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Highly selective catalyst-dependent competitive 1,2-C→C, -O→C and -N→C migrations from β-methylene-β-silyloxy-β-amido-α-diazoacetates

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Abstract

Transition metal catalysts direct 1,2-C→C, -O→C and -N→C migrations from β-methylene-β-silyloxy-β-amido-α-diazoacetates with high selectivity. The key to achieve this unique display of differential selectivities relies on steric and stereoelectronic control by their catalytically generated metal carbenes.

1,2-Migration to an electrophilic carbon center is a common transformation in organic chemistry that has been widely investigated for its intriguing mechanistic features¹ and extensive occurrence in catalysis.² Among the reactions that encompass these 1,2-migrations are the semipinacol rearrangement and its multiple variants,³ solvolysis reactions^{1d} that include Wagner-Meerwein rearrangements,⁴ ring-enlargement reactions⁵ and, more recently, gold-catalyzed migrations.⁶ With free rotation around the C–C bond to the electrophilic carbon, group migration is dependent upon migratory aptitude as well as on the spacial positioning of the migrating group relative to the electrophilic center.^{1a,b, 4a, 4c} In general, although highly selective migrations are most desirable, competition between two migrating groups is commonly observed.^{1c, 5b,c} In these reactions the product that is formed is dependent on the structure of the reactant,^{4a,b,e} and external control of which group migrates has long been problematic.^{3,4} Catalytically generated metal carbenes from α-diazo carbonyl compounds are highly electrophilic, and 1,2-migration occurs if a saturated carbon is directly bonded to the carbene center.⁷ However, examples of catalyst-controlled migrations are rarely encountered,⁸ and effective catalyst-controlled selectivity in these transformations remains unsolved.⁹

We have been intrigued with catalyst control of reaction outcomes that emanate from the same reactants, and we have previously presented diverse catalyst-dependent outcomes from reactions of enol diazoacetates with α,β-unsaturated aldehydes¹⁰ and with nitrones.¹¹ We asked the question “could a catalytically generated metal carbene intermediate with an adjacent saturated carbon atom having three different substituents be induced by different catalysts to undergo selective 1,2-migration by each of the substituents?” In order to answer this question, facile access to α-diazocompounds bearing β-quaternary carbons was our first objective. Inspired by our recent efforts in using enol diazoacetates in Lewis acid catalyzed

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Supporting Information

Experimental detail, optimization of reaction conditions, and characterization data, including crystal structures for **3a**, **4h**, **5k**, and **6c**, are available. This material is available free of charge via the Internet at <http://pubs.acs.org>.

reactions,¹² we envisioned that construction of α -diazo compounds could be accomplished by [3+2] cycloaddition of dipolar species and an enol diazoacetate (Scheme 1). Azomethine imines are promising candidates since they are stable, easily accessible dipolar compounds and precursors for the synthesis of dinitrogen-fused heterocyclic rings,¹³ which display broad biological activities.¹⁴ As expected, the synthesis of the aforementioned α -diazoacetates has been achieved by diastereoselective [3+2] cycloaddition reactions of azomethine imines **1** with enol diazoacetate **2** under Lewis acid catalysis. The β -quaternary carbon is directly bound to carbon, nitrogen, and oxygen substituents that are poised to rearrange to an adjacent electrophilic carbon. Herein we report that different metal catalysts direct migration by carbon, nitrogen, and oxygen substituents with a high degree of selectivity to generate a diverse array of highly functionalized fused-ring heterocyclic compounds in an efficient and controllable manner.

We initiated our study of Lewis acid catalyzed reaction between azomethine imines **1** ($R^2 = H$) and enol diazoacetate **2** by using $Sc(OTf)_3$ (eq 1). Highly diastereoselective [3+2] cycloaddition occurred with the pendant phenyl and TBSO groups *cis* as confirmed by X-ray analysis. Further investigations with 5-phenyl-azomethine imines **1** ($R^2 = Ph$) revealed that $In(OTf)_3$ afforded a higher level of diastereoselectivity than $Sc(OTf)_3$. As shown in Table 1, azomethine imines containing electron-withdrawing (entries 3, 9, 11 and 12) and electron-donating substituents (entries 2, 4, 5 and 10) on the phenyl rings afford the desired products in high isolated yields. Furthermore, substituents at the *para*- (entries 2–3, 5, 9–11), *meta*- (entry 12) and *ortho*- (entry 4) positions on the phenyl rings are well-tolerated. Azomethine imines derived from cinnamaldehyde (entry 7) and from cyclohexylcarboxaldehyde (entries 6 and 13) show similar reactivity profiles as those derived from aromatic aldehydes, and all substrates shown in Table 1 afford the cycloaddition products with complete diastereocontrol.

Having prepared highly functionalized α -diazoacetates **3** bearing quaternary carbons at the β -positions, we next investigated their transition-metal catalyzed dinitrogen extrusion and subsequent rearrangement of the catalytically generated metal carbene intermediate (eq 2), and these results are reported in Table 2. In the reaction of **3a** with $Rh_2(OAc)_4$ three products were obtained in 90% combined yield (eq 2), and these were determined by X-ray diffraction and/or spectroscopically to be those from 1,2-C $\rightarrow$ C migration (**4a**, 58%), stereoselective 1,2-O $\rightarrow$ C migration (**5a**, 25%) and 1,2-N $\rightarrow$ C migration (**6a**, 17%). Using the more Lewis acidic $Rh_2(tfa)_4$ (entry 2) and $Rh_2(pfb)_4$ (entry 3) under the same conditions showed that the 1,2-N $\rightarrow$ C migration pathway was inhibited in favor of 1,2-C $\rightarrow$ C and -O $\rightarrow$ C migrations with approximately 3:1 selectivity. In contrast, performing this reaction with the less Lewis acidic $Rh_2(cap)_4$ in $ClCH_2CH_2Cl$ at 80°C revealed that both the 1,2-N $\rightarrow$ C and -O $\rightarrow$ C migration pathways were suppressed, and 1,2-C $\rightarrow$ C migration was dominant (entry 4). In a control experiment, where the same reaction was conducted with $Rh_2(OAc)_4$ (entry 5) under otherwise identical conditions as that with $Rh_2(cap)_4$ comparable selectivity was shown relative to the reaction performed in CH_2Cl_2 at 40°C (entry 1) but with much lower selectivity than with $Rh_2(cap)_4$ (entry 4). The use of $Rh_2(piv)_4$ and $Rh_2(esp)_2$ that contain sterically bulky ligands gave high selectivities for both 1,2-N $\rightarrow$ C and -O $\rightarrow$ C migrations (entries 6 and 7). In contrast, copper and silver catalysts display distinctive and virtually exclusive selectivity for 1,2-N $\rightarrow$ C migration (entries 8–11) compared with dirhodium complexes. Thus, catalysts derived from different metals (Rh and Cu or Ag) direct competitive 1,2-C $\rightarrow$ C and -N $\rightarrow$ C migration pathways with high selectivities, and the 1,2-C $\rightarrow$ C migration product **4a** or the 1,2-N $\rightarrow$ C migration product **6a** can be obtained with high yields under catalysis of $Rh_2(cap)_4$ or $CuPF_6$, respectively. 1,2-C $\rightarrow$ C and -O $\rightarrow$ C migrations appear to be linked, but highly selective catalyst-directed 1,2-O $\rightarrow$ C migration could not be achieved with **1a**.

The influence of R^1 on the selective 1,2-C $\rightarrow$ C migration catalyzed by $Rh_2(cap)_4$ and the 1,2-N $\rightarrow$ C migration catalyzed by $CuPF_6$ was investigated, and their results are summarized in Table 3. Reactions performed with $CuPF_6$ as catalyst uniformly afford the 1,2-N $\rightarrow$ C migration product, and $Rh_2(cap)_4$ promotes the 1,2-C $\rightarrow$ C migration process with high selectivities but without significant dependence on R^1 .

In an effort to selectively achieve 1,2-C $\rightarrow$ C migration, 1,2-O $\rightarrow$ C migration, and 1,2-N $\rightarrow$ C migration with different catalysts, **3h**, which has an additional phenyl group on the pyrazolidinone ring, was subjected to the same series of catalytic reactions (Table 4). With 1 mol% of $Rh_2(OAc)_4$, the formation of the 1,2-C $\rightarrow$ C migration product **4h** and the stereoselective 1,2-O $\rightarrow$ C migration product **5h** occurred without evidence for formation of the 1,2-N $\rightarrow$ C migration product **6h** (eq 4). Once again, $Rh_2(cap)_4$ selected the 1,2-C $\rightarrow$ C migration pathway (entry 6), and $CuPF_6$ effected exclusive 1,2-N $\rightarrow$ C migration (entry 9). Consistent with entries 6 and 7 in Table 3, but more dramatic, increasing the steric size of the ligand by using $Rh_2(piv)_4$ (entry 4) significantly enhances the reaction selectivity towards the formation of the 1,2-O $\rightarrow$ C migration product **5h**, and this outcome is mirrored with the use of $Rh_2(esp)_2$ (entry 5) but in higher overall yield. Hence, by simply changing the ligand attachments to the dirhodium centers, the competing 1,2-C $\rightarrow$ C and 1,2-O $\rightarrow$ C migrations become dominant through catalysis by $Rh_2(esp)_2$ [or $Rh_2(piv)_4$] and $Rh_2(cap)_4$, respectively; and the 1,2-N $\rightarrow$ C migration product **6h**, which was not detected in dirhodium complex catalyzed reactions, was the sole migration outcome with catalysis by $CuPF_6$. In addition, as shown in Table 5, these reactions have the same selectivities irrespective of the electronic nature of the substituents on the phenyl ring of R^1 even when cyclohexyl is used in place of aryl.

Competition between formation of **4** (1,2-C $\rightarrow$ C migration) and **5** (1,2-O $\rightarrow$ C migration) is linked in dirhodium catalyzed reactions, and the causes for selectivity may be attributed to the steric [e.g., results with $Rh_2(piv)_4$ and $Rh_2(esp)_2$] and electronic [results with $Rh_2(cap)_4$] factors. However, the unexpected 1,2-N $\rightarrow$ C migration from **3**,¹⁵ which is formally an amide nitrogen migration, stands out as exceptionally favourable when copper, rather than dirhodium, catalysts are employed. This heightened selectivity for **6** may be due to coordination of the copper carbene intermediate¹⁶ with the carbonyl oxygen of the pyrazolidinone ring (**7** in Scheme 2) – a complexation that is not expected with the coordinatively saturated dirhodium complexes.¹⁷ Consequently, the overall 1,2-N $\rightarrow$ C migration is facilitated by transition metal catalysts with open coordination sites.

In summary, we have discovered catalyst-controlled highly selective 1,2-C $\rightarrow$ C, -O $\rightarrow$ C and -N $\rightarrow$ C migrations of β -methylene- β -silyloxy- β -amido- α -diazoacetates. These rearrangement reactions produce a variety of highly functionalized dinitrogen-fused heterocyclic compounds. Further studies of these intriguing migrations are underway.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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References

1. (a) Nickon A. *Acc Chem Res.* 1993; 26:84.(b) Liu MTH. *Acc Chem Res.* 1994; 27:287.(c) Farlow RA, Thamattoor DM. *J Org Chem.* 2002; 67:3257. [PubMed: 12003533] (d) Okuyama T. *Acc Chem Res.* 2002; 35:12. [PubMed: 11790084]
2. Recent examples of 1,2-migrations in catalytic reactions: Sromek AW, Kel'in AV, Gevorgyan V. *Angew Chem Int Ed.* 2004; 43:2280.Kirsch SF, Binder JT, Liebert C, Menz H. *Angew Chem Int Ed.* 2006; 45:5878.Dudnik AS, Gevorgyan V. *Angew Chem Int Ed.* 2007; 46:5195.Dudnik AS, Sromek AW, Rubina M, Kim JT, Kel'in AV, Gevorgyan V. *J Am Chem Soc.* 2008; 130:1440. [PubMed: 18173272] Dudnik AS, Xia Y, Li Y, Gevorgyan V. *J Am Chem Soc.* 2010; 132:7645. [PubMed: 20476771]
3. (a) Snape TJ. *Chem Soc Rev.* 2007; 36:1823. [PubMed: 18213988] (b) Wang B, Tu Y. *Acc Chem Res.* 2011; 44:1207. [PubMed: 21728380] (c) Song Z, Fan C, Tu Y. *Chem Rev.* 2011; 111:7523. [PubMed: 21851053]
4. Recent examples of Wagner-Meerwein rearrangements: Trost BM, Yasukata T. *J Am Chem Soc.* 2001; 123:7162. [PubMed: 11459498] Langer P, Bose G. *Angew Chem Int Ed.* 2003; 42:4033.Trost BM, Xie J. *J Am Chem Soc.* 2008; 130:6231. [PubMed: 18429612] Leboeuf D, Huang J, Gandon V, Frontier AJ. *Angew Chem Int Ed.* 2011; 50:10981.Leboeuf D, Gandon V, Ciesielski J, Frontier AJ. *J Am Chem Soc.* 2012; 134:6296. [PubMed: 22471833]
5. (a) House HO, Grubbs EJ, Gannon WF. *J Am Chem Soc.* 1960; 82:4099.(b) Namyslo JC, Kaufmann DE. *Chem Rev.* 2003; 103:1485. [PubMed: 12683789] (c) Leemans E, Matthias D, Kimpe ND. *Chem Rev.* 2011; 111:3268. [PubMed: 21488634] (d) Hashimoto T, Naganawa Y, Maruoka K. *J Am Chem Soc.* 2011; 133:8834. [PubMed: 21553888] (e) Li W, Liu X, Hao X, Cai Y, Lin L, Feng X. *Angew Chem Int Ed.* 2012; 51:8644.
6. (a) Marion N, Nolan SP. *Angew Chem Int Ed.* 2007; 46:2750.(b) Hashmi ASK. *Angew Chem Int Ed.* 2008; 47:6754.(c) Li Z, Brouwer C, He C. *Chem Rev.* 2008; 108:3239. [PubMed: 18613729] (d) Arcadi A. *Chem Rev.* 2008; 108:3266. [PubMed: 18651778] (e) Gorin DJ, Sherry BD, Toste FD. *Chem Rev.* 2008; 108:3351. [PubMed: 18652511] (f) Rudolph M, Hashmi ASK. *Chem Commun.* 2011; 47:6536.(g) Lu B, Dai L, Shi M. *Chem Soc Rev.* 2012; 41:3318. [PubMed: 22189460] (h) Hashmi ASK. *Angew Chem Int Ed.* 2012; 49:5232.
7. (a) Doyle, MP.; McKervey, MA.; Ye, T. *Modern Catalytic Methods for Organic Synthesis with Diazo Compounds.* Wiley; New York: 1998. (b) Ye T, McKervey MA. *Chem Rev.* 1994; 94:1901.
8. See one recent example of catalyst controlled 1,2-migration: Vitale M, Lecourt T, Sheldon CG, Aggarwal VK. *J Am Chem Soc.* 2006; 128:2524. [PubMed: 16492022]
9. (a) Aggarwal, Varinder K.; Sheldon, Chris G.; MacDonald, Gregor J.; Martin, William P. *J Am Chem Soc.* 2002; 124:10300. [PubMed: 12197731] (b) Jiang N, Ma Z, Qu Z, Xing X, Xie L, Wang J. *J Org Chem.* 2003; 68:893. [PubMed: 12558413] (c) Shi W, Jiang N, Zhang S, Wu W, Du D, Wang J. *Org Lett.* 2003; 5:2243. [PubMed: 12816419] (d) Shi W, Xiao F, Wang J. *J Org Chem.* 2005; 70:4318. [PubMed: 15903306] (e) Xu F, Shi W, Wang J. *J Org Chem.* 2005; 70:4191. [PubMed: 15876118]
10. Xu X, Hu W, Zavalij PY, Doyle MP. *Angew Chem Int Ed.* 2011; 50:11152.
11. (a) Wang X, Xu X, Zavalij PY, Doyle MP. *J Am Chem Soc.* 2011; 133:16402. [PubMed: 21932856] (b) Qian Y, Xu X, Wang X, Zavalij PJ, Hu W, Doyle MP. *Angew Chem Int Ed.* 2012; 51:5900.(c) Wang X, Abrahams QM, Zavalij PY, Doyle MP. *Angew Chem Int Ed.* 2012; 51:5907.
12. (a) Xu X, Ratnikov MO, Zavalij PY, Doyle MP. *Org Lett.* 2011; 13:6122. [PubMed: 22032199] (b) Xu X, Hu WH, Doyle MP. *Angew Chem Int Ed.* 2011; 50:6392.(c) Jaber D, Burgin RN, Helper P, Zavalij P, Doyle MP. *Org Lett.* 2012; 14:1676. [PubMed: 22409577]
13. (a) Shintani R, Fu GC. *J Am Chem Soc.* 2003; 125:10778. [PubMed: 12952444] (b) Suarez A, Downey CW, Fu GC. *J Am Chem Soc.* 2005; 127:11244. [PubMed: 16089444] (c) Shintani R, Hayashi T. *J Am Chem Soc.* 2006; 128:6330. [PubMed: 16683793] (d) Suga H, Funyu A, Kakehi A. *Org Lett.* 2007; 9:97. [PubMed: 17192094] (e) Shintani R, Murakami M, Hayashi T. *J Am Chem Soc.* 2007; 129:12356. [PubMed: 17894493] (f) Chan A, Scheidt KA. *J Am Chem Soc.* 2007; 129:5334. [PubMed: 17407298] (g) Chen W, Du W, Duan Y, Wu Y, Yang S, Chen Y. *Angew Chem Int Ed.* 2007; 46:7667.(h) Sibi MP, Rane D, Stanley LM, Soeta T. *Org Lett.* 2008; 10:2971. [PubMed: 18549218] (i) Shapiro ND, Shi Y, Toste FD. *J Am Chem Soc.* 2009;

- 131:11654. [PubMed: 19645449] (j) Perreault C, Goudreau SR, Zimmer LE, Charette AB. *Org Lett*. 2008; 10:689. [PubMed: 18257580] (k) Hashimoto T, Maeda Y, Omote M, Nakatsu H, Maruoka K. *J Am Chem Soc*. 2010; 132:4076. [PubMed: 20199072]
14. (a) Varvounis G, Fiamegos Y, Pilidis G. *Adv Heterocycl Chem*. 2001; 80:75.(b) Eicher, T.; Hauptmann, S. *The Chemistry of Heterocycles*. 2. Wiley-VCH; Weinheim: 2003. (c) Konaklieva MI, Plotkin BJ. *Curr Med Chem Anti-Infect Agents*. 2003; 2:287.
15. This 1,2-migration may be stepwise (e.g., cleavage of C-N_{amide} bond, then reattachment at carbene carbon) rather than concerted.
16. See a recent review of copper carbene complexes: Kirmse W. *Angew Chem Int Ed*. 2003; 42:1088.
17. (a) Drago RS, Long JR, Cosmano R. *Inorg Chem*. 1981; 20:2920.(b) Drago RS. *Inorg Chem*. 1982; 21:1697.(c) Drago RS, Long JR, Cosmano R. *Inorg Chem*. 1982; 21:2196.(d) Doyle MP, Mahapatro SN, Caughey AC, Chinn MS, Colsman MR, Harn NK, Redwine AE. *Inorg Chem*. 1987; 26:3070.

Scheme 1.

The strategy for the synthesis of α -diazoacetates bearing β -quaternary carbons and chemoselectivity of competitive 1,2-C $\rightarrow$ C, -O $\rightarrow$ C and -N $\rightarrow$ C migrations

Scheme 2.

Directing effect in Cu catalyzed 1,2-N→C migration.

Table 1

Lewis acid catalyzed diastereoselective [3+2] cycloaddition of azomethine imines **1** with enol diazoacetate **2**.

entry ^a	R ¹	R ²	3 ^d	yield, % ^e
1 ^b	Ph	H	3a	90
2 ^b	4-MeC ₆ H ₄	H	3b	74
3 ^b	4-ClC ₆ H ₄	H	3c	78
4 ^b	2-MeOC ₆ H ₄	H	3d	65
5 ^b	4-MeOC ₆ H ₄	H	3e	69
6 ^b	Cyclohexyl	H	3f	80
7 ^b	(<i>E</i>)-Ph-CH=CH-	H	3g	67
8 ^c	Ph	Ph	3h	81
9 ^c	4-NO ₂ C ₆ H ₄	Ph	3i	66
10 ^c	4-MeOC ₆ H ₄	Ph	3j	71
11 ^c	4-BrC ₆ H ₄	Ph	3k	78
12 ^c	3-BrC ₆ H ₄	Ph	3l	72
13 ^c	Cyclohexyl	Ph	3m	56

^aReaction performed with 0.25 mmol of azomethine imine **1** (1.0 equiv) and enol diazoacetate **2** (1.8 equiv) in CH₂Cl₂ for 12h at room temperature.

^b5 mol% Sc(OTf)₃ used as catalyst.

^c5 mol% In(OTf)₃ used as catalyst.

^dSingle diastereomer obtained.

^eIsolated yields.

Table 2

Catalyst screening with **3a** for selective 1,2-C→C, -O→C and -N→C migrations.

entry ^a	catalyst	temp	solvent	time, h	4a:5a ^d :6a ^e	yield, % ^f
1 ^b	Rh ₂ (OAc) ₄	40°C	CH ₂ Cl ₂	3	58:25:17	90
2 ^b	Rh ₂ (tfa) ₄	40°C	CH ₂ Cl ₂	3	78:22:—	94
3 ^b	Rh ₂ (pfb) ₄	40°C	CH ₂ Cl ₂	3	71:29:—	91
4 ^b	Rh ₂ (cap) ₄	80°C	(CH ₂ Cl) ₂	3	78:9:13	93
5 ^b	Rh ₂ (OAc) ₄	80°C	(CH ₂ Cl) ₂	3	61:25:14	85
6 ^b	Rh ₂ (piv) ₄	40°C	CH ₂ Cl ₂	3	12:39:49	82
7 ^b	Rh ₂ (esp) ₂	40°C	CH ₂ Cl ₂	3	20:39:41	87
8 ^c	Cu(OTf) ₂	rt	CH ₂ Cl ₂	12	—:—:100	70
9 ^c	Cu(hfacac) ₂	rt	CH ₂ Cl ₂	12	9:—:91	88
10 ^c	AgBF ₄	rt	CH ₂ Cl ₂	12	—:—:100	40
11 ^c	CuPF ₆	rt	CH ₂ Cl ₂	12	—:—:100	86

^aReaction performed with 0.1 mmol of **3a**.

^b1 mol% Rh₂L_n catalyst was used.

^c5 mol% catalyst was used.

^d**5a** was obtained as the (*E*)-configuration exclusively.

^eRatios determined by ¹H NMR analysis of reaction mixtures.

^fYields reported are combined yields of **4a**, **5a** and **6a**.

Table 3

Selective 1,2-C→C and -N→C migrations of **3** catalyzed by Rh₂(cap)₄ and CuPF₆.

3^a	R¹	Rh₂(cap)₄^b		CuPF₆^e	
		4	4/5^c	6	yield, %^d
3a	Ph	4a	85:15	6a	86
3b	4-MeC ₆ H ₄	4b	89:11	6b	85
3c	4-ClC ₆ H ₄	4c	88:12	6c	80
3d	2-MeOC ₆ H ₄	4d	81:19	6d	86
3e	4-MeOC ₆ H ₄	4e	88:12	6e	78
3f	Cyclohexyl	4f	87:13	6f	77
3g	(<i>E</i>)-Ph-CH=CH-	4g	86:14	6g	84

^aReaction performed with 0.1 mmol of **3**.

^bReaction performed with 1 mol% of Rh₂(cap)₄ in ClCH₂CH₂Cl at 80°C for 3h.

^cRatios determined by ¹H NMR analysis of crude reaction mixtures.

^dYields reported are combined (**4**+**5**) yields.

^eReaction performed with 5 mol% of CuPF₆ in CH₂Cl₂ for 12h at room temperature.

^fYields reported are isolated yields of **6**.

Table 4

Catalyst screening with **3h** for selective 1,2-C→C, -O→C and -N→C migrations.

entry ^a	catalyst	solvent	time, h	4h:5h ^d :6h ^e	yield, % ^f
1 ^b	Rh ₂ (OAc) ₄	CH ₂ Cl ₂	3	60:40:–	91
2 ^b	Rh ₂ (Oct) ₄	CH ₂ Cl ₂	3	43:57:–	88
3 ^b	Rh ₂ (OBz) ₄	CH ₂ Cl ₂	3	25:75:–	82
4 ^b	Rh ₂ (piv) ₄	CH ₂ Cl ₂	3	12:88:–	74
5 ^b	Rh ₂ (esp) ₂	CH ₂ Cl ₂	3	15:85:–	88
6 ^b	Rh ₂ (cap) ₄	(CH ₂ Cl) ₂	1	91:9:–	86
7 ^b	Rh ₂ (tta) ₄	CH ₂ Cl ₂	3	69:31:–	81
8 ^b	Rh ₂ (pfb) ₄	CH ₂ Cl ₂	3	64:36:–	79
9 ^c	CuPF ₆	CH ₂ Cl ₂	12	–:–:100	72

^aReactions performed with 0.1 mmol of **3h**.

^bReactions performed with 1 mol% of Rh₂L₄ as catalyst.

^cReaction performed with 5.0 mol% CuPF₆.

^d**5h** was obtained in the (*E*)-configuration exclusively.

^eRatio determined by ¹H NMR analysis of crude reaction mixture.

^fYields reported are combined yields of **4h**, **5h** and **6h**.

Table 5

Substrate scope for ligand-induced divergent 1,2-C→C and -O→C migrations.

3^a	R¹	Rh₂(cap)₄^b		Rh₂(esp)₂^c	
		4	4/5^d	5^f	4/5^d
3h	Ph	4h	91:9	5h	15:85
3i	4-NO ₂ C ₆ H ₄	4i	97:3	5i	16:84
3j	4-MeOC ₆ H ₄	4j	96:4	5j	17:83
3k	4-BrC ₆ H ₄	4k	93:7	5k	10:90
3l	3-BrC ₆ H ₄	4l	88:12	5l	14:86
3m	Cyclohexyl	4m	75:25	5m	15:85

^aReaction performed with 0.1 mmol of **3** with 1 mol% Rh₂L_n as catalyst.

^bReactions performed in ClCH₂CH₂Cl at 80°C for 1h.

^cReactions performed in CH₂Cl₂ at room temperature for 3h.

^dRatios determined by ¹H NMR analysis of the reaction mixture.

^eYields reported are combined yields of **4** and **5**.

^f**5** was obtained in the (*E*)-configuration exclusively.