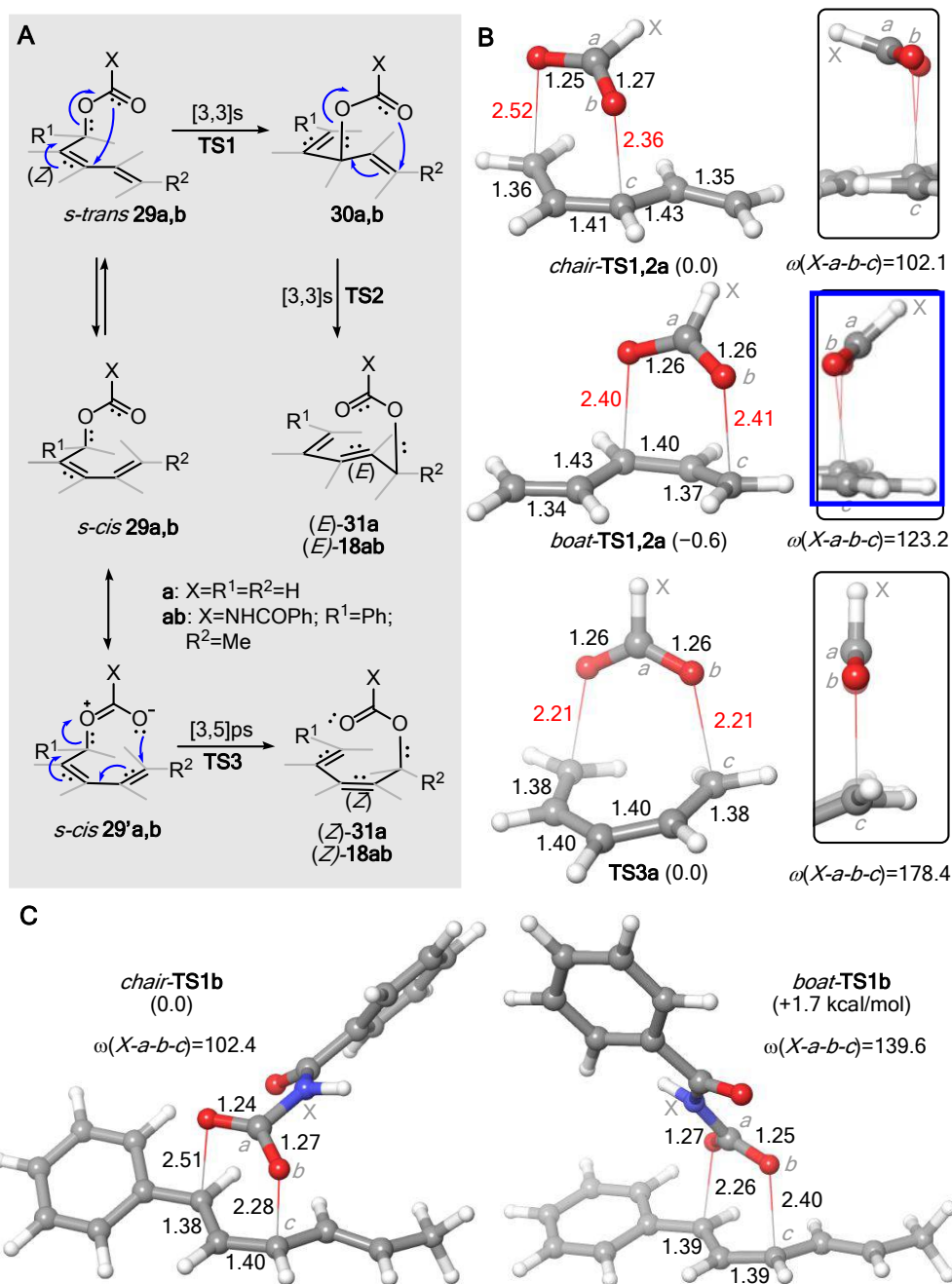


Figure 10. (A) Sequential vs. one-step (3,3) and (3,5) dioxo-rearrangements of model esters (*Z*)-**29a,b** to yield (*E*)- **31a,b** and (*Z*)-**31a,b**. (B) Optimized geometries (B3LYP-D3(PCM=CHCl₃)/6-311++G(d,p) level of theory) and relative energies of transition structures *chair-TS1,2a*, *boat-TS1,2a* and *TS3a*. (C) Chief geometric and energetic features (B3LYP-D3(PCM=CHCl₃)/6-311++G(d,p)/B3LYP/6-31G(d) level of theory) of transition structures *chair-TS1b* and *boat-TS1b*. Bond distances are given in Å. Numbers in parentheses are the relative energies, in kcal/mol. The dihedral angle ω (in deg.) is defined by the *X-a-b-c* atoms.

Our calculations showed that, in effect, *chair-TS12,a*, *boat-TS1,2a* and *TS3a* are practically isoenergetic. In particular, the [3,3] transition structures correspond to pericyclic

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3 supra,supra topologies, as indicated by the corresponding dihedral angles ω (Figure 10B). On
4 the contrary, **TS3a** eludes the geometrically demanding *supra, antara* pericyclic topology by
5 adopting a pseudopericyclic [3,5] geometry reflected by a ω value of ca. 180 deg. Next, we
6 computed the realistic case associated with the conversion of alcohol (*E,Z*)-**17a** into
7 carbamate (*E*)-**18ab** (Scheme 5) through analysis of the (*Z*)-**29b**→(*E/Z*)-**18ab** transformation.
8 In this case, the [3,5] pseudopericyclic mechanism disappeared from the potential energy
9 hypersurface and only the pericyclic [3,3] mechanism survived. In addition, saddle point *boat*-
10 **TS1b** was calculated to lie 1.7 kcal/mol above its congener *chair*-**TS1b** (Figure 10C). These
11 computational permitted us to conclude that, although the pseudopericyclic [3,5] mechanism
12 is conceivable, in this particular case the conversion of (*Z*)-**29b** into (*E*)-**18ab** via two
13 consecutive suprafacial [3,3] processes is the only accessible mechanism. These results agree
14 with the experimental findings summarized in Scheme 5, since a hypothetical
15 pseudopericyclic [3,5] mechanism should preserve the *Z*-stereochemistry of the starting
16 alcohol (*Z*)-**17a**.
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30 CONCLUSIONS

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32 In this paper, we have described a tandem reaction from 1-arylallyl alcohols involving
33 an initial carbamoylation reaction followed by an unexpected metal-free 1,3-dioxa-[3,3]-
34 sigmatropic rearrangement for a non-conventional access to linear allyl carbamates. Scope
35 and limitations of this one-pot process were carried out showing the crucial importance of the
36 electron density from aromatic ring as well as the nature of the isocyanate used. The synthetic
37 interest of this methodology is all greater given that this kind of sigmatropic rearrangement
38 can occur rapidly under mild reaction conditions (room temperature) and with a complete
39 transfer of chiral information.
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46 The mechanism of these [3,3] sigmatropic reactions has been investigated both
47 experimentally and computationally. ¹H-NMR studies show the very fast conversion of
48 starting alcohols **1b,c** to give rise to intermediate tosylcarbamates **13b,c** whose [3,3]
49 sigmatropic rearrangements yielded cinnamyl tosylcarbamates **14b,c** without any noticeable
50 reaction intermediate. The corresponding first-order reaction rates showed a relative reactivity
51 following the order H>Cl. Computational DFT studies showed asynchronous, but concerted,
52 suprafacial processes mediated by chair transition structures, in agreement with the observed
53 stereoselectivities with an enantiopure substrate and NMR experiments with a ¹⁷O labeled
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3 substrate. These latter saddle points reflect correctly the relative reaction rates and activation
4 energies and show a polar character, in which the carboxy moiety bears a significant negative
5 charge.
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8 9 EXPERIMENTAL SECTION

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11 **General Information and Materials.** Tetrahydrofuran (THF) was distilled over
12 sodium/benzophenone and dichloromethane (DCM) was distilled over P₂O₅. All other commercially available
13 chemicals were used without further purification. NMR spectra were recorded at 300, 400 or 500 MHz for ¹H
14 and 75, 101 or 126 MHz for ¹³C. Chemical shifts of ¹H were referenced to Me₄Si as internal reference. Data are
15 represented as follows: chemical shift (ppm), multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, m =
16 multiplet, br s = broad singlet), coupling constant *J* (Hz) and integration. Assignments were done with the aid of
17 DEPT 135, COSY and HSQC experiments. High-resolution mass spectra (HRMS) were recorded on a Micro-
18 Tof-Q II or on a Q-Tof 2 using positive ion electrospray. Purifications on silica gel were carried out on silica gel
19 0.006-0.200 mm, 60 Å. Infrared spectra were recorded on a FT-IR spectrometer equipped with a diamond
20 detection and an ATR unit or a single reflection ATR module; wavenumbers are given in cm⁻¹. Analytical thin
21 layer chromatography was performed on Silica gel 60 F₂₅₄ plates. Optical rotations were measured using 10-cm
22 cell at 22 °C (sodium D-line: 589 nm), and the concentration is expressed in g/dL. Melting points were measured
23 without correction on a digital melting point apparatus. All analytical high-performance liquid chromatography
24 (HPLC) were performed, using Daicel Chiralpak IB column. *1-(Phenyl)prop-2-en-1-ol* (**1b**) is a commercially
25 available compound. The [¹⁷O] labelled H₂O (11.1% H₂¹⁷O, 29.7% H₂¹⁸O and 59.2% H₂¹⁶O) was purchased from
26 Cortecnet. NMR spectra were recorded at 68 MHz for ¹⁷O.
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35 **General procedure for the synthesis of allylic alcohols 1, 5 and 20.** To a solution of
36 aldehyde (1.50 mmol) in THF (10 mL) was slowly added at 0° C a solution of vinyl or phenylmagnesium
37 bromide in THF (1.80 mmol, 1 M). The reaction mixture was stirred at room temperature for 16 hours after
38 which a saturated NH₄Cl solution (5 mL) was added. The aqueous layer was extracted with Et₂O (4 x 10 mL).
39 The organic layers were dried over MgSO₄, filtered and concentrated *in vacuo*. The residue was purified by flash
40 column chromatography on silica gel to afford the corresponding product.
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43 *1-(4-Methoxyphenyl)prop-2-en-1-ol* (**1a**).³⁸ Prepared from 4-methoxybenzaldehyde and vinyl
44 magnesium bromide. Purified using a hexane/ethyl acetate mixture (80/20, *R_f* 0.25) as eluent. The product was
45 isolated as a yellow oil (210 mg) in 85% yield. ¹H NMR (400 MHz, CDCl₃) δ 7.30 (d, *J* = 8.2 Hz, 2H), 6.89 (d,
46 *J* = 8.2 Hz, 2H), 6.05 (ddd, *J* = 17.2, 10.3, 5.9 Hz, 1H), 5.34 (dd, *J* = 17.2, 1.7 Hz, 1H), 5.22–5.12 (m, 2H), 3.81
47 (s, 3H), 1.89–1.86 (br s, 1H).
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50 *1-(4-Chlorophenyl)prop-2-en-1-ol* (**1c**).³⁹ Prepared from 4-chlorobenzaldehyde and vinyl magnesium
51 bromide. Purified using a hexane/ethyl acetate mixture (85/15, *R_f* 0.30) as eluent. The product was isolated as a
52 pale yellow oil (187 mg) in 74% yield. ¹H NMR (300 MHz, CDCl₃): δ 7.33–7.31 (m, 4H), 6.01 (ddd, *J* = 17.0,
53 10.1, 6.1 Hz, 1H), 5.34 (dt, *J* = 17.0, 1.2 Hz, 1H), 5.25–5.15 (m, 2H), 1.95 (d, *J* = 3.7 Hz, 1H).
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56 *1-(4-Nitrophenyl)prop-2-en-1-ol* (**1d**).⁴⁰ Prepared from 4-nitrobenzaldehyde and vinyl magnesium
57 bromide. Purified using a hexane/ethyl acetate mixture (80/20, *R_f* 0.20) as eluent. The product was isolated as an
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orange oil (81 mg) in 30% yield. ^1H NMR (400 MHz, CDCl_3): δ 8.15 (d, $J = 8.7$ Hz, 2H), 7.52 (d, $J = 8.7$ Hz, 2H), 5.96 (ddd, $J = 17.1, 10.2, 6.4$ Hz, 1H), 5.36 (ddd, $J = 17.1, 1.2, 1.2$ Hz, 1H), 5.28 (d, $J = 6.4$ Hz, 1H), 5.23 (ddd, $J = 10.3, 1.1, 1.1$ Hz, 1H), 2.67–2.65 (br s, 1H).

1-(4-Methylphenyl)prop-2-en-1-ol (Ie).⁴¹ Prepared from 4-methylbenzaldehyde and vinyl magnesium bromide. Purified using a hexane/ethyl acetate mixture (80/20, R_f 0.32) as eluent. The product was isolated as a yellow oil (218 mg) in 98% yield. ^1H NMR (400 MHz, CDCl_3): δ 7.26 (d, $J = 7.5$ Hz, 2H), 7.18 (d, $J = 7.5$ Hz, 2H), 6.05 (ddd, $J = 17.1, 10.2, 6.0$ Hz, 1H), 5.35 (d, $J = 17.1$ Hz, 1H), 5.21–5.17 (m, 2H), 2.35 (s, 3H), 1.93 (d, $J = 6.0$ Hz, 1H).

1-(4-Benzyloxyphenyl)prop-2-en-1-ol (If).⁴² Prepared from 4-benzyloxybenzaldehyde and vinyl magnesium bromide. Purified using a hexane/ethyl acetate mixture (75/25, R_f 0.30) as eluent. The product was isolated as a colorless oil (284 mg) in 79% yield. ^1H NMR (400 MHz, CDCl_3): δ 7.48–7.35 (m, 5H), 7.35–7.22 (m, 2H), 6.97 (d, $J = 8.3$ Hz, 2H), 6.05 (ddd, $J = 17.1, 10.3, 5.9$ Hz, 1H), 5.34 (d, $J = 17.1$ Hz, 1H), 5.21–5.15 (m, 2H), 5.07 (s, 2H), 1.86 (d, $J = 3.4$ Hz, 1H).

1-(2-Methoxyphenyl)prop-2-en-1-ol (Ig).⁴³ Prepared from 2-methoxybenzaldehyde and vinyl magnesium bromide. Purified using a hexane/ethyl acetate mixture (85/15, R_f 0.44) as eluent. The product was isolated as a colorless oil (172 mg) in 70% yield. ^1H NMR (400 MHz, CDCl_3): δ 7.32–7.25 (m, 2H), 7.01–6.94 (m, 1H), 6.90 (d, $J = 8.2$ Hz, 1H), 6.14 (ddd, $J = 17.2, 10.4, 5.6$ Hz, 1H), 5.41 (dd, $J = 5.6, 5.6$ Hz, 1H), 5.31 (dd, $J = 17.2, 4.4$ Hz, 1H), 5.17 (dd, $J = 10.4, 4.4$ Hz, 1H), 3.87 (s, 3H), 2.77 (dd, $J = 4.5, 3.8$ Hz, 1H).

1-(2,3-Dihydrobenzofuran-5-yl)prop-2-en-1-ol (Ih).⁴⁴ Prepared from 2,3-dihydrobenzofuran-5-carboxaldehyde and vinyl magnesium bromide. Purified using a hexane/ethyl acetate mixture (80/20, R_f 0.33) as eluent. The product was isolated as a colorless oil (259 mg) in 98% yield. ^1H NMR (400 MHz, CDCl_3): δ 7.32–7.29 (m, 1H), 7.16 (d, $J = 8.2$ Hz, 1H), 6.81 (d, $J = 8.2$ Hz, 1H), 6.10 (ddd, $J = 16.7, 10.3, 5.8$ Hz, 1H), 5.34 (ddd, $J = 17.1, 1.4, 1.4$ Hz, 1H), 5.24 (ddd, $J = 10.4, 1.4, 1.4$ Hz, 1H), 5.19 (d, $J = 5.8$ Hz, 1H), 4.63 (t, $J = 8.7$ Hz, 2H), 3.26 (t, $J = 8.7$ Hz, 2H), 1.92–1.86 (br s, 1H).

1-(3,4-Dimethoxyphenyl)prop-2-en-1-ol (Ii).⁴⁵ Prepared from 3,4-dimethoxybenzaldehyde and vinyl magnesium bromide. Purified using a hexane/ethyl acetate mixture (70/30, R_f 0.27) as eluent. The product was isolated as a pale yellow oil (117 mg) in 40% yield. ^1H NMR (400 MHz, CDCl_3): δ 6.94–6.89 (m, 2H), 6.85 (d, $J = 7.8$ Hz, 1H), 6.05 (ddd, $J = 17.1, 10.4, 5.9$ Hz, 1H), 5.36 (d, $J = 17.1$ Hz, 1H), 5.20 (d, $J = 10.4$ Hz, 1H), 5.17 (d, $J = 5.9$ Hz, 1H), 3.89 (s, 3H), 3.88 (s, 3H), 1.96–1.90 (br s, 1H).

1-(3-(Benzyloxy)-4-methoxyphenyl)prop-2-en-1-ol (Ij). Prepared from 3-benzyloxy-4-methoxybenzaldehyde and vinyl magnesium bromide. Purified using a hexane/ethyl acetate mixture (80/20, R_f 0.21) as eluent. The product was isolated as a pale yellow oil (324 mg) in 80% yield. ^1H NMR (400 MHz, CDCl_3): δ 7.45 (d, $J = 7.5$ Hz, 2H), 7.36 (dd, $J = 7.4, 7.4$ Hz, 2H), 7.31 (d, $J = 7.2$ Hz, 1H), 6.96 (s, 1H), 6.94–6.90 (m, 1H), 6.87 (d, $J = 8.2$ Hz, 1H), 5.99 (ddd, $J = 17.2, 10.3, 5.7$ Hz, 1H), 5.30 (d, $J = 17.2$ Hz, 1H), 5.19–5.16 (m, 1H), 5.14 (s, 2H), 5.12–5.10 (m, 1H), 3.87 (s, 3H), 1.87 (d, $J = 3.8$ Hz, 1H). ^{13}C { ^1H } NMR (101 MHz, CDCl_3): δ 149.1, 148.1, 140.3, 136.9, 135.3, 128.4, 127.7, 127.4, 119.2, 114.6, 112.3 (d, $J = 5.7$ Hz), 111.6 (d, $J = 4.6$ Hz), 74.6, 70.9, 55.9. IR (cm^{-1}) 3488, 3054, 1511, 1263, 1157, 1135, 1021, 730, 698. HRMS (ESI): m/z calcd. for $\text{C}_{17}\text{H}_{19}\text{O}_3$ [$\text{M}+\text{H}$] $^+$ 271.1334; found: 271.1335.

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3 *1-(Benzo[d][1,3]dioxol-5-yl)prop-2-en-1-ol (1k)*.⁴⁶ Prepared from piperonal and vinyl magnesium
4 bromide. Purified using a hexane/ethyl acetate mixture (90/10, R_f 0.17) as eluent. The product was isolated as a
5 colorless oil (203 mg) in 76% yield. ¹H NMR (400 MHz, CDCl₃): δ 6.88 (d, J = 1.6 Hz, 1H), 6.83 (dd, J = 8.0,
6 1.6 Hz, 1H), 6.78 (d, J = 8.0 Hz, 1H), 6.02 (ddd, J = 17.1, 10.3, 5.9 Hz, 1H), 5.95 (s, 2H), 5.34 (ddd, J = 17.1,
7 1.4, 1.4 Hz, 1H), 5.19 (ddd, J = 10.4, 1.4, 1.4 Hz, 1H), 5.13 (m, 1H), 1.88 (d, J = 3.6 Hz, 1H).

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10 *(E)-1-(4-Methoxyphenyl)penta-1,4-dien-3-ol (5a)*. Prepared from *(E)*-3-(4-methoxyphenyl)-2-propenal
11 and vinyl magnesium bromide. Purified using a hexane/ethyl acetate mixture (75/25, R_f 0.24) as eluent. The
12 product was isolated as a yellow oil (242 mg) in 85% yield. ¹H NMR (400 MHz, CDCl₃): δ 7.33 (d, J = 8.7 Hz,
13 2H), 6.85 (d, J = 8.7 Hz, 2H), 6.56 (d, J = 15.9 Hz, 1H), 6.10 (dd, J = 15.9, 6.6 Hz, 1H), 5.98 (ddd, J = 17.2,
14 10.4, 5.8 Hz, 1H), 5.33 (ddd, J = 17.2, 1.4, 1.4 Hz, 1H), 5.19 (ddd, J = 10.5, 1.4, 1.4 Hz, 1H), 4.80–4.78 (m, 1H),
15 3.81 (s, 3H), 1.77–1.73 (br s, 1H). ¹³C{¹H} NMR (101 MHz, CDCl₃): δ 159.5, 139.6, 130.6, 129.5, 128.3, 127.9,
16 115.3, 114.1, 74.1, 55.4. IR (cm⁻¹) 3422, 2837, 1606, 1510, 1247, 1174, 1031, 967, 732, 702. HRMS (ESI): m/z
17 calcd. for C₁₂H₁₃O [M+H-H₂O]⁺ 173.0960; found 173.0963.

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20 *(E)-1-Phenylpenta-1,4-dien-3-ol (5b)*.⁴⁷ Prepared from *(E)*-3-phenyl-2-propenal and vinyl magnesium
21 bromide. Purified using a hexane/ethyl acetate mixture (85/15, R_f 0.23) as eluent. The product was isolated as a
22 pale yellow oil (204 mg) in 85% yield. ¹H NMR (300 MHz, CDCl₃): δ 7.42–7.36 (m, 2H), 7.35–7.30 (m, 1H),
23 7.30–7.20 (m, 2H), 6.62 (d, J = 16.1 Hz, 1H), 6.23 (dd, J = 16.1, 6.4 Hz, 1H), 5.98 (ddd, J = 17.2, 10.4, 5.9 Hz,
24 1H), 5.34 (ddd, J = 17.2, 1.4, 1.4 Hz, 1H), 5.20 (ddd, J = 10.4, 1.3, 1.3 Hz, 1H), 4.89–4.76 (m, 1H), 1.77–1.74
25 (m, 1H).

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28 *(E)-1-(4-Chlorophenyl)penta-1,4-dien-3-ol (5c)*. Prepared from *(E)*-3-(4-chlorophenyl)-2-propenal and
29 vinyl magnesium bromide. Purified using a hexane/ethyl acetate mixture (75/25, R_f 0.35) as eluent. The product
30 was isolated as a pale yellow oil (213 mg) in 73% yield. ¹H NMR (400 MHz, CDCl₃): δ 7.34–7.24 (m, 4H), 6.57
31 (dd, J = 16.0, 1.4 Hz, 1H), 6.21 (dd, J = 16.0, 6.3 Hz, 1H), 5.96 (ddd, J = 17.4, 10.3, 6.0 Hz, 1H), 5.34 (ddd, J =
32 17.4, 1.3, 1.3 Hz, 1H), 5.21 (ddd, J = 10.4, 1.3, 1.3 Hz, 1H), 4.83–4.79 (m, 1H). ¹³C{¹H} NMR (101 MHz,
33 CDCl₃): δ 139.1, 135.1, 133.3, 131.1, 129.4, 128.7, 127.7, 115.5, 73.5. IR (cm⁻¹) 3271, 3086, 1638, 1588, 1488,
34 1085, 1008, 967, 924, 805. HRMS (ESI): m/z calcd. for C₁₁H₁₀Cl [M+H-H₂O]⁺ 177.0467; found 177.0469.

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37 *(E)-1-(4-Nitrophenyl)penta-1,4-dien-3-ol (5d)*.⁴⁸ Prepared from *(E)*-3-(4-nitrophenyl)-2-propenal and
38 vinyl magnesium bromide. Purified using a hexane/ethyl acetate mixture (75/25, R_f 0.24) as eluent. The product
39 was isolated as an orange oil (123 mg) in 40% yield. ¹H NMR (400 MHz, CDCl₃): δ 8.21–8.16 (m, 2H), 7.56–
40 7.47 (m, 2H), 6.71 (d, J = 16.9 Hz, 1H), 6.42 (dd, J = 16.9, 5.8 Hz, 1H), 5.97 (ddd, J = 17.1, 10.3, 6.1 Hz, 1H),
41 5.38 (ddd, J = 17.1, 1.2, 1.2 Hz, 1H), 5.25 (ddd, J = 10.3, 1.2, 1.2 Hz, 1H), 4.93–4.82 (m, 1H), 1.83 (d, J = 4.2
42 Hz, 1H).

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45 *Racemic (E)-1-phenylbut-2-enol (20)*. Prepared from *(E)*-crotonaldehyde and phenylmagnesium
46 bromide. Purified using a hexane/ethyl acetate mixture (80/20, R_f 0.25) as eluent. The product was isolated as a
47 yellow oil (190 mg) in 85% yield. ¹H NMR (400 MHz, CDCl₃): δ 7.40–7.32 (m, 4H), 7.31–7.27 (m, 1H), 5.84–
48 5.63 (m, 2H), 5.16 (d, J = 6.4 Hz, 1H), 1.72 (d, J = 5.9 Hz, 3H), 1.61 (d, J = 3.4 Hz, 1H). The separation of
49 enantiomers was carried out using a Daicel Chiralpak IB, hexane/*i*-PrOH = 99/1, flow rate = 1 mL/min, 220 nm,
50 the (*R,E*) enantiomer **20** t_R = 24 min (ee >99%, $[\alpha]_D$ = -16.9 (c 0.95, CHCl₃)), the (*S,E*) enantiomer **20** t_R = 28 min
51 (ee 98%, $[\alpha]_D$ = +24.6 (c 0.65, CHCl₃)).⁴⁹

General procedure for the synthesis of allylic carbamates **3, **6**, **4**, **7**, **13**, **14**, **15**, **16**, **18**, **22**.**

Using trichloroacetyl isocyanate. A solution of allylic alcohol **1** or **5** (0.3 mmol) in anhydrous toluene CHCl₃ or CH₂Cl₂ (0.2 M) under argon atmosphere was cooled to 0 °C and trichloroacetyl isocyanate (0.36 mmol) was added slowly. The reaction mixture was stirred during the time and temperature indicated in Table 1 and 2. Solvent was removed *in vacuo* and in some cases, intermediates have been identified.

(E)-3-(4-methoxyphenyl)allyl (2,2,2-trichloroacetyl)carbamate (**3a**). Prepared from allylic alcohol **1a** (rt, 0.25 h). The product was isolated as a colorless oil (103 mg) in 98% yield and used in the next step without further purification. ¹H NMR (300 MHz, CDCl₃): δ 8.50–8.46 (br s, 1H), 7.34 (d, *J* = 8.7 Hz, 2H), 6.86 (d, *J* = 8.7 Hz, 2H), 6.69 (d, *J* = 15.8 Hz, 1H), 6.17 (dt, *J* = 15.7, 6.9 Hz, 1H), 4.88 (dd, *J* = 6.9, 1.2 Hz, 2H), 3.81 (s, 3H). ¹³C{¹H} NMR (75 MHz, CDCl₃) δ 159.9, 157.9, 149.8, 136.2, 128.1, 118.9, 114.1, 91.8, 68.3, 55.3.

(2E,4E)-5-phenylpenta-2,4-dien-1-yl (2,2,2-trichloroacetyl)carbamate (**6b**). Prepared from allylic alcohol **5b** (rt, 4 h). The product was isolated as a white solid (102 mg) in 98% yield and used in the next step without further purification; mp 101–104 °C. ¹H NMR (300 MHz, CDCl₃) δ 8.50–8.45 (br s, 1H), 7.42–7.36 (m, 2H), 7.35–7.28 (m, 2H), 7.27–7.21 (m, 1H), 6.76 (dd, *J* = 15.6, 10.2 Hz, 1H), 6.62 (d, *J* = 15.6 Hz, 1H), 6.53 (ddd, *J* = 15.1, 1.1, 1.1 Hz, 1H), 5.88 (dt, *J* = 15.1, 6.9 Hz, 1H), 4.83 (dd, *J* = 6.9, 1.1 Hz, 2H). ¹³C{¹H} NMR (75 MHz, CDCl₃) δ 157.8, 149.7, 136.7, 135.1, 128.7, 128.2, 127.2, 126.7, 124.7, 91.8, 67.7.

To the resulting mixture or pure compound **3** or **6**, K₂CO₃ (1.2 mmol) in a mixture of MeOH (1.6 mL) and water (0.4 mL) was added. The solution was stirred at room temperature overnight and then MeOH was removed *in vacuo*. The aqueous layer was extracted with CH₂Cl₂ (4 x 1 mL). The organic layers were dried over MgSO₄, filtered and concentrated *in vacuo*. The residue was purified by flash column chromatography on silica gel to afford the corresponding product.

(E)-3-(4-Methoxyphenyl)allyl carbamate (**4a**). Prepared from **3a**. Purified using a hexane/ethyl acetate mixture (70/30, *R_f* 0.31) as eluent. The product was isolated as a white solid (45 mg) in 73% yield from **1a**. mp 131–134 °C. ¹H NMR (400 MHz, acetone-*d*₆) δ 7.35 (d, *J* = 8.8 Hz, 2H), 6.86 (d, *J* = 8.8 Hz, 2H), 6.57 (d, *J* = 15.9 Hz, 1H), 6.17 (dt, *J* = 15.9, 6.3 Hz, 1H), 5.9–05.84 (br s, 2H), 4.57 (dd, *J* = 6.3, 1.5 Hz, 2H), 3.75 (s, 3H). ¹³C{¹H} NMR (126 MHz, CD₃OD) δ 161.0, 159.8, 134.1, 130.5, 128.8, 122.7, 115.0, 66.4, 55.7. IR (cm⁻¹) 3423, 3329, 3263, 3203, 2954, 2834, 1682, 1603, 1509, 1244, 1028, 510. HRMS (ESI): *m/z* calcd. for C₁₁H₁₃NO₃Na [M+Na]⁺ 230.0793; found 230.0789.

(E)-3-(phenyl)allyl carbamate (**4b**).^{14d} Prepared from the commercially available 1-(Phenyl)prop-2-en-1-ol (90 °C, 16 h). Purified using a hexane/ethyl acetate mixture (70/30, *R_f* 0.28) as eluent. The product was isolated as a white solid (49 mg) in 92% yield. mp 116–119 °C. ¹H NMR (400 MHz, CDCl₃) δ 7.37 (d, *J* = 7.1 Hz, 2H), 7.33–7.27 (m, 2H), 7.27–7.21 (m, 1H), 6.63 (d, *J* = 15.9 Hz, 1H), 6.27 (dt, *J* = 15.9, 6.3 Hz, 1H), 5.01–4.92 (br s, 2H), 4.70 (dd, *J* = 6.3, 1.4 Hz, 2H). ¹³C{¹H} NMR (126 MHz, CDCl₃) δ 156.9, 136.4, 133.9, 128.7, 128.1, 126.7, 123.7, 65.8. HRMS (ESI): *m/z* calcd. for C₁₀H₁₁NO₂Na [M+Na]⁺ 200.0687; found 200.0686.

(E)-3-(4-Chlorophenyl)allyl carbamate (**4c**).^{15c} Prepared from allylic alcohol **1c** (90 °C, 20 h). Purified using a hexane/ethyl acetate mixture (70/30, *R_f* 0.27) as eluent. The product was isolated as a white solid (32 mg)

in 50% yield. ¹H NMR (400 MHz, CDCl₃) δ 7.32–7.28 (m, 4H), 6.60 (d, *J* = 15.9 Hz, 1H), 6.26 (dt, *J* = 15.9, 6.3 Hz, 1H), 4.78–4.74 (br s, 2H), 4.72 (dd, *J* = 6.3, 1.4 Hz, 2H).

(*E*)-3-(4-Nitrophenyl)allyl carbamate (**4d**).^{15c} Prepared from allylic alcohol **1d** (90 °C, 120 h). Purified using a hexane/ethyl acetate mixture (70/30, *R_f* 0.10) as eluent. The product was isolated as a yellow solid (28 mg) in 43% yield. ¹H NMR (400 MHz, CDCl₃) δ 8.19 (d, *J* = 8.5 Hz, 2H), 7.52 (d, *J* = 8.5 Hz, 2H), 6.71 (d, *J* = 16.0 Hz, 1H), 6.46 (dt, *J* = 16.0, 5.8 Hz, 1H), 4.78 (dd, *J* = 5.8, 1.5 Hz, 2H), 4.73–4.66 (br s, 2H).

(2*E*,4*E*)-5-(4-methoxyphenyl)penta-2,4-dien-1-yl carbamate (**7a**). Prepared from allylic alcohol **5a** (rt, 2 h). Purified using a hexane/ethyl acetate mixture (65/35, *R_f* 0.29) as eluent. The product was isolated as a pale yellow solid (17 mg) in 24% yield. mp 150–153 °C. ¹H NMR (400 MHz, CDCl₃) δ 7.33 (d, *J* = 8.7 Hz, 2H), 6.85 (d, *J* = 8.7 Hz, 2H), 6.65 (dd, *J* = 15.6, 10.3 Hz, 1H), 6.53 (d, *J* = 15.6 Hz, 1H), 6.43 (dd, *J* = 15.2, 10.2 Hz, 1H), 5.83 (dt, *J* = 15.1, 6.6 Hz, 1H), 4.71–4.67 (br s, 2H), 4.64 (dd, *J* = 6.6, 1.3 Hz, 2H), 3.81 (s, 3H). ¹³C{¹H} NMR (101 MHz, CDCl₃) δ 159.6, 156.8, 134.9, 133.5, 129.9, 127.9, 126.2, 125.9, 114.36, 65.7, 55.5. IR (cm⁻¹) 3436, 3394, 3331, 3269, 3216, 3014, 2955, 1685, 1600, 1508, 1418, 1351, 1246, 1028, 988, 820, 552, 522. HRMS (ESI): *m/z* calcd. for C₁₃H₁₅NO₃Na [M+Na]⁺ 256.0950; found 256.0953.

(2*E*,4*E*)-5-phenylpenta-2,4-dien-1-yl carbamate (**7b**).^{20b} Prepared from **6b**. Purified using a hexane/ethyl acetate mixture (70/30, *R_f* 0.27) as eluent. The product was isolated as a yellow solid (40 mg) in 65% yield from **5b**. ¹H NMR (400 MHz, CDCl₃) δ 7.45–7.37 (m, 2H), 7.37–7.29 (m, 2H), 7.29–7.22 (m, 1H), 6.78 (dd, *J* = 15.8, 10.4 Hz, 1H), 6.59 (d, *J* = 15.8 Hz, 1H), 6.46 (dd, *J* = 15.3, 10.4 Hz, 1H), 5.89 (dt, *J* = 15.3, 6.4 Hz, 1H), 4.77–4.68 (br s, 2H), 4.66 (dd, *J* = 6.6, 1.5 Hz, 2H).

(2*E*,4*E*)-5-(4-Chlorophenyl)penta-2,4-dien-1-yl carbamate (**7c**). Prepared from allylic alcohol **5c** (rt, 4 h). Purified using a hexane/ethyl acetate mixture (70/30, *R_f* 0.27) as eluent. The product was isolated as a pale yellow solid (53 mg) in 75% yield. mp 167–170 °C. ¹H NMR (400 MHz, CDCl₃) δ 7.36–7.24 (m, 4H), 6.74 (dd, *J* = 15.8, 10.4 Hz, 1H), 6.53 (d, *J* = 15.7 Hz, 1H), 6.44 (dd, *J* = 15.2, 10.5 Hz, 1H), 5.90 (dt, *J* = 15.2, 6.4 Hz, 1H), 4.66 (dd, *J* = 6.4, 1.5 Hz, 2H), 4.63–4.58 (br s, 2H). ¹³C{¹H} NMR (126 MHz, CD₃OD) δ 159.7, 137.3, 134.4, 134.2, 132.9, 130.0, 129.9, 129.8, 128.9, 65.8. IR (cm⁻¹) 3410, 3348, 3286, 3210, 3028, 2955, 1644, 1486, 1421, 1348, 1318, 1053, 986, 827, 508. HRMS (ESI): *m/z* calcd. for C₁₂H₁₂ClNO₂Na [M+Na]⁺ 260.0454; found 260.0457.

Using *p*-toluenesulfonyl isocyanate. To a solution of allylic alcohol **1**, **5** or **17** (0.3 mmol) in chloroform, dichloromethane or toluene (0.2 M) under argon atmosphere, *p*-toluenesulfonylisocyanate (0.36 mmol) was added dropwise and the mixture was stirred at room temperature or warmed at 90 °C during the time indicated in Table 3, Table 4 and Scheme 5. The conversion of the reaction can be followed by ¹H NMR using deuterated solvent. The resulting mixture was concentrated in *vacuo* and the product was purified by flash column chromatography on silica gel to afford the desired product.

1-phenylallyl tosylcarbamate (**13b**).^{5c} Prepared from **1b** (rt, 5 min) and purified using a hexane/ethyl acetate mixture (80/20, *R_f* 0.31) as eluent. The product was isolated as a colorless oil (91 mg) in 92% yield. ¹H NMR (400 MHz, CDCl₃) δ 7.88 (d, *J* = 8.3 Hz, 2H), 7.55–7.53 (br s, 1H), 7.34–7.26 (m, 5H), 7.21 (dd, *J* = 6.8, 3.0 Hz, 2H), 6.11 (dd, *J* = 6.0, 1.5 Hz, 1H), 5.92 (ddd, *J* = 16.7, 10.5, 5.9 Hz, 1H), 5.27–5.23 (m, 2H), 2.43 (s, 3H). ¹³C{¹H} NMR (101 MHz, CDCl₃) δ 149.6, 145.2, 137.5, 135.1, 129.7, 128.7, 128.5, 127.3, 118.2, 79.4, 21.8; HRMS (ESI): *m/z* calcd. for C₁₇H₁₇NO₄SK [M+K]⁺: 370.0515; found: 370.0514.

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1-(4-chlorophenyl)allyl tosylcarbamate (13c). Prepared from **1c** (rt, 5 min) and purified using a hexane/ethyl acetate mixture (80/20, R_f 0.30) as eluent. The product was isolated as a colorless oil (93 mg) in 85% yield. ^1H NMR (400 MHz, CDCl_3) δ 7.86 (d, $J = 8.5$ Hz, 2H), 7.70–7.67 (br s, 1H), 7.33–7.23 (m, 4H), 7.14 (d, $J = 8.5$ Hz, 2H), 6.07 (d, $J = 5.9$ Hz, 1H), 5.87 (ddd, $J = 16.7, 10.8, 5.9$ Hz, 1H), 5.27–5.23 (m, 2H), 2.44 (s, 3H). $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3) δ 149.6, 145.3, 136.1, 135.6, 134.6, 129.8, 128.9, 128.7, 128.5, 118.6, 78.5, 21.8. IR (cm^{-1}) 3301, 2997, 1725, 1448, 1435, 1155, 1088, 906, 728, 664, 647, 547. HRMS (ESI): m/z calcd. for $\text{C}_{17}\text{H}_{16}\text{ClNO}_4\text{SNa}$ $[\text{M}+\text{Na}]^+$: 388.0381; found: 388.0380.

1-(4-nitrophenyl)allyl tosylcarbamate (13d). Prepared from **1d** (rt, 5 min) and purified using a hexane/ethyl acetate mixture (60/40, R_f 0.31) as eluent. The product was isolated as a yellow oil (101 mg) in 90% yield. ^1H NMR (400 MHz, CDCl_3) δ 8.14 (d, $J = 8.5$ Hz, 2H), 7.88 (d, $J = 8.1$ Hz, 2H), 7.37 (d, $J = 8.5$ Hz, 2H), 7.31 (d, $J = 8.1$ Hz, 2H), 6.16 (d, $J = 6.1$ Hz, 1H), 5.85 (ddd, $J = 16.8, 10.5, 6.1$ Hz, 1H), 5.33–5.24 (m, 2H), 2.44 (s, 3H). $^{13}\text{C}\{^1\text{H}\}$ NMR (126 MHz, CDCl_3) δ 149.5, 147.9, 145.5, 144.7, 135.5, 133.9, 129.8, 128.4, 127.8, 123.9, 119.7, 77.9, 21.8. IR (cm^{-1}) 3236, 3112, 2858, 1748, 1520, 1444, 1345, 1221, 1158, 1098, 853, 665, 548. HRMS (ESI) m/z calcd. for $\text{C}_{17}\text{H}_{20}\text{N}_3\text{O}_6\text{S}$ $[\text{M}+\text{NH}_4]^+$: 394.1073; found: 394.1070.

(E)-3-(4-Methoxyphenyl)allyl tosylcarbamate (14a). Prepared from **1a** (rt, 15 min.) and purified using a hexane/ethyl acetate mixture (70/30, R_f 0.23) as eluent. The product was isolated as a colorless oil (98 mg) in 90% yield. NMR spectra of **14a** in CDCl_3 at 298K revealed the presence of two conformers (rotamers) in a ratio (55/45). ^1H NMR (400 MHz, CDCl_3) δ 7.93 (d, $J = 8.5$ Hz, 1.1H), 7.81 (d, $J = 8.6$ Hz, 0.9H), 7.37–7.28 (m, 4H), 6.85 (d, $J = 4.7$ Hz, 2H), 6.53 (d, $J = 15.9$ Hz, 1H), 6.01 (dt, $J = 15.9, 6.6$ Hz, 1H), 4.77–4.75 (br s, 1H), 4.69 (dd, $J = 6.6, 1.3$ Hz, 2H), 3.81 (s, 3H), 2.43 (s, 1.65H), 2.42 (s, 1.35H). $^{13}\text{C}\{^1\text{H}\}$ NMR (126 MHz, CDCl_3) δ 159.9, 150.6, 145.1, 143.6, 139.2, 135.6, 135.3, 129.8, 129.7, 128.6, 128.5, 128.1, 126.5, 119.4, 114.2, 67.8, 55.4, 21.8, 21.6. IR (cm^{-1}) 3356, 3259, 2959, 1744, 1606, 1510, 1442, 1300, 1245, 1153, 1088, 812, 660, 545, 532. HRMS (ESI): m/z calcd. for $\text{C}_{18}\text{H}_{23}\text{N}_2\text{O}_5\text{S}$ $[\text{M}+\text{NH}_4]^+$ 379.1328; found 379.1324.

(E)-3-(phenyl)allyl tosylcarbamate (14b).⁵⁰ Prepared from **1b** (90 °C, 6 h) and purified using a hexane/ethyl acetate mixture (60/40, R_f 0.39) as eluent. The product was isolated as a white solid (94 mg) in 95% yield. mp 73–76 °C. NMR spectra of **14b** in CDCl_3 at 298K revealed the presence of two conformers (rotamers) in a ratio (75/25). ^1H NMR (400 MHz, CDCl_3) δ 7.97–7.90 (m, 1.5H), 7.82 (m, 0.5H), 7.37–7.25 (m, 7H), 6.58 (d, $J = 15.8$ Hz, 1H), 6.14 (dt, $J = 15.9, 6.6$ Hz, 1H), 4.72 (dd, $J = 6.6, 1.3$ Hz, 2H), 2.43 (s, 0.75H), 2.42 (s, 2.25H). $^{13}\text{C}\{^1\text{H}\}$ NMR (126 MHz, CDCl_3): δ 150.7, 145.1, 143.5, 139.2, 135.8, 135.5, 135.2, 129.7, 129.6, 128.7, 128.4, 128.3, 126.7, 126.4, 121.7, 67.3, 21.7, 21.5. HRMS (ESI): m/z calcd. for $\text{C}_{17}\text{H}_{21}\text{N}_2\text{O}_4\text{S}$ $[\text{M}+\text{NH}_4]^+$ 349.1222; found 349.1222.

(E)-3-(4-Chlorophenyl)allyl tosylcarbamate (14c). Prepared from **1c** (90 °C, 20 h) and purified using a hexane/ethyl acetate mixture (65/35, R_f 0.26) as eluent. The product was isolated as a white solid (77 mg) in 70% yield. mp 86–87 °C. NMR spectra of **14c** in CDCl_3 at 298K revealed the presence of two conformers (rotamers) in a ratio (60/40). ^1H NMR (400 MHz, CDCl_3) δ 7.93 (d, $J = 8.1$ Hz, 1.2H), 7.82 (d, $J = 8.1$ Hz, 0.8H), 7.37–7.22 (m, 6H), 6.53 (d, $J = 15.9$ Hz, 1H), 6.12 (dt, $J = 16.0, 6.6$ Hz, 1H), 4.83–4.81 (br s, 1H), 4.71 (dd, $J = 6.6, 1.3$ Hz, 2H), 2.43 (s, 1.8H), 2.42 (s, 1.2H). $^{13}\text{C}\{^1\text{H}\}$ NMR (126 MHz, CDCl_3): δ 150.6, 145.2, 143.7, 139.2, 134.4, 134.1, 133.9, 129.8, 129.7, 129.6, 128.9, 128.5, 128.3, 127.9, 126.5, 122.5, 67.1, 21.8. IR (cm^{-1}) 3355,

3259, 3086, 2849, 1737, 1304, 1285, 1160, 1080, 969, 813, 658, 583, 533. HRMS (ESI): m/z calcd. for $C_{17}H_{20}ClN_2O_4S$ $[M+NH_4]^+$ 383.0832; found 383.0829.

(*E*)-3-(4-Nitrophenyl)allyl tosylcarbamate (**14d**). Prepared from **1d** (90 °C, 4 days, 70% conversion) and purified using a hexane/ethyl acetate mixture (80/20, R_f 0.15) as eluent. The product was isolated as a yellow oil (45 mg) in 40% yield. NMR spectra of **14d** in $CDCl_3$ at 298K revealed the presence of two conformers (rotamers) in a ratio (99/1). 1H NMR (400 MHz, $CDCl_3$) δ 8.18 (d, J = 8.5 Hz, 2H), 7.94 (d, J = 8.1 Hz, 2H), 7.47 (d, J = 8.5 Hz, 2H), 7.34 (d, J = 8.1 Hz, 2H), 6.64 (d, J = 16.0 Hz, 1H), 6.34 (dt, J = 16.0, 6.2 Hz, 1H), 4.77 (dd, J = 6.2, 1.4 Hz, 2H), 2.43 (s, 3H). $^{13}C\{^1H\}$ NMR (101 MHz, $CDCl_3$) δ 145.4, 142.3, 135.5, 132.41, 129.8, 128.6, 127.4, 126.8, 124.2, 66.6, 21.9. IR (cm^{-1}) 3450, 2996, 2950, 1723, 1448, 1434, 1272, 1241, 1190, 1148, 907, 727, 641. HRMS (ESI): m/z calcd. for $C_{17}H_{20}N_3O_6S$ $[M+NH_4]^+$: 394.1067; found: 394.1067.

(*E*)-3-(4-methylphenyl)allyl tosylcarbamate (**14e**). Prepared from **1e** (90 °C, 6 h) and purified using a hexane/ethyl acetate mixture (70/30, R_f 0.26) as eluent. The product was isolated as a white solid (72 mg) in 70% yield. mp 82–85 °C. NMR spectra of **14e** in $CDCl_3$ at 298K revealed the presence of two conformers (rotamers) in a ratio (65/35). 1H NMR (400 MHz, $CDCl_3$) δ 7.93 (d, J = 8.1 Hz, 1.3 H), 7.82 (d, J = 8.1 Hz, 0.7H), 7.32 (d, J = 7.9 Hz, 2H), 7.23 (d, J = 8.1 Hz, 2H), 7.13 (d, J = 7.9 Hz, 2H), 6.55 (d, J = 15.8 Hz, 1H), 6.09 (dt, J = 15.8, 6.7 Hz, 1H), 4.73–4.69 (br s, 1H), 4.71 (dd, J = 6.7, 1.2 Hz, 2H), 2.43 (s, 1.05H), 2.42 (s, 1.95H), 2.34 (s, 3H). $^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$) δ 150.7, 145.1, 143.6, 139.2, 138.4, 135.4, 133.1, 129.8, 129.7, 129.4, 128.4, 126.7, 126.5, 120.7, 67.6, 21.7, 21.6, 21.3. IR (cm^{-1}) 3354, 3229, 3048, 2948, 1754, 1596, 1436, 1344, 1219, 1147, 1088, 970, 875, 665, 582, 544. HRMS (ESI): m/z calcd. for $C_{18}H_{23}N_2O_4S$ $[M+NH_4]^+$ 363.1379; found 363.1378.

(*E*)-3-(4-(benzyloxy)phenyl)allyl tosylcarbamate (**14f**). Prepared from **1f** (rt, 15 min.) and purified using a hexane/ethyl acetate mixture (65/35, R_f 0.38) as eluent. The product was isolated as a white solid (97 mg) in 74% yield. mp 106–109 °C. NMR spectra of **14f** in $CDCl_3$ at 298K revealed the presence of two conformers (rotamers) in a ratio (65/35). 1H NMR (400 MHz, $CDCl_3$) δ 7.97–7.88 (d, J = 8.4 Hz, 1.3H), 7.86–7.78 (d, J = 8.4 Hz, 0.7H), 7.50–7.25 (m, 9H), 6.97–6.86 (d, J = 8.4 Hz, 2H), 6.53 (d, J = 15.8 Hz, 1H), 6.01 (dt, J = 15.8, 6.8 Hz, 1H), 5.07 (s, 2H), 4.76–4.73 (br s, 1H), 4.69 (dd, J = 6.9, 1.3 Hz, 2H), 2.43 (s, 1.05H), 2.42 (s, 1.95H). $^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$) δ 159.1, 150.6, 145.2, 143.6, 139.2, 136.8, 135.6, 135.2, 129.8, 129.7, 128.9, 128.7, 128.5, 128.2, 128.1, 127.6, 126.5, 119.6, 115.1, 70.1, 67.7, 21.76, 21.62. IR (cm^{-1}) 3356, 3250, 2950, 2869, 1738, 1605, 1512, 1433, 1300, 1153, 1064, 813, 660, 530. HRMS (ESI): m/z calcd. for $C_{24}H_{27}N_2O_5S$ $[M+NH_4]^+$ 455.1641; found 455.1643.

(*E*)-3-(2-methoxyphenyl)allyl tosylcarbamate (**14g**). Prepared from **1g** (rt, 16 h) and purified using a hexane/ethyl acetate mixture (70/30 R_f 0.24) as eluent. The product was isolated as a yellow oil (92 mg) in 85% yield. NMR spectra of **14g** in $CDCl_3$ at 298K revealed the presence of two conformers (rotamers) in a ratio (65/35). 1H NMR (400 MHz, $CDCl_3$) δ 7.92 (d, J = 8.1 Hz, 1.3H), 7.81 (d, J = 8.1 Hz, 0.7H), 7.34–7.22 (m, 4H), 6.94–6.84 (m, 2H), 6.16 (dt, J = 16.0, 6.6 Hz, 1H), 5.25–5.20 (br s, 1H), 4.70 (dd, J = 6.6, 1.3 Hz, 2H), 3.82 (s, 3H), 2.40 (s, 1.05H), 2.39 (s, 1.95H). $^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$) δ 157.0, 150.6, 145.1, 143.5, 139.3, 135.6, 130.6, 129.8, 129.7, 129.5, 128.5, 127.3, 126.5, 124.9, 122.3, 120.7, 111.0, 68.0, 55.5, 21.7, 21.6. IR (cm^{-1}) 3355, 2946, 1744, 1596, 1488, 1437, 1343, 1242, 1152, 1067, 868, 812, 751, 659, 576, 544. HRMS (ESI): m/z calcd. for $C_{18}H_{23}N_2O_5S$ $[M+NH_4]^+$ 379.1328; found 379.1325.

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(E)-3-(2,3-dihydrobenzofuran-5-yl)allyl tosylcarbamate (**14h**). Prepared from **1h** (rt, 1 h) and purified using a hexane/ethyl acetate mixture (60/40 R_f 0.30) as eluent. The product was isolated as a colorless oil (40 mg) in 36% yield. NMR spectra of **14h** in CDCl₃ at 298K revealed the presence of two conformers (rotamers) in a ratio (99/1). ¹H NMR (400 MHz, CDCl₃) δ 7.97–7.88 (m, 2H), 7.31 (m, 2H), 7.22–7.19 (m, 1H), 7.07 (dd, J = 8.2, 1.9 Hz, 1H), 6.72 (d, J = 8.2 Hz, 1H), 6.52 (d, J = 15.7 Hz, 1H), 5.98 (dt, J = 15.7, 6.8 Hz, 1H), 4.68 (dd, J = 6.8, 1.2 Hz, 2H), 4.58 (t, J = 8.7 Hz, 2H), 3.19 (t, J = 8.7 Hz, 2H), 2.42 (s, 3H). ¹³C{¹H} NMR (101 MHz, CDCl₃) δ 160.6, 150.5, 145.2, 135.9, 135.6, 129.7, 128.6, 127.5, 123.2, 118.7, 109.5, 71.7, 67.9, 29.6, 21.8. IR (cm⁻¹) 3374, 3280, 3054, 1746, 1599, 1491, 1264, 1161, 731, 702, 546. HRMS (ESI): m/z calcd. for C₁₉H₁₉NO₅SNa [M+Na]⁺ 396.0882; found 396.0881.

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(E)-3-(3,4-dimethoxyphenyl)allyl tosylcarbamate (**14i**). Prepared from **1i** (rt, 45 min.) and purified using a hexane/ethyl acetate mixture (60/40 R_f 0.20) as eluent. The product was isolated as a colorless oil (38 mg) in 32% yield. NMR spectra of **14i** in CDCl₃ at 298K revealed the presence of two conformers (rotamers) in a ratio (99/1). ¹H NMR (400 MHz, CDCl₃) δ 7.96–7.89 (m, 2H), 7.29 (d, J = 8.0 Hz, 2H), 6.90–6.84 (m, 2H), 6.79 (d, J = 8.1 Hz, 1H), 6.51 (d, J = 15.8 Hz, 1H), 6.02 (dt, J = 15.8, 6.7 Hz, 1H), 4.69 (dd, J = 6.7, 0.9 Hz, 2H), 3.86 (s, 6H), 2.39 (s, 3H). ¹³C{¹H} NMR (126 MHz, CDCl₃) δ 150.6, 149.5, 149.1, 145.1, 135.6, 135.5, 129.7, 128.9, 128.57, 120.3, 119.7, 111.1, 108.9, 67.6, 56.0, 55.9, 21.7. IR (cm⁻¹) 3254, 3057, 2957, 2936, 1746, 1597, 1513, 1451, 1343, 1263, 1158, 1089, 1024, 732, 510. HRMS (ESI): m/z calcd. for C₁₉H₂₅N₂O₆S [M+NH₄]⁺ 409.1433; found 409.1431.

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(E)-3-(3-(benzyloxy)-4-methoxyphenyl)allyl tosylcarbamate (**14j**). Prepared from **1j** (rt, 45 min.) and purified using a hexane/ethyl acetate mixture (60/40 R_f 0.33) as eluent. The product was isolated as a yellow oil (76 mg) in 54% yield. NMR spectra of **14j** in CDCl₃ at 298K revealed the presence of two conformers (rotamers) in a ratio (90/10). ¹H NMR (400 MHz, CDCl₃) δ 7.95–7.89 (d, J = 8.3 Hz, 1.8H), 7.80 (d, J = 8.3 Hz, 0.2H), 7.44 (d, J = 7.1 Hz, 2H), 7.40–7.30 (m, 5H), 6.95–6.83 (m, 3H), 6.47 (d, J = 15.7 Hz, 1H), 5.95 (dt, J = 15.7, 6.7 Hz, 1H), 5.13 (s, 2H), 4.67 (dd, J = 6.7, 1.3 Hz, 2H), 3.88 (s, 3H), 2.42 (s, 0.3H), 2.40 (s, 2.7H). ¹³C{¹H} NMR (101 MHz, CDCl₃) δ 150.4, 150.3, 148.4, 145.2, 137.1, 135.6, 129.73, 128.90, 128.71, 128.6, 128.1, 127.5, 120.8, 119.6, 112.2, 111.8, 71.3, 67.7, 56.2, 21.8. IR (cm⁻¹) 3258, 2958, 2930, 1744, 1596, 1510, 1440, 1257, 1155, 1135, 1016, 660, 545. HRMS (ESI): m/z calcd. for C₂₅H₂₉N₂O₆S [M+NH₄]⁺ 485.1746; found 485.1745.

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(E)-3-(benzo[d][1,3]dioxol-5-yl)allyl tosylcarbamate (**14k**). Prepared from **1k** (rt, 3 h) and purified using a hexane/ethyl acetate mixture (65/35 R_f 0.27) as eluent. The product was isolated as a white solid (95 mg) in 84% yield. mp 89–91 °C. NMR spectra of **14k** in CDCl₃ at 298K revealed the presence of two conformers (rotamers) in a ratio (90/10). ¹H NMR (400 MHz, CDCl₃) δ 7.92 (d, J = 8.1 Hz, 1.6H), 7.81 (d, J = 8.1 Hz, 0.4H), 7.33–7.29 (m, 2H), 6.84 (s, 1H), 6.75 (d, J = 2.2 Hz, 2H), 6.47 (d, J = 15.8 Hz, 1H), 6.04–5.88 (m, 3H), 5.05–5.00 (br s, 1H), 4.68 (dd, J = 6.9, 1.3 Hz, 2H), 2.41 (s, 3H). ¹³C{¹H} NMR (101 MHz, CDCl₃) δ 150.6, 148.2, 147.9, 145.2, 135.6, 135.3, 130.3, 129.7, 128.5, 126.5, 121.8, 119.9, 108.4, 105.9, 101.3, 67.5, 21.7, 21.6. IR (cm⁻¹) 3355, 3258, 1737, 1492, 1431, 1250, 1156, 1086, 1036, 852, 810, 662, 576, 549. HRMS (ESI): m/z calcd. for C₁₈H₁₇NO₆SNa [M+Na]⁺ 398.0670; found 398.0672.

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(2E,4E)-5-(4-methoxyphenyl)penta-2,4-dien-1-yl tosylcarbamate (**16a**). Prepared from **5a** (rt, 30 min.) and purified using a hexane/ethyl acetate mixture (65/35 R_f 0.24) as eluent. The product was isolated as a yellow oil (29 mg) in 25% yield. NMR spectra of **16a** in CDCl₃ at 298K revealed the presence of two conformers

(rotamers) in a ratio (75/25). ^1H NMR (400 MHz, CDCl_3) δ 7.93 (d, $J = 8.2$ Hz, 1.5H), 7.82 (d, $J = 8.2$ Hz, 0.5H), 7.36–7.30 (m, 4H), 6.86 (d, $J = 8.7$ Hz, 2H), 6.63–6.52 (m, 2H), 6.36 (dd, $J = 15.1, 9.8$ Hz, 1H), 5.70 (dt, $J = 14.5, 6.9$ Hz, 1H), 4.75–4.74 (br s, 1H), 4.63 (d, $J = 6.9$ Hz, 2H), 3.81 (s, 3H), 2.44 (s, 2.25H), 2.41 (s, 0.75H). $^{13}\text{C}\{1\text{H}\}$ NMR (101 MHz, CDCl_3) δ 159.8, 150.4, 145.2, 136.4, 134.4, 129.8, 128.6, 127.9, 126.6, 124.0, 114.3, 67.4, 55.5, 21.8, 21.7. IR (cm^{-1}) 3268, 2957, 2925, 1735, 1601, 1510, 1458, 1341, 1249, 1160, 814, 664, 547. HRMS (ESI): m/z calcd. for $\text{C}_{20}\text{H}_{21}\text{NO}_5\text{SNa}$ $[\text{M}+\text{Na}]^+$ 410.1038; found 410.1036.

(2*E*,4*E*)-5-phenylpenta-2,4-dien-1-yl tosylcarbamate (**16b**). Prepared from **5b** (rt, 4 h) and purified using a hexane/ethyl acetate mixture (70/30 R_f 0.29) as eluent. The product was isolated as a yellow oil (80 mg) in 75% yield. NMR spectra of **16b** in CDCl_3 at 298K revealed the presence of two conformers (rotamers) in a ratio (63/37). ^1H NMR (400 MHz, CDCl_3) δ 7.95–7.91 (m, 1.3H), 7.84–7.80 (m, 0.7H), 7.41–7.36 (m, 2H), 7.36–7.29 (m, 4H), 7.27–7.24 (m, 1H), 6.71 (dd, $J = 15.7, 10.3$ Hz, 1H), 6.56 (d, $J = 15.7$ Hz, 1H), 6.37 (dd, $J = 15.2, 10.4$ Hz, 1H), 5.75 (dt, $J = 14.1, 6.7$ Hz, 1H), 5.02–4.93 (br s, 1H), 4.64 (d, $J = 6.7$ Hz, 2H), 2.43 (s, 1.9H), 2.42 (s, 1.1H). $^{13}\text{C}\{1\text{H}\}$ NMR (126 MHz, CDCl_3) δ 150.6, 145.2, 143.6, 139.2, 136.8, 135.6, 134.5, 129.8, 128.7, 128.4, 128.1, 127.4, 126.6, 126.5, 125.4, 67.1, 21.7, 21.6. IR (cm^{-1}) 3355, 3259, 1745, 1441, 1302, 1152, 660, 544. HRMS (ESI): m/z calcd. for $\text{C}_{19}\text{H}_{19}\text{NO}_4\text{SNa}$ $[\text{M}+\text{Na}]^+$ 380.0932; found 380.0929.

(2*E*,4*E*)-5-(4-chlorophenyl)penta-2,4-dien-1-yl tosylcarbamate (**16c**). Prepared from **5c** (rt, 4 h) and purified using a hexane/ethyl acetate mixture (70/30 R_f 0.22) as eluent. The product was isolated as pale yellow oil (80 mg) in 68% yield. NMR spectra of **16c** in CDCl_3 at 298K revealed the presence of two conformers (rotamers) in a ratio (75/25). ^1H NMR (400 MHz, CDCl_3) δ 7.96–7.88 (m, 1.5H), 7.85–7.76 (m, 0.5H), 7.31 (d, $J = 8.1$ Hz, 2H), 7.29–7.22 (m, 4H), 6.64 (dd, $J = 15.7, 10.5$ Hz, 1H), 6.46 (d, $J = 15.7$ Hz, 1H), 6.33 (dd, $J = 15.2, 10.4$ Hz, 1H), 5.75 (dt, $J = 15.2, 6.5$ Hz, 1H), 4.62 (d, $J = 6.5$ Hz, 2H), 2.40 (s, 2.25H), 2.39 (s, 0.75H). $^{13}\text{C}\{1\text{H}\}$ NMR (126 MHz, CDCl_3) δ 150.5, 145.2, 143.7, 139.2, 135.5, 135.2, 133.7, 133.1, 129.8, 129.7, 128.9, 128.5, 127.9, 127.8, 126.5, 125.9, 67.0, 21.8, 21.6. IR (cm^{-1}) 3272, 3055, 1749, 1595, 1344, 1264, 1159, 1089, 732, 510. HRMS (ESI): m/z calcd. for $\text{C}_{19}\text{H}_{18}\text{ClNO}_4\text{SNa}$ $[\text{M}+\text{Na}]^+$ 414.0543; found 414.0542.

(2*E*,4*E*)-5-(4-nitrophenyl)penta-2,4-dien-1-yl tosylcarbamate (**16d**). Prepared from **5d** (90 °C, 5 days) and purified using a hexane/ethyl acetate mixture (60/40 R_f 0.26) as eluent. The product was isolated as an orange oil (44 mg) in 36% yield. NMR spectra of **16d** in CDCl_3 at 298K revealed the presence of two conformers (rotamers) in a ratio (99/1). ^1H NMR (400 MHz, CDCl_3) δ 8.18 (d, $J = 8.5$ Hz, 2H), 7.93 (d, $J = 8.1$ Hz, 2H), 7.50 (d, $J = 8.5$ Hz, 2H), 7.35 (d, $J = 8.1$ Hz, 2H), 6.85 (dd, $J = 15.7, 10.5$ Hz, 1H), 6.60 (d, $J = 15.7$ Hz, 1H), 6.41 (dd, $J = 15.3, 10.6$ Hz, 1H), 5.90 (dt, $J = 15.3, 5.9$ Hz, 1H), 4.67 (d, $J = 5.9$ Hz, 2H), 2.44 (s, 3H). $^{13}\text{C}\{1\text{H}\}$ NMR (101 MHz, CDCl_3) δ 150.3, 147.1, 145.4, 143.3, 135.5, 134.3, 131.9, 129.8, 128.7, 128.5, 127.1, 124.2, 66.6, 21.8. IR (cm^{-1}) 3237, 2957, 2927, 1749, 1594, 1514, 1450, 1340, 1158, 1089, 860, 662, 577, 547. HRMS (ESI): m/z calcd. for $\text{C}_{19}\text{H}_{18}\text{N}_2\text{O}_6\text{SNa}$ $[\text{M}+\text{Na}]^+$ 425.0783; found 425.0785.

(3*E*,5*E*)-6-(4-Chlorophenyl)hexa-3,5-dien-2-yl tosylcarbamate (**18ba**). Prepared from **17b** (rt, 2 h). The compound is unstable on silica gel but a pure sample can be obtained by flash chromatography using a cyclohexane/ethyl acetate mixture (70/30 R_f 0.28) as eluent. The product was isolated as a yellow oil. ^1H NMR (300 MHz, CD_2Cl_2) δ 7.90 (d, $J = 8.4$ Hz, 2H), 7.80–7.77 (br s, 1H), 7.38–7.34 (m, 2H), 7.36–7.25 (m, 4H), 6.75–6.63 (m, 1H), 6.51 (d, $J = 15.7$ Hz, 1H), 6.32 (ddd, $J = 15.2, 10.3, 1.1$ Hz, 1H), 5.71 (dd, $J = 15.2, 6.8$ Hz, 1H), 5.36–5.24 (m, 1H), 2.43 (s, 3H), 1.32 (d, $J = 6.5$ Hz, 3H). $^{13}\text{C}\{1\text{H}\}$ NMR (75 MHz, CD_2Cl_2) δ 149.8, 145.3, 135.6, 135.5, 133.2, 132.5, 132.2, 131.9, 129.6, 128.7, 128.3, 128.2, 127.6, 126.3, 74.1, 21.4, 19.9. IR (cm^{-1})

3227, 1740, 1596, 1490, 1436, 1344, 1222, 1157, 1088, 986, 813, 767, 660. HRMS (ESI): m/z calcd. for $C_{20}H_{19}ClNO_4S$ [M-H]⁻ 404.0729; found 404.0729.

Using phenyl and isopropyl isocyanate. To a solution of allylic alcohol **1a** (0.7 mmol) in dry dichloromethane (0.35M) were added the desired isocyanate (1.05 mmol, 1.5 eq), Et₃N (1.05 mmol, 1.5 eq) and DMAP (0.04 mmol, 5 mol%). The reaction was stirred at reflux for 16 hours. Dichloromethane was evaporated and the crude product was purified by silica gel chromatography to afford the branched carbamate.

1-(4-Methoxyphenyl)allyl phenylcarbamate (11). Prepared from phenyl isocyanate and purified using a cyclohexane/ethyl acetate mixture (80/20, R_f 0.28) as eluent. The product was isolated as a colorless oil (53 mg) in 30% yield. ¹H NMR (300 MHz, CDCl₃) δ 7.43–7.26 (m, 6H), 7.11–7.05 (m, 1H), 6.93 (d, J = 8.7 Hz, 2H), 6.87–6.83 (br s, 1H), 6.28 (d, J = 5.7 Hz, 1H), 6.10 (ddd, J = 17.2, 10.4, 5.6 Hz, 1H), 5.42–5.26 (m, 2H), 3.83 (s, 3H). ¹³C{¹H} NMR (101 MHz, Acetone-*d*₆) δ 160.5, 153.5, 140.1, 138.1, 132.4, 129.6, 129.4, 123.4, 119.1, 116.2, 114.6, 76.7, 55.5. IR (cm⁻¹) 3325, 2934, 2482, 1704, 1601, 1501, 1402, 1242, 1174, 1027, 827, 750, 691. HRMS (ESI) m/z calcd. for C₁₇H₁₇NO₃Na [M+Na]⁺ 306.1101; found 306.1099.

1-(4-Methoxyphenyl)allyl isopropylcarbamate (12). Prepared from isopropyl isocyanate and purified using a cyclohexane/ethyl acetate mixture (90/10, R_f 0.18) as eluent. The product was isolated as a yellow solid (62 mg) in 65% yield. m.p. 120–123 °C. ¹H NMR (300 MHz, CDCl₃) δ 7.28 (d, J = 8.7 Hz, 2H), 6.88 (d, J = 8.7 Hz, 2H), 6.13 (d, J = 5.7 Hz, 1H), 6.01 (ddd, J = 17.1, 10.4, 5.6 Hz, 1H), 5.34–5.11 (m, 2H), 4.60–4.55 (br s, 1H), 3.88–3.80 (m, 1H), 3.80 (s, 3H), 1.14 (dd, J = 8.7, 6.4 Hz, 6H). ¹³C{¹H} NMR (75 MHz, CDCl₃) δ 159.5, 154.9, 137.1, 131.7, 128.7, 116.1, 114.0, 113.6, 76.0, 55.3, 23.1. IR (cm⁻¹) 3329, 2972, 1685, 1612, 1523, 1512, 1242, 1175, 1070, 1031, 926, 828, 816, 778. HRMS (ESI) m/z calcd. for C₁₄H₁₉NO₃Na [M+Na]⁺ 272.1257; found 272.1254.

Using benzoyl isocyanate. To a solution of allylic alcohol **1a** or **17** (0.7 mmol) in dry CH₂Cl₂ or CDCl₃ (0.70M) was added the desired isocyanate (0.84 mmol, 1.2 eq). The reaction was stirred at room temperature for desired time (Scheme 4 and Scheme 5). Solvent was evaporated and the crude product was purified by silica gel chromatography to afford the desired compound.

(E)-3-(4-Methoxyphenyl)allyl benzoylcarbamate (15). Prepared from **1a** in 30 min. and purified using a cyclohexane/ethyl acetate mixture (70/30, R_f 0.31) as eluent. The product was isolated as a colorless oil (137 mg) in 63% yield. ¹H NMR (400 MHz, CDCl₃) δ 8.57–8.53 (br s, 1H), 7.81 (d, J = 7.2 Hz, 2H), 7.53–7.47 (m, 1H), 7.39 (dd, J = 8.3, 7.1 Hz, 2H), 7.23 (d, J = 8.8 Hz, 2H), 6.79 (d, J = 8.8 Hz, 2H), 6.56 (d, J = 15.8 Hz, 1H), 6.09 (dt, J = 15.9, 6.8 Hz, 1H), 4.75 (dd, J = 6.8, 1.2 Hz, 2H), 3.74 (s, 3H). ¹³C{¹H} NMR (101 MHz, CDCl₃) δ 165.2, 159.8, 151.2, 135.2, 133.0, 132.9, 130.6, 128.8, 128.7, 128.0, 127.8, 119.9, 114.1, 67.7, 67.0, 55.3. IR (cm⁻¹) 3241, 3189, 3035, 3008, 2835, 1747, 1683, 1606, 1507, 1488, 1192, 1173, 1054, 1033, 1025, 969, 834, 778, 701. HRMS (ESI) m/z calcd. for C₁₈H₁₇NO₄Na [M+Na]⁺ 334.1050; found 334.1050.

(3E,5E)-6-Phenylhexa-3,5-dien-2-yl benzoylcarbamate (18ab). Prepared from **17a** (rt, 2 h). The compound is unstable on silica gel but a pure sample can be obtained by flash chromatography using a cyclohexane/ethyl acetate mixture (70/30, R_f 0.24) as eluent. The product was isolated as a slight yellow oil. ¹H NMR (300 MHz, CDCl₃) δ 8.02–7.59 (br s, 1H), 7.87–7.77 (m, 2H), 7.62–7.54 (m, 1H), 7.52–7.45 (m, 3H), 7.45–7.33 (m, 2H), 7.35–7.28 (m, 2H), 6.74 (dd, J = 15.6, 10.2 Hz, 1H), 6.61 (d, J = 15.7 Hz, 1H), 6.50 (dd, J = 15.1, 9.8 Hz, 1H), 5.82 (dd, J = 15.1, 7.0 Hz, 1H), 5.54 (m, 1H), 1.47 (d, J = 6.5 Hz, 3H). ¹³C{¹H} NMR (75 MHz, CDCl₃) δ 165.3, 151.4, 150.6, 134.2, 133.2, 133.0, 132.9, 132.0, 128.8, 128.6, 128.5, 128.3, 127.9, 127.7,

127.5, 126.5, 73.3, 20.3. IR (cm⁻¹) 3285, 3028, 2984, 1754, 1665, 1510, 1488, 1192, 1035, 989, 690. HRMS (ESI) *m/z* calcd. for C₂₀H₁₉NO₃Na [M+Na]⁺ 344.1257; found 344.1257.

(3*E*,5*E*)-6-(4-Chlorophenyl)hexa-3,5-dien-2-yl benzoylcarbamate (**18bb**). Prepared from **17b** (rt, 2 h). The compound is unstable on silica gel but a pure sample can be obtained by flash chromatography using a cyclohexane/ethyl acetate mixture (70/30, *R_f* 0.34) as eluent. The product was isolated as a yellow oil. ¹H NMR (300 MHz, CD₂Cl₂) δ 8.32–8.30 (br s, 1H), 7.86–7.80 (m, 2H), 7.64–7.55 (m, 1H), 7.53–7.45 (m, 2H), 7.39–7.25 (m, 4H), 6.75 (dd, *J* = 15.4, 10.6 Hz, 1H), 6.56 (d, *J* = 15.7 Hz, 1H), 6.48 (ddd, *J* = 15.2, 10.4, 1.1 Hz, 1H), 5.86 (dd, *J* = 15.2, 6.8 Hz, 1H), 5.49 (m, 1H), 1.44 (d, *J* = 6.5 Hz, 3H). ¹³C{¹H} NMR (75 MHz, CD₂Cl₂) δ 164.8, 150.1, 135.6, 133.3, 133.2, 132.9, 132.5, 132.4, 132.2, 128.8, 128.7, 128.5, 128.4, 127.7, 127.5, 127.3, 72.9, 20.0. IR (cm⁻¹) 3252, 2982, 2930, 1742, 1683, 1519, 1488, 1288, 1202, 1121, 1088, 992, 830, 776, 703. HRMS (ESI) *m/z* calcd. for C₂₀H₁₈ClNO₃ [M-H]⁻ 354.0902; found 354.0902.

Using (R)-(+)-(4-fluorophenyl)ethyl isocyanate.

(*S,E*)-4-phenylbut-3-en-2-yl ((*R*)-1-(4-fluorophenyl)ethyl)carbamate (**22**). To a solution of (+)-(*S,E*)-1-phenylbut-2-enol **20** (*ee* 98%, 0.15 mmol) in toluene (0.2 M) under argon atmosphere, (*R*)-(+)-(4-fluorophenyl)ethyl isocyanate **19** (0.17 mmol) and triethylamine (0.05 mmol) were added and the mixture was stirred at 90 °C for 6 h. The initial mixture was concentrated in *vacuo*, diluted with Et₂O (2 mL) and washed with saturated NaCl (3x 2mL). The resulting crude mixture was diluted in toluene (0.2 M) and stirred at 110 °C for 48 h. The final mixture was purified by flash column chromatography on neutral aluminium oxide using a hexane/ethyl acetate mixture (83/17, *R_f* 0.64) as eluent. The product was isolated as a colorless oil (19 mg) in 39% yield. ¹H NMR (400 MHz, CDCl₃) δ 7.39–7.26 (m, 7H), 7.00 (dd, *J* = 8.6, 8.6 Hz, 2H), 6.56 (d, *J* = 16.0 Hz, 1H), 6.17 (dd, *J* = 16.0, 6.5 Hz, 1H), 5.41 (dd, *J* = 6.5, 6.5 Hz, 1H), 4.92–4.90 (br s, 1H), 4.86–4.78 (m, 1H), 1.50–1.45 (m, 3H), 1.43–1.36 (m, 3H). ¹³C{¹H} NMR (101 MHz, CDCl₃) δ 162.08 (d, ¹*J*_{CF} = 244.9 Hz), 155.21, 136.56, 131.24, 129.38, 128.68, 127.97, 127.68 (d, ³*J*_{CF} = 8.3 Hz), 126.68, 115.53 (d, ²*J*_{CF} = 21.1 Hz), 71.66, 50.15, 22.68, 20.75; ¹⁹F NMR (376 MHz, CDCl₃) δ -115.58. IR (cm⁻¹) 3343, 2979, 2931, 1680, 1529, 1508, 1221, 1058, 548. HRMS (ESI) *m/z* calcd. for C₁₉H₂₀FNO₂Na [M+Na]⁺ 336.1376; found 336.1371. HPLC (ChiralPak IB, hexane/iPrOH = 97:3, flow rate 1 mL/min, λ 210 nm), *t_R* (minor) 13.64 min, *t_R* (major) 15.71 min; 95% *de*. [α]_D²² = -15.91 (*c* 0.35, CHCl₃).

General procedure for the synthesis of allylamine derivatives **8**, **9** and **10** via an allyl cyanate/isocyanate rearrangement from **4a**.

To a solution of carbamate **4a** (0.25 mmol) in dry dichloromethane (0.13M) cooled at 0 °C under argon atmosphere was added TFAA (0.75 mmol) and triethylamine (1.13 mmol). The reaction mixture was stirred at 0 °C for 1 hour and then the desired nucleophile (0.38 mmol), and Ti(*Ot*-Bu)₄ (0.025 mmol) if necessary, were added at 0 °C. The reaction mixture was stirred at room temperature during the required time (Scheme 2). Water was added and the aqueous layer was extracted three times with CH₂Cl₂. The collected organic layers were dried over MgSO₄, filtered and concentrated under *vacuo*. The crude product was purified by silica gel chromatography.

1,1-Diethyl-3-(1-(4-methoxyphenyl)allyl)urea (**8**). Prepared using HNEt₂ as nucleophile and purified using a cyclohexane/ethyl acetate mixture (70/30, *R_f* 0.51) as eluent. The product was isolated as a colorless oil (33 mg) in 50% yield. ¹H NMR (400 MHz, CDCl₃) δ 7.24 (d, *J* = 8.6 Hz, 2H), 6.87 (d, *J* = 8.6 Hz, 2H), 6.04

(ddd, $J = 16.8, 10.6, 5.2$ Hz, 1H), 5.50 (dddd, $J = 7.2, 5.2, 1.7, 1.7$ Hz, 1H), 5.24–5.14 (m, 2H), 4.52 (d, $J = 7.6$ Hz, 1H), 3.79 (s, 3H), 3.27 (q, $J = 7.4$ Hz, 4H), 1.14 (t, $J = 7.4$ Hz, 6H). $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3) δ 159.0, 156.5, 139.1, 134.2, 128.5, 115.0, 114.1, 55.8, 55.4, 41.4, 14.1. IR (cm^{-1}) 3348, 2977, 2931, 1618, 1510, 1249, 1177, 1031, 908, 828, 810, 762. HRMS (ESI) m/z calcd. for $\text{C}_{15}\text{H}_{22}\text{N}_2\text{O}_2\text{Na}$ $[\text{M}+\text{Na}]^+$ 285.1574; found 285.1574.

1-Allyl-1-benzyl-3-(1-(4-methoxyphenyl)allyl)urea (**9**). Prepared using *N*-benzyl allylamine as nucleophile and purified using a cyclohexane/ethyl acetate mixture (70/30, R_f 0.54) as eluent. The product was isolated as a colorless oil (46 mg) in 55% yield. ^1H NMR (400 MHz, CDCl_3) δ 7.36–7.27 (m, 2H), 7.28–7.23 (m, 3H), 7.12 (d, $J = 8.6$ Hz, 2H), 6.83 (d, $J = 8.6$ Hz, 2H), 5.95 (ddd, $J = 17.2, 10.4, 5.2$ Hz, 1H), 5.78 (ddt, $J = 17.5, 9.9, 5.5$ Hz, 1H), 5.52–5.45 (m, 1H), 5.20–5.15 (m, 2H), 5.13–5.04 (m, 2H), 4.73 (d, $J = 7.8$ Hz, 1H), 4.57–4.40 (m, 2H), 3.88 (dd, $J = 5.5, 1.6$ Hz, 2H), 3.78 (s, 3H). $^{13}\text{C}\{^1\text{H}\}$ NMR (101 MHz, CDCl_3) δ 158.9, 157.5, 138.9, 138.1, 134.1, 133.9, 128.8, 128.3, 127.5, 117.1, 114.8, 114.0, 56.0, 55.4, 50.5, 49.9. IR (cm^{-1}) 3316, 2960, 2917, 2849, 1613, 1531, 1511, 1240, 1176, 1028, 927, 803, 702. HRMS (ESI) m/z calcd. for $\text{C}_{21}\text{H}_{24}\text{N}_2\text{O}_2\text{Na}$ $[\text{M}+\text{Na}]^+$ 359.1730; found 359.1729.

Benzyl (1-(4-methoxyphenyl)allyl)carbamate (**10**).⁵¹ Prepared using benzyl alcohol as nucleophile and purified using a cyclohexane/ethyl acetate mixture (80/20, R_f 0.50) as eluent. The product was isolated as a colorless oil (33 mg) in 45% yield. ^1H NMR (300 MHz, CDCl_3) δ 7.37–7.32 (m, 5H), 7.21 (d, $J = 8.3$ Hz, 2H), 6.83 (d, $J = 8.3$ Hz, 2H), 6.00 (ddd, $J = 17.4, 10.1, 5.2$ Hz, 1H), 5.34–5.07 (m, 6H), 3.80 (s, 3H). $^{13}\text{C}\{^1\text{H}\}$ NMR (75 MHz, CDCl_3) δ 159.2, 155.6, 137.9, 136.5, 132.9, 128.6, 128.4, 128.2, 115.6, 114.2, 67.0, 55.4.

Preparation of [^{17}O] labelled compounds.

$^{17}\text{O}_2$ benzoic acid ($^{17}\text{O}_2$ 25).³⁰ (Trichloromethyl)benzene (1.75 mmol) and 0.59 mL of H_2^{17}O were placed in a microwave vessel and sealed. The resulting mixture was irradiated with microwaves at 150 W, 130 °C and 6 bar for 30 minutes. Once the mixture was cooled down to room temperature, the solid formed was filtered and washed with hexane. The desired pure compound was obtained as a white solid (200 mg) in 93% yield. ^1H NMR (400 MHz, Acetone- d_6): δ 8.07 – 8.02 (m, 2H), 7.66 – 7.60 (m, 1H), 7.51 (dd, $J = 8.4, 7.1$ Hz, 2H). ^{17}O NMR (68 MHz, Acetone- d_6): δ 245.

$^{17}\text{O}_2$ 2-ethoxy-2-oxoethyl benzoate ($^{17}\text{O}_2$ 26).³¹ To a solution of $^{17}\text{O}_2$ 25 (1.62 mmol) and $\text{Cu}(\text{OTf})_2$ (5.9 mg) in toluene (10 mL) ethyl diazoacetate was added dropwise (3.24 mmol) and the resulting mixture was warmed up to 80 °C and stirred for 12h. After completion, the reaction mixture was filtered and toluene was evaporated in vacuo. The final product was used without further purification. ^1H NMR (500 MHz, Acetone- d_6): δ 8.09 (d, $J = 7.7$ Hz, 2H), 7.68 (t, $J = 7.5$ Hz, 1H), 7.56 (q, $J = 8.0$ Hz, 2H), 4.91 (s, 2H), 4.23 (q, $J = 7.1$ Hz, 2H), 1.27 (tq, $J = 7.2, 3.6, 2.6$ Hz, 3H). ^{17}O NMR (68 MHz, Acetone- d_6): δ 340, 136.

^{17}O Benzyl alcohol ^{17}O 27. Compound $^{17}\text{O}_2$ 25 (1.60 mmol) was dissolved in THF (20 mL). A solution of LiAlH_4 in THF (1.48 mL, 2.5 M) was slowly added to the resulting mixture at 0 °C and the reaction was allowed to stir at room temperature until total consumption of starting material. After completion, a solution of NaOH 1N (10 mL) was used to quench the reaction and the aqueous layer was extracted with CH_2Cl_2 (3 x 10 mL). The organic layers were dried over MgSO_4 , filtered and concentrated in vacuo. The final product was purified by flash column chromatography on silica gel using a hexane/ethyl acetate mixture (60/40, R_f 0.59) as

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3 eluent, and isolated as a pale yellow oil (149 mg) in 85% yield. ¹H NMR (500 MHz, CDCl₃): δ 7.37 (d, *J* = 4.5
4 Hz, 4H), 7.32 – 7.28 (m, 1H), 4.70 (d, *J* = 2.3 Hz, 2H), 1.67 (s, 1H). ¹⁷O NMR (68 MHz, Acetone-*d*₆): δ 0.

5
6 [¹⁷O]Benzaldehyde ([¹⁷O]28).⁵² A solution of oxalyl chloride (2.33 mmol) in CH₂Cl₂ (3 mL) was cooled
7 to -84 °C and dimethyl sulfoxide (4.65 mmol) was added slowly. The resulting mixture was stirred for additional
8 15 minutes. [¹⁷O]27 (1.37 mmol) was added to the reaction and the mixture was allowed to stir for 15 minutes.
9 Triethylamine (6.85 mmol) was slowly added and the resulting white suspension was stirred at the indicated
10 temperature for 2h. After completion, the reaction was warmed up to 0 °C, quenched with HCl (3 mL) and
11 extracted with CH₂Cl₂ (3 x 5 mL). The organic layer was washed with NaHCO₃ sat. (2 x 5 mL) and the combined
12 organic layers were dried over MgSO₄, filtered and concentrated *in vacuo* at 0 °C. The desired compound was
13 isolated as a colorless oil (95 mg) in 65% yield and used in the next step without further purification. ¹H NMR
14 (400 MHz, CDCl₃): δ 10.06 (s, 1H), 7.95 – 7.88 (m, 2H), 7.72 – 7.63 (m, 1H), 7.57 (dd, *J* = 8.2, 6.9 Hz, 2H). ¹⁷O
15 NMR (68 MHz, CDCl₃): δ 554.

16
17 [¹⁷O]1-Phenylprop-2-en-1-ol ([¹⁷O]1b).⁵³ To a solution of [¹⁷O]28 (0.89 mmol) in THF (6 mL) was
18 slowly added at 0° C a solution of vinylmagnesium bromide in THF (1.07 mmol, 1 M). The reaction mixture was
19 stirred at room temperature for 4 hours after which a saturated NH₄Cl solution (3 mL) was added. The aqueous
20 layer was extracted with Et₂O (4 x 6 mL). The organic layers were dried over MgSO₄, filtered and concentrated
21 *in vacuo*. The residue was purified by flash column chromatography on silica gel using a hexane/ethyl acetate
22 mixture (70:30, *R_f* 0.60) to afford the desired product as a yellow oil (64 mg) in 54% yield. ¹H NMR (400 MHz,
23 CDCl₃): δ 7.42 – 7.34 (m, 4H), 7.29 (td, *J* = 5.7, 2.5 Hz, 1H), 6.06 (ddd, *J* = 16.7, 10.3, 6.0 Hz, 1H), 5.35 (dd, *J*
24 = 16.7, 1.6 Hz, 1H), 5.24 – 5.18 (m, 2H). ¹⁷O NMR (68 MHz, CDCl₃): δ 31.

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26 [¹⁷O]1-phenylallyl tosylcarbamate ([¹⁷O]13b).^{5c} To a solution of 1-phenylprop-2-en-1-ol [¹⁷O]1b
27 (0.073 mmol) in toluene (0.2 M) under argon atmosphere, *p*-toluenesulfonylisocyanate (0.088 mmol) was added
28 dropwise and the mixture was stirred at room temperature for 5 minutes. The resulting mixture was concentrated
29 *in vacuo* and purified using a hexane/ethyl acetate mixture (80/20, *R_f* 0.31) as eluent. The product was isolated as
30 a colorless oil (21 mg) in 90% yield. ¹H NMR (400 MHz, CDCl₃) δ 7.88 (d, *J* = 8.3 Hz, 2H), 7.55–7.53 (br s,
31 1H), 7.34–7.26 (m, 5H), 7.21 (dd, *J* = 6.8, 3.0 Hz, 2H), 6.11 (dd, *J* = 6.0, 1.5 Hz, 1H), 5.92 (ddd, *J* = 16.7, 10.5,
32 5.9 Hz, 1H), 5.27–5.23 (m, 2H), 2.43 (s, 3H). ¹⁷O NMR (68 MHz, CDCl₃): δ 150, 129.

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34 [¹⁷O]1(E)-3-(phenyl)allyl tosylcarbamate ([¹⁷O]14b).⁵⁰ Prepared from [¹⁷O]1b (90 °C, 4 h) and
35 purified using a hexane/ethyl acetate mixture (60/40, *R_f* 0.39) as eluent. The product was isolated as a white solid
36 (21 mg) in 86% yield. ¹H NMR (400 MHz, CDCl₃) δ 7.97–7.90 (m, 1.5H), 7.82 (m, 0.5H), 7.37–7.25 (m, 7H),
37 6.58 (d, *J* = 15.8 Hz, 1H), 6.14 (dt, *J* = 15.9, 6.6 Hz, 1H), 4.72 (dd, *J* = 6.6, 1.3 Hz, 2H), 2.43 (s, 0.75H), 2.42 (s,
38 2.25H). ¹⁷O NMR (68 MHz, Chloroform-*d*) δ 264, 125. HRMS (ESI): *m/z* calcd. for [¹⁷O]14b: calculated for
39 C₁₇H₁₇NO₄SNa [M+Na]⁺ 354.0763; found: 354.0763 (59%); calculated for C₁₇H₁₇NO₃¹⁷OSNa [(M+1)+Na]⁺
40 355.0805; found: 355.0799 (11%); calculated for C₁₇H₁₇NO₃¹⁸OSNa [(M+2)+Na]⁺ 356.0806; found: 356.0799
41 (30%).

42 Procedure for NMR monitoring of the [¹⁷O]13b → [¹⁷O]14b transformation

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44 To a solution of 1-phenylprop-2-en-1-ol [¹⁷O]1b (0.373 mmol) in toluene (0.2 M) under argon
45 atmosphere, *p*-toluenesulfonylisocyanate (0.447 mmol) was added dropwise. The reaction was heated to 90 °C,
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3 and 200 μL were taken from the reaction medium every 20 minutes. The solvent was removed and the resulting
4 colorless oil was dissolved in CDCl_3 to perform ^{17}O NMR experiments at room temperature.
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9 **Computational Methods.** All of the calculations reported in this work were carried out with the GAUSSIAN 09
10 suite of programs⁵⁴ and using the hybrid DFT functional B3LYP⁵⁵ with the D3 dispersion empirical correction⁵⁶
11 and the 6-311++G(d,p) basis set.⁵⁷ The most stable conformations of reactants and products were previously
12 determined by MM Monte Carlo simulations using the OPLS force field⁵⁸ as implemented in the MacroModel
13 program Implemented in the Schrödinger Maestro suite⁵⁹ and then subjected to DFT optimizations. All the
14 stationary points were characterized by harmonic analysis. Reactants and products showed positive definite
15 Hessians. Transition structures (TSs) showed one and only one imaginary frequency associated with nuclear
16 motion along the chemical transformation under study. Free energies at 363.15 K were calculated by including
17 the corresponding thermal corrections to Gibbs free energies (TCGE). Solvent effects were considered by means
18 of the PCM method.⁶⁰ The solvent introduced in the calculations was toluene. Natural bonding analysis
19 calculations were performed using the NBO program⁶¹ as implemented in Gaussian 09.
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26 ASSOCIATED CONTENT

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28 **Supporting Information.** This material is available free of charge via the Internet at
29 <http://pubs.acs.org>.
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- Copies of ^1H , ^{13}C NMR spectra and chiral HPLC chromatography of all new compounds. Copies of ^{17}O NMR of **25**, **26**, **27**, **28**, **1b**, **13b**, **14b**. First order linear plot obtained for compounds **14a-c**. Cartesian coordinates, number of imaginary frequencies (NIMAG), and energy data of stationary points gathered in Figure 5, 7, 8, 9 and 10.
 - Crystal data, CCDC 1824810 for **14e** (CIF)

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48 Notes

49 The authors declare no competing financial interest.
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