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Domino [2+2]/[2+1] and [3+2]/[2+1] Reaction Sequences of Alkynyl(alkoxy) Chromium Fischer Carbene Complexes

Alexandra Pérez-Anes,[a] Patricia García-García,[a] Ángel Luis Suárez-Sobrino,[a][‡] and and Enrique Aguilar*[a]

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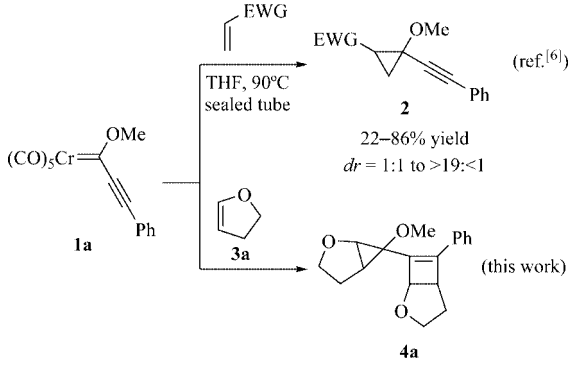
A tandem [2+2]/[2+1] sequence takes place between alkynyl(alkoxy) Fischer carbene complexes and 2,3-dihydrofuran, producing three-component adducts diastereoselectively in moderate yields. On the other hand, a [3+2]/[2+1] (1,3-dipolar cycloaddition/cyclopropanation) sequence takes place between an alkynyl(alkoxy) Fischer carbene complex, trimethylsilyldiazomethane, and methyl acrylate or 2,3-dihydrofuran.

Introduction

Fischer carbene complexes (FCCs) are easily recognized as valuable and versatile reagents in organic synthesis;[1] especially, they have shown a high ability to combine with alkynes (Dötz benzannulation)[2] or alkenes (cyclopropanation).[3] Particularly, this last reaction has been extensively developed; thus, (1) alkyl, aryl, or alkenyl FCCs can perform the cyclopropanation of either electron-deficient olefins or, under high pressure of CO, electron rich olefins, and (2) neutral olefins are able to react with alkenyl or heteroaryl FCCs.[4] However, the ability of alkynyl FCCs **1** to undergo such a reaction had remained unexplored until the beginning of this century, when they were mixed with strained and/or highly reactive alkenes to furnish the corresponding cyclopropanes.[5] Very recently, we found that alkynyl FCCs **1** react with electron-deficient alkenes when heated in THF, in a sealed tube at 90 °C, to produce captodative alkynylcyclopropanes **2** in moderate-to-good yields (Scheme 1).[6,7] When we tested the reaction conditions by warming **1a** with an electron-rich olefin such as 2,3-dihydrofuran (**3a**), we obtained adduct **4a** as the major reaction product, as a mixture of diastereomers.

Close analysis revealed that compound **4a** incorporated two units of alkene and the carbene ligand, and that it was formed by a [2+2]/[2+1] domino reaction sequence. We considered such a result relevant for the following reasons: (1) an electron-rich olefin underwent cyclopropanation, avoiding the employment of high pressures of CO,[8] (2) it represented an example of a multicomponent reaction (MCR),[9]



Scheme 1. Reactivity of FCC **1a** towards different types of olefins.

which typically are advantageous in terms of operational simplicity and atom economy, and (3) it provided straightforward access to a highly complex structure. Therefore, we decided to analyze the scope and limitations of such a transformation and we present in this article our findings.

Results and Discussion

We started our investigation by checking the reaction conditions regarding temperature, number of equivalents of olefin, and solvent (Table 1). To examine the solvent effect, we carried out reactions in toluene, hexane, acetonitrile, 1,2-dimethoxyethane (DME), 1,2-dichloroethane (DCE), THF and neat (Table 1, Entries 1–8). In all cases, a mixture of four diastereomers was detected; the major *cis*-**4a** isomers could be separated from the minor *trans*-**4a** isomers and isolated as diastereomeric mixtures by flash chromatography. Interestingly, the lowest *trans*/*cis* ratio was observed when the reaction was carried out neat (Table 1, Entry 8). The reaction did not proceed at temperatures below 90 °C, and the yield was only slightly improved at higher tempera-

[a] Instituto Universitario de Química Organometálica "Enrique Moles", Unidad Asociada al C.S.I.C., Universidad de Oviedo, C/Julián Clavería 8, 33006 Oviedo, Spain
E-mail: EAH@uniovi.es
[‡] X-ray structure determination.
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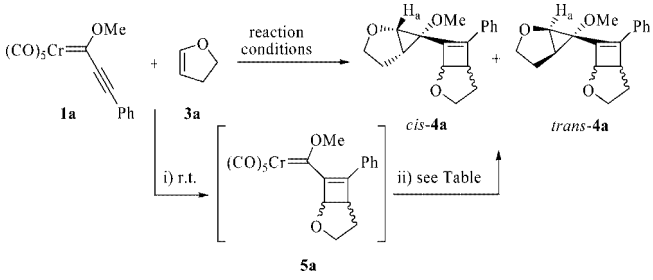
tures (Table 1, Entry 1 vs. 2). A high excess of olefin (20 equiv.) was also required to reach the reaction yields reported in Table 1.

Table 1. Optimization of the conditions for the formation of **4a** by reaction of FCC **1a** with 2,3-dihydrofuran (**3a**; 20 equiv.).

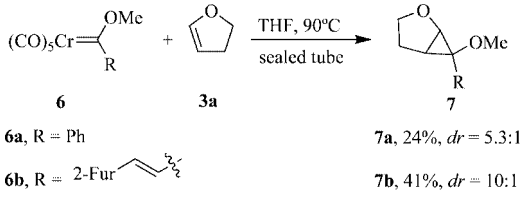


Entry	Solvent	T [°C]	Yield[a] [%]	*dr* (*trans*:*cis*)[b]
1	toluene	90	21	7:5 : 54:34 (1:7.3)
2	toluene	110	24	9:6 : 53:32 (1:5.7)
3	hexane	90	8	–:– : 67:33[c]
4	CH_3CN	90	48	18:11 : 34:37 (1:2.4)
5	DME	90	38	12:13 : 38:37 (1:3)
6	DCE	90	36	10:7 : 43:40 (1:4.9)
7	THF	90	52	2:3 : 65:30 (1:19)
8	neat	90	26	11:21 : 29:39 (1:1.8)
9	toluene	i) r.t., ii) 110	45	2:1 : 65:32 (1:32)
10	THF	i) r.t., ii) 90	39	3:3 : 60:34 (1:15.7)
11	neat	i) r.t., ii) 90	34	3:9 : 35:53 (1:7.3)

[a] Yield of isolated *cis*-**4a** (as a mixture of diastereomers (maj:min)] after flash chromatography. [b] Ratio of the four diastereomers, determined by ^{1}H NMR (300 or 400 MHz) spectroscopy from the crude reaction mixture on the basis of the signal corresponding to H_a; diastereomers are listed from low field to high field (below, in brackets, *trans*/*cis* ratio). [c] The *trans*/*cis* ratio and the ratio of the *trans* isomers could not be determined.

Taking into account that alkynyl FCCs and electron-rich olefins add in a [2+2] fashion at room temperature,[10] the stepwise option, which consisted of carrying out the reaction at room temperature until disappearance of **1a** and then heating the reaction mixture until the disappearance of intermediate **5a** (Table 1, Entries 9–11), was also tested. Among the combination of parameters, both reactions performed in THF at 90 °C gave the highest, yet moderate, yields (Table 1, Entry 7).

Therefore, under these optimized conditions, cyclobutenyl FCC **5a** underwent cyclopropanation with 2,3-dihydrofuran (**3a**). To check if the presence of the cyclobutene ring was a structural requirement to accomplish such a transformation, we mixed **3a** with aryl or alkenyl FCCs **6** under identical conditions, which provided corresponding cyclopropanes **7** in modest yields and diastereoselectivities (Scheme 2). From these results, it is clear that the presence of the cyclobutene ring in the FCC is not required to achieve the cyclopropanation of **3a**; the fact that it is accomplished under the described reaction conditions may be attributed to the sealed tube, which somehow may mimic the high CO pressure conditions.



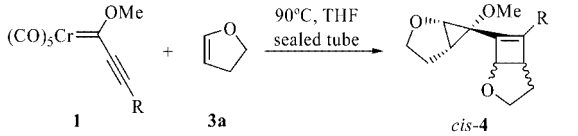
Scheme 2. Cyclopropanation of 2,3-dihydrofuran (**3a**) with different FCCs **6**.

We next turned our attention to analyze the scope of the [2+2]/[2+1] reaction sequence, for both electron-rich olefins **3** and alkynyl FCCs **1**. The process presented severe limitations regarding the nature of the olefin substrates; reactions with 2,3-dihydropyran (**3b**), ethyl vinyl ether (**3c**), or 2,3-dihydro-5-trimethylsilyloxyfuran (**3d**) gave either polymerization or only the [2+2] cycloaddition without the final cyclopropanation. At best, a small amount of the [2+2]/[2+1] cycloadduct was detected by GC–MS when the olefin was 2,3-dihydro-2-phenylfuran (**3e**).

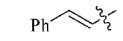
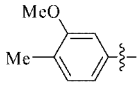
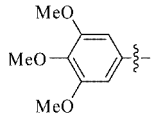
Regarding the reactivity of alkynyl FCCs **1**, less than 10% of adduct was detected by GC–MS when R was aliphatic (R = *n*-hexyl, *tert*-butyl) and, not surprisingly, only a 16% yield of **4b** was estimated by ^{1}H NMR spectroscopy when R was an alkenyl group[11] (Table 2, Entry 2). However, the [2+2]/[2+1] reaction took place successfully for aromatic substituted alkynyl FCCs **1c**–**h**, and the moderate yields reached are in the usual range for most of the cyclopropanations involving alkynyl FCCs.[6] Thus, electron-withdrawing- (Table 2, Entries 3, 4) or electron-donating- (Table 2, Entries 5–7), and mono- (Table 2, Entry 6) or polysubstituted (Table 2, Entries 5, 7) phenylalkynyl FCCs **1** react with 2,3-dihydrofuran (**3a**) in the expected way to form the corresponding three-component adducts in the yields displayed in Table 2. Even sterically demanding naphthyl-substituted FCC **1h** partook in the [2+2]/[2+1] sequence, albeit to a lower extent.[12] Again, four diastereomers were generally obtained, the *cis*-isomers being the major ones, except for FCC **1h** where only two diastereomers of **4h** were observed and the same stereochemistry as for the other adducts was assumed (Table 2, Entry 8). The analogous tungsten FCCs also formed cyclopropane derivatives **4a**,**b** when reacted with **3a**, although less efficiently (Table 2, Entries 1, 2, values in brackets).

The identity of adducts **4** was determined by 1D- and 2D-NMR spectroscopy, including NOESY experiments. Thus, nOe crosspeaks were observed between H^a and H^b for the major diastereomers of **4a**: this result indicates a *cis*-relationship between the cyclopropane-fused tetrahydrofuran ring and the –OMe group for both major diastereomers (Figure 1). An X-ray structure for *cis*-**4g**-min,[13]

Table 2. Scope of the reaction.

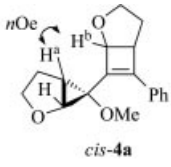


1 3a *cis*-4

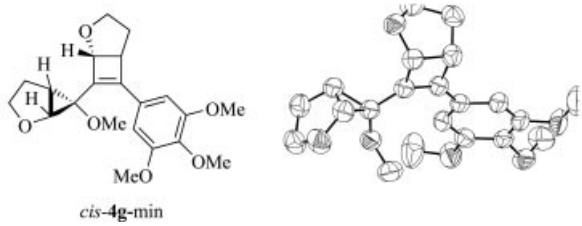
Entry	1	R	4	Yield [%][a]	*dr*[b]
1	**1a**	Ph	**4a**	52 (34)[c]	7:5 : 54:34 (3:9 : 23:65)[c]
2[d]	**1b**		**4b**	16 (4)[c]	–[e]
3	**1c**	*p*-Cl-C_6H_4	**4c**	34	3:3 : 68:26
4	**1d**	*p*-F-C_6H_4	**4d**	43	8:8 : 59:33
5	**1e**		**4e**	48	2:3 : 62:33
6	**1f**	*p*-MeO-C_6H_4	**4f**	39	–:–[e] : 62:38
7	**1g**		**4g**	31	2:3 : 57:38
8	**1h**	1-Naphthyl	**4h**	17[f]	–:– : 78:22[g]

[a] Yield of isolated *cis*-**4** products after flash chromatography unless otherwise stated. [b] Ratio of the four diastereomers, determined by ^{1}H NMR (300 or 400 MHz) spectroscopy from the crude reaction mixture on the basis of the signal corresponding to H_a (see Table 1); diastereomers are listed from low field to high field (the two first values correspond to the *trans* isomers and the final two values correspond to the *cis* isomers). [c] In brackets, yields and *dr* obtained by employing the analogue tungsten FCCs. [d] Product not isolated; yields estimated by ^{1}H NMR (300 MHz or 400 MHz) spectroscopy. [e] Not determined. [f] See ref.[11] [g] Only two diastereomers were detected; *dr* determined by integration of the MeO– signal.

obtained after crystallization from the diastereomeric mixture, allowed the determination of the relative configuration for the minor of the two *cis* isomers (Figure 1).



cis-**4a**



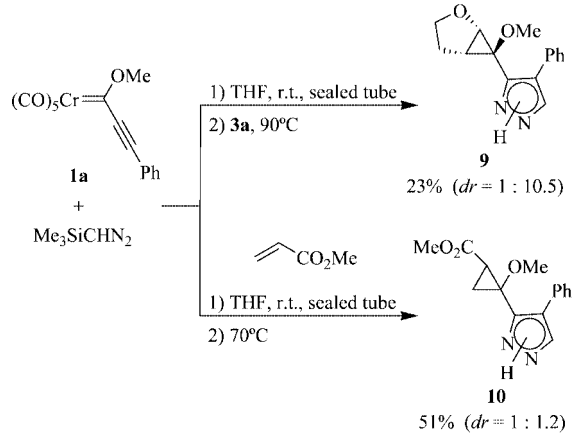
cis-**4g**-min

Figure 1. Structural elucidation based on: a) NOESY crosspeaks for *cis*-**4a** and b) X-ray crystallographic analysis for *cis*-**4g**-min.

The formation of adducts **4** can be explained by a initial [2+2] cycloaddition[10] followed by a cyclopropanation according to the nondissociative mechanism proposed by Casey and Cesa.[8a] The stereochemical results indicate that the *cyclopropanation reaction is highly stereoselective* [from 7.3:1 to 19:1 (Table 2, Entry 1 vs. 5)] *in regard to the configuration of the cyclopropane ring*, probably for steric reasons: the less-hindered substituent of the carbene complex (the –OMe group) places at the same side than the bulkier substituents of the double bond.

Additionally, we also explored the feasibility of alternative tandem [*n*+2]/cyclopropanation sequences involving complexes **1**. Thus, we tested other [2+2]/[2+1] reactions, involving: (1) an electron-rich olefin (**3a**,**e**) for the first step and an electron-deficient olefin (methyl acrylate) for the second one, or (2) a different electron-rich olefin for the first step [**3b**, 1,1-diethoxyethene (**3f**), 1-methoxy-2-methyl-1-trimethylsilyloxy-1-propene (**3g**)] and 2,3-dihydrofuran (**3a**) for the second step. However, those reactions produced multiple compounds and/or low ratios of the expected adducts were detected by GC–MS.

However, we succeeded in performing a tandem [3+2]/[2+1] reaction. Thus, the reaction of FCC **1a** with trimethylsilyldiazomethane (as a 1,3-dipole, for the [3+2]-cycloaddition[14]) and 2,3-dihydrofuran or methyl acrylate originated the corresponding adducts **9** or **10** as mixtures of diastereomers (Scheme 3). For the formation of **10**, the reagents were mixed together at room temperature and, once the TLC indicated disappearance of **1a**, warmed to 70 °C. By employing this procedure the possible cyclopropanation of methyl acrylate as a side reaction[6] was minimized. However, for the synthesis of **9**, 2,3-dihydrofuran was added at a later stage, to avoid its [2+2] cycloaddition to **1a**.



Scheme 3. [3+2]/[2+1] reaction sequences.

Conclusions

We developed a [2+2]/[2+1] reaction sequence, between aryl-substituted alkynyl carbene complexes and two units of 2,3-dihydrofuran. The sequence presents limitations regarding the scope of the olefin substrate and the reaction efficiency. On the other hand, some of the salient features of the process are: (1) it is a multicomponent process that involves the *one-pot creation of four C–C bonds*, (2) products with *high structural complexity* were obtained, (3) the cyclo-

propanation reaction takes place with *high diastereoselectivity regarding the configuration of the cyclopropane ring*, and (4) the reaction conditions proved that the cyclopropanation of 2,3-dihydrofuran *does not require the use of high pressures of CO*. Moreover, a tandem [3+2]/[2+1] reaction was developed, demonstrating the feasibility of sequential reactions of alkynyl FCCs with a 1,3-dipole followed by electron-deficient or electron-rich olefin.

Experimental Section

General Considerations: All reactions involving air sensitive compounds were carried out under a N_2 atmosphere (99.99%). All glassware was oven-dried (120 °C), evacuated, and purged with nitrogen. 2,3-Dihydrofuran (**3a**), trimethylsilyldiazomethane, methyl acrylate, and all common reagents and solvents were obtained from commercial suppliers and used without any further purification unless otherwise indicated. Solvents were dried by standard methods. Hexane and ethyl acetate were purchased as extra-pure grade reagents and used as received. TLC was performed on aluminum-backed plates coated with silica gel 60 with F_{254} indicator; the chromatograms were visualized under ultraviolet light and/or by staining with a Ce/Mo reagent and subsequent heating. R_f values are reported on silica gel. Flash column chromatography was carried out on silica gel 60, 230–240 mesh. Routine NMR measurements were recorded with Bruker AC-300, DPX-300, or AV-400 spectrometers. ^{1}H NMR: splitting pattern abbreviations are: s, singlet; br. s, broad singlet; d, doublet; t, triplet; q, quartet; m, multiplet; dd, double doublet; dt, double triplet. ^{13}C NMR: multiplicities were determined by DEPT, abbreviations are: q, CH_3; t, CH_2; d, CH; s, quaternary carbons; in the case of compounds bearing F, the abbreviation refers to the number of hydrogen atoms linked to a determined carbon atom and the F–C coupling constant is reported for those carbon atoms which appeared as doublets due to F–C coupling. ^{19}F NMR chemical shifts are referenced to $CFCl_3$. COSY, HSQC, HMBC, and NOESY experiments were carried out with Bruker AV-400 and/or AV-600 spectrometers. Standard pulse sequences were employed for the DEPT experiments. FTIR was performed with a Mattson 3000 FTIR spectrometer. Mass spectra were determined by Universidad de Oviedo and Universidad de Vigo (CACTI) with a Finnigan Mat95 and a VG AutoSpec M Mass Spectrometers, respectively, for high-resolution mass spectra (HRMS); low-resolution mass spectra were obtained with a Hewlett–Packard 5880 A Spectrometer. Electron impact (70 eV) or fast atom bombardment (FAB) techniques were employed. Melting points were determined with a Büchi-Tottoli apparatus and are uncorrected. Elemental analyses were carried out with a Perkin–Elmer 240 B microanalyzer.

Preparation of Alkynyl Fischer Carbene Complexes 1: Fischer carbene complexes (FCCs) **1a**[15] and **1b**[16] were prepared as described in the literature. FCCs **1c**[11] and **1f**[11,17] were previously prepared in our labs following a general procedure[3] from the corresponding acetylenes but their spectroscopic data have not been reported in publications other than a Ph. D. Thesis[17] and are reproduced below. FCCs **1d**,**e**,**g**,**h** were prepared for the first time from the corresponding acetylenes,[18] according to the General Procedure.

General Procedure: A Schlenk flask was charged with the corresponding acetylene (0.023 mol) and $Cr(CO)_6$ (4.79 g, 0.021 mol) in THF (70 mL). The suspension was cooled to –78 °C, and *n*-BuLi (1.6 M in hexane, 16.3 mL, 0.026 mol) was added dropwise over 20–25 min. The mixture was stirred overnight allowing the temperature to rise slowly to ambient temperature. The orange solution was then cooled to –20 °C before MeOTf (2.46 mL, 0.021 mol) was added. The stirring was maintained for 20 min, and the dark purple reaction mixture was quenched with saturated K_2CO_3 (50 mL). The aqueous phase was extracted with diethyl ether until colorless (4 × 50 mL), and the resulting organic solution was dried with $MgSO_4$, filtered, and concentrated to dryness. The residue was flash chromatographed over silica gel (hexane/EtOAc), collecting the dark purple spot. When the complexes were solids they were further purified by recrystallization from hexanes at –25 °C.

Pentacarbonyl[3-(4-chlorophenyl)-1-methoxypropynylidene]chromium(0) 1c: Black solid, m.p. 123–125 °C; yield 52%. R_f = 0.42 (hexane/EtOAc: 5:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.52 (d, J = 8.2 Hz, 2 H), 7.43 (d, J = 8.5 Hz, 2 H), 4.42 (s, 3 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 315.1 (s), 225.9 (s), 216.5 (s, 4 C), 138.5 (s), 134.1 (d, 2 CH), 129.8 (d, 2 CH), 119.7 (s), 92.6 (s), 66.3 (q) ppm, the signal corresponding to the β-acetylenic carbon (around 130–135 ppm) was not observed. FTIR (neat): $\tilde{\nu}$ = 2253, 2151, 2061, 1955 cm^{-1}. HRMS (EI): calcd. for $C_{15}H_7ClCrO_6$ $[M]^+$ 369.9331; found 369.9316.

Pentacarbonyl[3-(4-fluorophenyl)-1-methoxypropynylidene]chromium(0) (1d): Purple solid, m.p. 119–121 °C; yield 34%. R_f = 0.50 (hexane/EtOAc, 5:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.63–7.60 (m, 2 H), 7.21–7.15 (m, 2 H), 4.44 (s, 3 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 315.1 (s), 225.8 (s), 216.5 (s, 4 C), 165.2 (s, $^1J_{C-F}$ = 254.5 Hz), 135.5 (d, $^3J_{C-F}$ = 9.2 Hz, 2 C), 117.5 (s, $^4J_{C-F}$ = 3.5 Hz), 116.9 (d, $^2J_{C-F}$ = 22.4 Hz, 2 C), 92.3 (s), 66.3 (q) ppm, the signal corresponding to the β-acetylenic carbon (around 130–135 ppm) was not observed. ^{19}F NMR (282.4 MHz, $CDCl_3$): δ = –105.01 (s) ppm. FTIR (neat): $\tilde{\nu}$ = 2152, 2063, 1968 cm^{-1}. MS: *m*/*z* (%) = 354 (15) $[M]^+$, 298 (30), 270 (33), 242 (39), 214 (100), 184 (62), 171 (41). HRMS (EI): calcd. for $C_{15}H_7CrFO_6$ $[M]^+$ 353.9632; found 353.9624. $C_{15}H_7CrFO_6$ (354.21): calcd. C 50.86, H 1.99; found C 51.07, H 2.03.

Pentacarbonyl[3-(3-methoxy-4-methylphenyl)-1-methoxypropynylidene]chromium(0) (1e): Purple solid, m.p. 106–108 °C; yield 71%. R_f = 0.31 (hexane/EtOAc, 5:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.20 (d, J = 6.0 Hz, 1 H), 7.12 (dd, ^3J = 7.6 Hz, ^4J = 1.0 Hz, 1 H), 7.01 (s, 1 H), 4.42 (s, 3 H), 3.86 (s, 3 H), 2.28 (s, 3 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 314.7 (s), 225.0 (s), 216.7 (s, 4 C), 158.2 (s), 132.7 (d), 131.4 (d), 125.7 (s), 119.4 (s), 113.9 (d), 92.6 (s), 66.1 (q), 55.8 (q), 17.0 (q) ppm, the signal corresponding to the β-acetylenic carbon (around 130–135 ppm) was not observed. FTIR (neat): $\tilde{\nu}$ = 2145, 2059, 1951 cm^{-1}. HRMS (EI): calcd. for $C_{17}H_{12}CrO_7$ $[M]^+$ 379.9983; found 379.9969.

Pentacarbonyl[1-methoxy-3-(4-methoxyphenyl)propynylidene]chromium(0) (1f): Black solid, m.p. 75–78 °C; yield 87%. R_f = 0.31 (hexane). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.58–7.54 (m, 2 H), 6.99–6.94 (m, 2 H), 4.39 (s, 3 H), 3.88 (s, 3 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 313.3 (s), 225.8 (s), 216.8 (s, 4 CO), 163.2 (s), 138.0 (s), 135.6 (d, 2 CH), 115.1 (d, 2 CH), 113.1 (s), 93.6 (s), 65.9 (q), 55.9 (q) ppm. FTIR (neat): $\tilde{\nu}$ = 2059, 1940 cm^{-1}. $C_{16}H_{10}CrO_7$ (366.24): calcd. C 52.47, H 2.75; found C 52.21, H 3.03.

Pentacarbonyl[1-methoxy-3-(3,4,5-trimethoxyphenyl)propynylidene]-chromium(0) (1g): Red solid, m.p. 91–92 °C; yield 29%. R_f = 0.15 (hexane/EtOAc, 5:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 6.82 (s, 2 H), 4.42 (s, 3 H), 3.93 (s, 3 H), 3.88 (s, 6 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 314.2 (s), 225.8 (s), 216.6 (s, 4 C), 153.7 (s, 2 C), 142.3 (s), 115.8 (s), 110.6 (d, 2 CH), 92.3 (s), 66.2 (q), 61.4 (q), 56.6 (q, 2 CH_3) ppm, the signal corresponding to the β-acetylenic carbon (around 130–135 ppm) was not observed. FTIR (neat): $\tilde{\nu}$ = 2306, 2039, 1951 cm^{-1}. MS: *m*/*z* (%) = 426 (6) $[M]^+$, 370 (13),

342 (16), 314 (18), 286 (72). HRMS (EI): calcd. for $C_{16}H_{14}CrO_7$ $[M - 2(CO)]^+$ 370.0139; found 370.0154.

Pentacarbonyl[1-methoxy-3-(1-naphthyl)propynylidene]chromium(0) (1h): Purple solid, m.p. 110–112 °C; yield 56%. R_f = 0.54 (hexane/EtOAc, 5:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 8.21 (d, J = 8.2 Hz, 1 H), 8.03 (d, J = 8.2 Hz, 1 H), 7.95–7.90 (m, 2 H), 7.69–7.54 (m, 3 H), 4.56 (s, 3 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 314.2 (s), 225.9 (s), 216.7 (s, 4 C), 134.5 (d), 133.6 (s), 133.1 (d), 132.8 (s), 129.1 (d), 128.3 (d), 127.5 (d), 125.9 (d, 2 CH), 118.9 (s), 97.2 (s), 66.2 (q) ppm, the signal corresponding to the β-acetylenic carbon (around 130–135 ppm) was not observed. FTIR (neat): $\tilde{\nu}$ = 2253, 2137, 2060, 1953 cm^{-1}. MS: m/z (%) = 386 (10) $[M]^+$, 330 (28), 302 (18), 274 (36), 246 (100), 216 (78), 152 (56). HRMS (EI): calcd. for $C_{19}H_{10}CrO_6$ $[M]^+$ 385.9877; found 385.9877. $C_{19}H_{10}CrO_6$ (386.28): calcd. C 59.08, H 2.61; found C 58.6, H 2.65.

[2+2]/[2+1] Reaction Between 2,3-Dihydrofuran (3a) and Alkynyl Fischer Carbene Complexes 1 – General Procedure for the Synthesis of Adducts *cis*-4: A solution of the appropriate carbene complex **1** (0.5 mmol) and 2,3-dihydrofuran (**3a**; 10 mmol, 20 equiv.) in dry THF (10 mL) under an inert atmosphere was warmed at 90 °C in a sealed tube until the starting carbene complex was completely consumed (1.5–18 h) as indicated by a color change of the solution in the reaction vessel and further confirmed by TLC analysis. The solvents were then removed under vacuum, and the residue was redissolved in a mixture of hexane/ethyl acetate and exposed to light in an open-air vessel to induce decomplexation of the metal species present. The resulting suspension was filtered through Celite, and the solvents were removed under vacuum. A ^{1}H NMR spectrum was recorded of the crude residue to determine the reaction diastereoselectivities, as indicated in Table 2. The residue was purified by flash column chromatography (hexane/EtOAc, 20:1 to 5:1) to give cyclopropanes *cis*-**4** in the yields reported in Table 2. Occasionally, the methyl esters that resulted from the oxidation of the cyclobutenyl carbene complexes (which result from the initial [2+2] cycloaddition between **1** and **3a**) could not be separated from the *cis*-**4a** adducts by column chromatography. Basic hydrolysis of such methyl esters by employing LiOH, followed by an acid–base extraction in basic aqueous media to separate the formed acid, and evaporation of the organic solvents, yielded adducts *cis*-**4a** in the yields listed in Table 2. NMR spectroscopic data: the abbreviation "min" refers to the signals assigned to the minor *cis* isomer and the abbreviation "maj" to the signals belonging to the major one; in the cases where nothing is specified, either it hasn't been possible to assign the signal to any of the isomers or it belongs to both of them.

(1*S,5*S**,1′*R**,5′*S**,6′*R**)-7-(6′-Methoxy-2′-oxabicyclo[3.1.0]-hexan-6′-yl)-6-phenyl-2-oxabicyclo[3.2.0]hept-6-ene (*cis*-4a-maj) and (1*R**,5*R**,1′*R**,5′*S**,6′*R**)-7-(6′-Methoxy-2′-oxabicyclo[3.1.0]-hexan-6′-yl)-6-phenyl-2-oxabicyclo[3.2.0]hept-6-ene (*cis*-4a-min):** Yellow oil; data retrieved from a 1.8:1 mixture of nonseparated diastereomers. Combined yield: 52%. R_f = 0.23 (hexane/EtOAc, 5:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.71–7.67 (m, 2 H, maj; 2 H, min), 7.41–7.31 (m, 2 H, maj; 2 H, min), 7.30–7.25 (m, 1 H, maj; 1 H, min), 4.73 (d, J = 3.2 Hz, 1 H, maj), 4.65 (d, J = 3.2 Hz, 1 H, min), 4.32–3.78 (m, 5 H, maj; 5 H, min), 3.63 (dd, J = 3.2 Hz, J = 7.4 Hz, 1 H, maj), 3.57 (dd, J = 3.6 Hz, J = 7.6 Hz, 1 H, min), 3.33 (s, 3 H, min), 3.32 (s, 3 H, maj), 2.28–2.21 (m, 2 H, maj; 2 H, min), 2.09–2.05 (m, 1 H, maj), 2.02–1.98 (m, 1 H, min), 1.94 (dd, J = 5.3 Hz, J = 12.5 Hz, 1 H, min), 1.82 (dd, J = 5.3 Hz, J = 12.6 Hz, 1 H, maj), 1.72–1.62 (m, 1 H, maj; 1 H, min) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 140.1 (s, maj), 139.7 (s, min), 135.4 (s, min), 134.9 (s, maj), 132.9 (s, min), 132.6 (s, maj), 128.2 (d, 4 CH), 127.9 (d, 2 CH), 127.8 (d, 4 CH), 77.2 (d, maj), 76.7 (d, min), 73.1 (t, maj), 72.9 (t, min), 66.7 (s, 2 C), 66.3 (t, 2 CH_2), 66.1 (d, maj), 66.0 (d, min), 56.3 (q, 2 CH_3), 44.3 (d, min), 44.2 (d, maj), 29.1 (d, maj), 29.0 (d, min), 26.8 (t, min), 26.4 (t, maj), 25.7 (t, 2 CH_2) ppm. FTIR (neat): $\tilde{\nu}$ = 1634, 1493, 1447, 1117, 1064 cm^{-1}. MS: m/z (%) = 284 (6) $[M]^+$, 253 (91), 239 (100), 128 (53), 115 (65). HRMS (EI): calcd. for $C_{18}H_{20}O_3$ $[M]^+$ 284.1412; found 284.1424.

(1*S,5*S**,1′*R**,5′*S**,6′*R**)-6-(4-Chlorophenyl)-7-(6′-methoxy-2′-oxabicyclo[3.1.0]hexan-6′-yl)-2-oxabicyclo[3.2.0]hept-6-ene (*cis*-4c-maj) and (1*R**,5*R**,1′*R**,5′*S**,6′*R**)-6-(4-Chlorophenyl)-7-(6′-methoxy-2′-oxabicyclo[3.1.0]hexan-6′-yl)-2-oxabicyclo[3.2.0]hept-6-ene (*cis*-4c-min):** Yellow oil; data retrieved from a 2.2:1 mixture of nonseparated diastereomers. Combined yield: 34%. R_f = 0.22 (hexane/EtOAc, 5:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.67–7.61 (m, 4 H), 7.37–7.32 (m, 4 H), 4.72 (d, J = 3.5 Hz, 1 H, maj), 4.63 (d, J = 3.4 Hz, 1 H, min), 4.30–3.77 (m, 10 H), 3.61 (dd, J = 3.4 Hz, J = 7.5 Hz, 1 H, maj), 3.54 (dd, J = 3.5 Hz, J = 7.4 Hz, 1 H, min), 3.34 (s, 3 H, min), 3.32 (s, 3 H, maj), 2.31–2.22 (m, 4 H), 2.13–2.08 (m, 1 H, maj), 2.05–1.99 (m, 1 H, min), 1.90 (dd, J = 5.2 Hz, J = 12.6 Hz, 1 H, min), 1.80 (dd, J = 5.4 Hz, J = 12.6 Hz, 1 H, maj), 1.72–1.59 (m, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 138.5 (s, maj), 138.0 (s, min), 136.2 (s, min), 135.7 (s, maj), 133.78 (s, maj), 133.76 (s, min), 131.4 (s, min), 131.1 (s, maj), 129.3 (d, 4 CH), 128.5 (d, 4 CH), 77.2 (d, maj), 76.6 (d, min), 73.1 (t, maj), 72.9 (t, min), 66.9 (s, maj), 66.6 (s, min), 66.5 (t, min), 66.4 (t, maj), 66.2 (d, maj) 66.1 (d, min), 56.3 (q), 44.3 (d, min), 44.2 (d, maj), 29.3 (d, maj), 29.2 (d, min), 26.8 (t, min), 26.3 (t, maj), 25.8 (t, min), 25.7 (t, maj) ppm. FTIR (neat): $\tilde{\nu}$ = 1705, 1604, 1509, 1254, 1177 cm^{-1}. MS: m/z (%) = 318 (5) $[M]^+$, 317 (15), 287 (38), 273 (100), 163 (39). HRMS (EI): calcd. for $C_{18}H_{19}ClO_3$ $[M]^+$ 318.1023; found 318.1010.

(1*S,5*S**,1′*R**,5′*S**,6′*R**)-6-(4-Fluorophenyl)-7-(6′-methoxy-2′-oxabicyclo[3.1.0]hexan-6′-yl)-2-oxabicyclo[3.2.0]hept-6-ene (*cis*-4d-maj) and (1*R**,5*R**,1′*R**,5′*S**,6′*R**)-6-(4-Fluorophenyl)-7-(6′-methoxy-2′-oxabicyclo[3.1.0]hexan-6′-yl)-2-oxabicyclo[3.2.0]hept-6-ene (*cis*-4d-min):** Yellow oil; data retrieved from a 1.66:1 mixture of nonseparated diastereomers. Combined yield: 43%. R_f = 0.37 (hexane/EtOAc, 5:1). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.70–7.63 (m, 4 H), 7.09–7.02 (m, 4 H), 4.71 (d, J = 3.3 Hz, 1 H, maj), 4.62 (d, J = 3.6 Hz, 1 H, min), 4.26–3.75 (m, 10 H), 3.59 (dd, J = 3.4 Hz, J = 7.7 Hz, 1 H, maj), 3. 52 (dd, J = 3.3 Hz, J = 7.8 Hz, 1 H, min), 3.32 (s, 3 H, min), 3.30 (s, 3 H, maj), 2.27–2.20 (m, 4 H), 2.06 (td, J = 1.1 Hz, J = 6.1 Hz, 1 H, maj), 1.99 (td, J = 1.0 Hz, J = 6.1 Hz, 1 H, min), 1.88 (dd, J = 5.1 Hz, J = 12.3 Hz, 1 H, min), 1.78 (dd, J = 5.4 Hz, J = 12.6 Hz, 1 H, maj), 1.73–1.60 (m, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 162.48 (s, $^1J_{C-F}$ = 248.7 Hz, maj), 162.47 (s, $^1J_{C-F}$ = 248.7 Hz, min), 139.0 (s, maj), 138.5 (s, min), 134.8 (s, $^6J_{C-F}$ = 2.3 Hz, maj), 134.4 (s, $^6J_{C-F}$ = 2.3 Hz, min), 129.87 (d, $^3J_{C-F}$ = 8.2 Hz, maj, 2 CH), 129.81 (d, $^3J_{C-F}$ = 8.2 Hz, min, 2 CH), 129.2 (s, $^4J_{C-F}$ = 2.9 Hz, min), 129.0 (s, $^4J_{C-F}$ = 3.5 Hz, maj), 115.3 (d, $^2J_{C-F}$ = 21.5 Hz, 4CH), 77.3 (d, maj), 76.8 (d, min), 73.2 (t, maj), 73.0 (t, min), 66.8 (s), 66.49 (t, min), 66.43 (t, maj), 66.1 (d, maj), 66.0 (d, min), 56.3 (q), 44.4 (d, min), 44.3 (d, maj), 29.2 (d, maj), 29.0 (d, min), 26.8 (t, maj), 26.4 (t, min), 25.81 (t, min), 25.78 (t, maj) ppm. ^{19}F NMR (282.4 MHz, $CDCl_3$): δ = –112.98 (s, maj), –112.97 (s, maj) ppm. FTIR (neat): $\tilde{\nu}$ = 1727, 1600, 1507, 1230, 1119, 1063 cm^{-1}. MS: m/z (%) = 301 (18) $[M - H]^+$, 271 (40), 257 (100). HRMS (EI): calcd. for $C_{18}H_{18}FO_3$ $[M - H]^+$ 301.1235; found 301.1231.

(1*S,5*S**,1′*R**,5′*S**,6′*R**)-6-(3-Methoxy-4-methylphenyl)-7-(6′-methoxy-2′-oxabicyclo[3.1.0]hexan-6′-yl)-2-oxabicyclo[3.2.0]hept-6-ene (*cis*-4e-maj) and (1*R**,5*R**,1′*R**,5′*S**,6′*R**)-6-(3-Methoxy-4-**

methylphenyl)-7-(6′-methoxy-2′-oxabicyclo[3.1.0]hexan-6′-yl)-2-oxabicyclo[3.2.0]hept-6-ene (*cis*-4e-min): Brown oil; data retrieved from a 2.0:1 mixture of nonseparated diastereomers. Combined yield: 48%. R_f = 0.25 (hexane/EtOAc, 5:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.42–7.39 (m, 2 H), 7.17–7.08 (m, 4 H), 4.78 (d, J = 3.4 Hz, 1 H, maj), 4.66 (d, J = 3.5 Hz, 1 H, min), 4.28–3.93 (m, 8 H), 3.88 (s, 6 H), 3.84–3.77 (m, 2 H), 3.63 (dd, J = 3.4 Hz, J = 7.6 Hz, 1 H, maj), 3.56 (dd, J = 3.4 Hz, J = 7.6 Hz, 1 H, min), 3.39 (s, 3 H, min), 3.37 (s, 3 H, maj), 2.25 (s, 6 H, m, 2 H), 2.07–1.96 (m, 4 H), 1.93 (dd, J = 5.2 Hz, J = 12.6 Hz, 1 H, min), 1.84 (dd, J = 5.4 Hz, J = 12.6 Hz, 1 H, maj), 1.76–1.63 (m, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 157.8 (s), 140.8 (s, maj), 140.5 (s, min), 134.5 (s, min), 134.1 (s, maj), 131.9 (s, min), 131.7 (s, maj), 130.4 (d, 2 CH), 127.0 (s), 1198 (d, maj), 119.7 (d, min), 109.93 (d, maj), 109.87 (d, min), 77.6 (d, maj), 76.9 (d, min), 73.3 (t, maj), 73.1 (t, min), 66.8 (s), 66.47 (t, min), 66.45 (t, maj), 66.10 (d, maj), 66.05 (d, min), 56.5 (q), 55.3 (q), 44.5 (d, min), 44.3 (d, maj), 29.3 (d, maj), 29.1 (d, min), 27.0 (t, min), 26.6 (t, maj), 25.89 (t, min), 25.83 (t, maj) 16.2 (q) ppm. FTIR (neat): $\tilde{\nu}$ = 1651, 1507, 1240, 1116, 1064 cm^{-1}. MS: m/z (%) = 328 (60) $[M]^+$, 327 (41), 313 (93), 297 (100), 283 (97). HRMS (EI): calcd. for $C_{20}H_{24}O_4$ 328.1675; found 328.1685.

(1*S,5*S**,1′*R**,5′*S**,6′*R**)-7-(6′-Methoxy-2′-oxabicyclo[3.1.0]-hexan-6′-yl)-6-(4-methoxyphenyl)-2-oxabicyclo[3.2.0]hept-6-ene (*cis*-4f-maj) and (1*R**,5*R**,1′*R**,5′*S**,6′*R**)-7-(6′-Methoxy-2′-oxabicyclo[3.1.0]hexan-6′-yl)-6-(4-methoxyphenyl)-2-oxabicyclo[3.2.0]hept-6-ene (*cis*-4f-min):** Brown oil; data retrieved from a 1.6:1 mixture of nonseparated diastereomers. Combined yield: 39%. R_f = 0.16 (hexane/EtOAc, 5:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.68–7.63 (m, 4 H), 6.95–6.91 (m, 4 H), 4.75 (d, J = 3.4 Hz, 1 H, maj), 4.67 (d, J = 3.5 Hz, 1 H, min), 4.25–3.78 (m, 10 H), 3.85 (s, 6 H), 3.60 (dd, J = 3.4 Hz, J = 7.5 Hz, 1 H, maj), 3.54 (dd, J = 3.5 Hz, J = 7.6 Hz, 1 H, min), 3.37 (s, 3 H, min), 3.35 (s, 3 H, maj), 2.30–2.22 (m, 4 H), 2.04 (m, 1 H, maj), 1.99 (m, 1 H, min), 1.91 (dd, J = 5.2 Hz, J = 12.6 Hz, 1 H, min), 1.83 (dd, J = 5.3 Hz, J = 12.6 Hz, 1 H, maj), 1.77–1.62 (m, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 159.5 (s), 140.2 (s, maj), 139.8 (s, min), 132.6 (s, min), 132.3 (s, maj), 129.51 (d, 4 CH), 125.8 (s, min), 125.6 (s, maj), 113.8 (d, 4 CH), 77.5 (d, maj), 76.9 (d, min), 73.2 (t, maj), 73.0 (t, min), 66.7 (s), 66.41 (t, min), 66.36 (t, maj), 66.05 (d, maj), 66.02 (d, min), 56.3 (q), 55.2 (q), 44.3 (d, min), 44.2 (d, maj), 29.0 (d, maj), 28.8 (d, min), 26.8 (t, min), 26.5 (t, maj), 25.86 (t, min), 25.83 (t, maj) ppm. FTIR (neat): $\tilde{\nu}$ = 1718, 1488, 1092, 1064 cm^{-1}. MS: m/z (%) = 314 (4) $[M]^+$, 313 (14), 283 (47), 269 (41), 149 (50), 86 (64), 84 (100). HRMS (EI): calcd. for $C_{19}H_{22}O_4$ 314.1518; found 314.1510.

(1*S,5*S**,1′*R**,5′*S**,6′*R**)-7-(6′-Methoxy-2′-oxabicyclo[3.1.0]-hexan-6′-yl)-2-oxa-6-(3,4,5-trimethoxyphenyl)bicyclo[3.2.0]hept-6-ene (*cis*-4g-maj) and (1*R**,5*R**,1′*R**,5′*S**,6′*R**)-7-(6′-Methoxy-2′-oxabicyclo[3.1.0]hexan-6′-yl)-2-oxa-6-(3,4,5-trimethoxyphenyl)bicyclo[3.2.0]hept-6-ene (*cis*-4g-min):** White solid; data retrieved from a 5.8:1 mixture of nonseparated diastereomers. Combined yield: 31%. R_f = 0.11 (hexane/EtOAc, 5:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.01 (s, 2 H, min), 7.00 (s, 2 H, maj), 4.75 (d, J = 3.5 Hz, 1 H, maj), 4.62 (d, J = 3.4 Hz, 1 H, min), 4.28–3.73 (m, 10 H), 3.89 (s, 12 H), 3.88 (s, 3 H, maj), 3.87 (s, 3 H, min), 3.59 (dd, J = 3.2 Hz, J = 7.4 Hz, 1 H, maj), 3.53 (dd, J = 3.5 Hz, J = 7.6 Hz, 1 H, min), 3.38 (s, 3 H, min), 3.35 (s, 3 H, maj), 2.25–2.20 (m, 4 H), 2.04–1.99 (m, 1 H, maj), 1.98–1.93 (m, 1 H, min), 1.92 (dd, J = 5.1 Hz, J = 12.6 Hz, 1 H, min), 1.82 (dd, J = 4.7 Hz, J = 12.0 Hz, 1 H, maj), 1.72–1.59 (m, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 153.1 (s, 4 C), 140.3 (s, maj), 140.0 (s, min), 138.27 (s, maj), 138.25 (s, min), 135.0 (s, min), 134.5 (s, maj), 128.5 (s, min), 128.3 (s, maj), 105.28 (d, 2 CH, maj), 105.22 (d, 2 CH, min), 77.1 (d, maj), 76.6 (d, min), 73.2 (t, maj), 72.9 (t, min), 66.7 (s), 66.4 (t), 66.1 (d, min), 66.0 (d, maj), 60.8 (q, 2 CH_3), 56.5 (q, 2 CH_3), 56.2 (q, 2 CH_3), 56.1 (q, 2 CH_3), 44.3 (d, min), 44.2 (d, maj), 29.4 (d, maj), 29.2 (d, min), 26.5 (t, maj), 26.2 (t, min), 25.79 (t, min), 25.71 (t, maj) ppm. FTIR (neat): $\tilde{\nu}$ = 1702, 1579, 1502, 1462, 1231, 1126 cm^{-1}. MS: m/z (%) = 374 (17) $[M]^+$, 359 (15), 343 (95), 329 (100). HRMS (EI): calcd. for $C_{21}H_{26}O_6$ 374.1724; found 374.1722. $C_{21}H_{26}O_6$ (374.43): calcd. C 67.36, H 7.00; found C 66.56, H 6.89.

(1*S,5*S**,1′*R**,5′*S**,6′*R**)-7-(6′-Methoxy-2′-oxabicyclo[3.1.0]-hexan-6′-yl)-6-(1-naphthyl)-2-oxabicyclo[3.2.0]hept-6-ene (*cis*-4h-maj) and (1*R**,5*R**,1′*R**,5′*S**,6′*R**)-7-(6′-Methoxy-2′-oxabicyclo[3.1.0]hexan-6′-yl)-6-(1-naphthyl)-2-oxabicyclo[3.2.0]hept-6-ene (*cis*-4h-Min):** Yellow oil; data retrieved from a 4.4:1 mixture of nonseparated diastereomers. Combined yield: 17%. R_f = 0.22 (hexane/EtOAc, 5:1). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.10 (m, 2 H), 7.94–7.80 (m, 4 H), 7.54–7.45 (m, 8 H), 4.98 (d, J = 3.1 Hz, 2 H), 4.20–4.05 (m, 10 H), 3.89–3.74 (m, 2 H), 3.19 (s, 3 H, min), 3.04 (s, 3 H, maj), 2.22–2.17 (m, 4 H), 2.12–2.08 (m, 1 H, maj), 1.94–1.90 (m, 1 H, min), 1.85 (dd, J = 4.6 Hz, J = 13.0 Hz, 1 H, min), 1.71–1.58 (m, 3 H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 139.3 (s), 133.0 (s), 132.3 (s), 131.3 (s), 131.2 (s), 128.27 (d), 128.26 (d), 128.1 (d), 126.5 (d), 126.2 (d), 125.92 (d), 125.88 (d), 125.85 (d), 125.81 (d), 125.1 (d), 77.83 (d, min), 77.81 (d, maj), 72.8 (t, maj), 72.7 (t, min), 66.9 (s), 66.6 (t, maj), 66.5 (t, min), 66.30 (d, maj), 66.26 (d, min), 56.6 (q), 48.9 (d), 29.5 (d, maj), 29.0 (d, min), 26.9 (t, min), 26.4 (t, maj), 25.8 (t, min), 25.7 (t, maj) ppm. FTIR (neat): $\tilde{\nu}$ = 1716, 1118, 1064 cm^{-1}. MS: m/z (%) = 334 (10) $[M]^+$, 303 (34), 289 (100). HRMS (EI): calcd. for $C_{22}H_{22}O_3$ 334.1563; found 334.1565.

Cyclopropanation Reaction Between 2,3-Dihydrofuran (3a) and FCCs 6 – General Procedure for the Synthesis of Cyclopropanes 7: A solution of the appropriate carbene complex **6** (0.5 mmol) and 2,3-dihydrofuran (**3a**; 10 mmol, 20 equiv.) in dry THF (10 mL) under an inert atmosphere was warmed at 90 °C in a sealed tube until the starting carbene complex was completely consumed (1.5–18 h) as indicated by a color change of the solution in the reaction vessel and further confirmed by TLC analysis. The solvents were then removed under vacuum, and the residue was redissolved in a mixture of hexane/ethyl acetate and exposed to light in an open-air vessel to induce decomplexation of the metal species present. The resulting suspension was filtered through Celite, and the solvents were removed under vacuum. A ^{1}H NMR spectrum was recorded of the crude residue to determine the reaction diastereoselectivities, as indicated in Scheme 2. The residue was purified by flash column chromatography (hexane/EtOAc, 20:1 to 5:1) to give cyclopropanes **7** in the yields reported in Scheme 2. NMR spectroscopic data: the abbreviation "min" refers to the signals assigned to the minor isomer and the abbreviation "maj" to the signals belonging to the major one; in the cases where nothing is specified, either it hasn't been possible to assign the signal to any of the isomers or it belongs to both of them. NOESY experiments (300 MHz), performed on **7a**,**b** and **8** were inconclusive, and they did not allow the unambiguous determination of the relative stereochemistry for such compounds.

6-Methoxy-6-phenyl-2-oxabicyclo[3.1.0]hexane (7a): Yellow oil; data retrieved from a 2.8:1 mixture of nonseparated diastereomers. Combined yield: 24%. R_f = 0.28 (hexane/EtOAc, 5:1). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.51–7.49 (m, 2 H), 7.37–7.33 (m, 4 H), 7.28–7.18 (m, 4 H), 4.26 (aq, J = 5.7 Hz, 1 H, maj), 4.20–4.16 (m, 2 H, min; d, J = 8.0 Hz, 1 H, maj), 4.18 (aq, J = 5.1 Hz, 1 H, maj), 3.83–3.79 (m, 1 H, min), 3.42 (s, 3 H, maj), 3.11 (s, 3 H, min), 2.34–2.28 (m, 2 H, maj), 2.13–2.10 (m, 2 H, min), 1.98–1.94 (m, 1 H, maj), 1.75–1.69 (m, 1 H, min) ppm. ^{13}C NMR (100 MHz,

$CDCl_3$): δ = 139.8 (s, maj), 132.6 (s, min), 131.3 (d, maj), 128.4 (d, 2 CH, maj; 2 CH, min), 128.3 (d, min), 126.8 (d, 2 CH, min), 125.6 (d, 2 CH, maj), 73.1 (t, maj), 70.8 (t, min), 69.6 (s, maj), 69.5 (s, min), 67.4 (d, maj), 66.0 (d, min), 56.0 (q, maj), 53.5 (q, min), 31.9 (d, maj), 29.2 (d, min), 26.6 (t, min), 26.2 (t, maj) ppm. FTIR (neat): $\tilde{\nu}$ = 1664, 1448, 1119, 1067 cm^{-1}.

(*E*)-6-[-2-(Furan-2-yl)vinyl]-6-methoxy-2-oxabicyclo[3.1.0]hexane (7b): Yellow oil; data listed only for the major diastereomer, retrieved from a 10:1 mixture of nonseparated diastereomers. Combined yield: 41%. R_f = 0.33 (hexane/EtOAc, 5:1). ^1H NMR (300 MHz, $CDCl_3$): δ = 7.29 (br. s, 1 H), 6.33 (m, 1 H), 6.19 (d, J = 16.2 Hz, 1 H), 6.15 (d, J = 3.4 Hz, 1 H), 5.75 (d, J = 16.0 Hz, 1 H), 4.20–4.11 (m, 1 H), 3.95–3.86 (m, 2 H), 3.46 (s, 3 H), 2.23–2.13 (m, 2 H), 1.85–1.79 (m, 1 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 152.5 (s), 141.5 (d), 126.5 (d), 115.3 (d), 111.2 (d), 107.1 (d), 72.6 (t), 68.7 (s), 68.1 (d), 56.2 (q), 30.5 (d), 25.6 (t) ppm.

6-Methoxy-6-[2-(1-naphthyl)ethynyl]-2-oxabicyclo[3.1.0]hexane (8): Isolated as a byproduct of the reaction between FCC **1h** and 2,3-dihydrofurane (**3a**), according to the general procedure described above. Yellow oil; yield 8% (isolated). Only one diastereomer was detected. R_f = 0.34. ^1H NMR (400 MHz, $CDCl_3$): δ = 8.37 (d, J = 8.3 Hz, 1 H), 7.84 (at, J = 7.6 Hz, 2 H), 7.71 (d, J = 7.4 Hz, 1 H), 7.62–7.40 (m, 3 H), 4.23–4.08 (m, 3 H), 3.51 (s, 3 H), 2.39–2.24 (m, 2 H), 2.19–2.13 (m, 1 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 133.6 (s), 133.5 (s), 131.1 (d), 129.2 (d), 128.6 (d), 127.3 (d), 126.8 (d), 126.5 (d), 125.5 (d), 120.8 (s), 88.8 (s), 87.6 (s), 73.4 (t), 68.1 (d), 64.0 (s), 55.9 (q), 31.8 (d), 27.2 (t) ppm. FTIR: $\tilde{\nu}$ = 2975, 2926, 1712, 1470 cm^{-1}. MS: *m/z* (%) = 264 (10) $[M]^+$, 236 (60), 179 (100), 165 (69). HRMS (EI): calcd. for $C_{18}H_{16}O_2$ 264.1145; found 264.1140.

[3+2]/[2+1] Reaction Between (Trimethylsilyl)diazomethane, 2,3-Dihydrofuran, and Alkynyl FCC 1a – (1*S,5*R**,6*R**)-6-Methoxy-6-(4-phenylpyrazol-5-yl)-2-oxa-bicyclo[3.1.0]hexane (9):** A solution of alkynyl FCC **1a** (0.5 mmol), (trimethylsilyl)diazomethane (0.65 mmol, 0.33 mL, 1.3 equiv.) in dry THF (10 mL) was stirred at room temperature in a sealed tube under an inert atmosphere until TLC analysis showed complete consumption of the starting carbene complex (1 h). 2,3-Dihydrofuran (5 mmol, 0.75 mL, 10 equiv.) was added dropwise by syringe, and the resulting solution was warmed at 90 °C until the intermediate [3+2] product was completely consumed (1 d) as confirmed by TLC monitoring. Then, the solvents were removed under vacuum, and the residue was redissolved in a mixture of hexane/ethyl acetate (9:1) and exposed to light in an open-air vessel to induce decomplexation of the metal species present. The resulting suspension was filtered through Celite, and the solvents removed under vacuum; a ^1H NMR spectrum was recorded of the crude residue to determine the reaction diastereoselectivity. The residue was purified by flash column chromatography (hexane/EtOAc, 9:1 to 3:1) to give product **9**. Yellow oil; yield 23%. Data for the major (1*S**,5*R**,6*R**) diastereomer was retrieved from a 1:8.3 diastereomeric mixture. R_f = 0.12 (hexane/EtOAc, 5:1). ^1H NMR (300 MHz, $CDCl_3$): δ = 7.94 (br. s, 1 H), 7.75–7.71 (m, 2 H), 7.43–7.37 (m, 2 H), 7.31–7.27 (m, 1 H), 4.23 (d, J = 6.6 Hz, 1 H), 3.90–3.82 (m, 1 H), 3.23 (s, 3 H), 2.90 (dd, J = 15.6 Hz, J = 8.5 Hz, 1 H), 2.27–2.21 (m, 1 H), 2.06–1.96 (m, 1 H), 1.50–1.40 (m, 1 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 132.6 (s), 129.0 (d, 2 CH), 127.5 (d, 2 CH), 127.1 (d), 72.2 (t), 65.9 (d), 62.7 (s), 55.3 (q), 31.3 (d), 26.7 (t) ppm. Three carbon signals (around 140–145, 137, and 122 ppm) were not observed in the spectrum; however, the carbon signals at 122 and 137 ppm were detected in the HMBC and HSQC spectra, respectively; the signal around 140–145 ppm was not observed in those spectra either. FTIR (neat): $\tilde{\nu}$ = 1713, 1606, 1450, 1264, 1104 cm^{-1}.

Synthesis of Compounds 10 by [3+2]/[2+1] Reaction Between (Trimethylsilyl)diazomethane, Methylacrylate, and Alkynyl FCC (1a): A solution of alkynyl FCC **1a** (0.5 mmol), (trimethylsilyl)diazomethane (0.65 mmol, 0.33 mL, 1.3 equiv.) and methyl acrylate (5 mmol, 0.45 mL, 10 equiv.) in dry THF (10 mL) was stirred at room temperature in a sealed tube under an inert atmosphere until TLC analysis showed complete consumption of the starting carbene complex (1 h). The resulting solution was warmed at 70 °C until the intermediate [3+2] product was completely consumed (1 d) as confirmed by TLC monitoring. Then, the solvents were removed under vacuum, and the residue was redissolved in a mixture of hexane/ethyl acetate (9:1) and exposed to light in an open-air vessel to induce decomplexation of the metal species present. The resulting suspension was filtered through Celite, and the solvents removed under vacuum; a ^1H NMR spectrum was recorded of the crude residue to determine the reaction diastereoselectivity. The residue was purified by flash column chromatography (hexane/EtOAc, 9:1 to 3:1) to give products **10**.

(1*R,2*S**)-Methyl 2-Methoxy-2-(4-phenylpyrazol-5-yl)cyclopropanecarboxylate (10-min):** Yellow oil; minor diastereomer from a 1:1.2 mixture; yield 23%. R_f = 0.25 (hexane/EtOAc, 1:1). ^1H NMR (300 MHz, $CDCl_3$): δ = 7.87 (br. s, 2 H), 7.69–7.63 (d, 2 H), 7.43–7.37 (m, 2 H), 7.33–7.28 (m, 1 H), 3.77 (s, 3 H), 3.27 (s, 3 H), 2.28 (dd, J = 8.9 Hz, J = 7.0 Hz, 1 H), 2.00 (at, 1 H, J = 6.0 Hz), 1.43 (dd, 1 H, J = 9.0 Hz, J = 6.0 Hz) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 170.2 (s), 143.9 (s), 132.0 (s), 130.8 (d), 128.5 (d, 2 CH), 128.0 (d, 2 CH), 126.8 (d), 122.0 (s), 63.1 (s), 55.6 (q), 52.1 (q), 27.0 (d), 19.3 (t) ppm. FTIR (neat): $\tilde{\nu}$ = 1731, 1437, 1374, 1171, 1068 cm^{-1}. MS: *m/z* (%) = 272 (8) $[M]^+$, 257 (100), 225 (54), 197 (69), 181 (61), 171 (70). HRMS (EI): calcd. for $C_{15}H_{16}N_2O_3$ 272.1161; found 272.1169.

(1*S,2*S**)-2-Methyl 2-Methoxy-2-(4-phenylpyrazol-5-yl)cyclopropanecarboxylate (10-maj):** Yellow oil; major diastereomer from a 1:1.2 mixture; yield 28%. R_f = 0.13 (hexane/EtOAc, 1:1). ^1H NMR (300 MHz, $CDCl_3$): δ = 7.74 (br. s, 1 H), 7.61 (m, 2 H), 7.43–7.25 (m, 3 H), 3.36 (s, 3 H), 3.29 (s, 3 H), 2.33 (m, 1 H), 1.66 (m, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 170.8 (s), *137.9 (s), 132.4 (s), 132.2 (d)*, 128.4 (d, 2 CH + s), 128.0 (d, 2 CH), 126.5 (d), *63.2 (s)*, 54.9 (q), 52.1 (q), 28.1 (d), 19.4 (t) ppm, the carbon atom signals in italics required a much higher number of scans than usual to be observed; some of them were indirectly detected in 2D-NMR spectroscopic experiments; see Table in the Supporting Information. FTIR (neat): $\tilde{\nu}$ = 1728, 1440, 1376, 1165, 1068 cm^{-1}. MS: *m/z* (%) = 272 (10) $[M]^+$, 257 (100), 225 (57), 197 (71), 181 (60), 171 (78), 84 (82). HRMS (EI): calcd. for $C_{15}H_{16}N_2O_3$ 272.1161; found 272.1157.

Supporting Information (see footnote on the first page of this article): Tables with the 2D NMR (HSQC, COSY, HMBC, and NOESY) spectroscopic experiments for selected compounds and reproductions of the ^1H and ^{13}C NMR spectra are provided.

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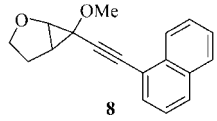

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