



Cite this: *New J. Chem.*, 2016,
40, 245

Received (in Montpellier, France)
8th September 2015,
Accepted 23rd October 2015

DOI: 10.1039/c5nj02406d

www.rsc.org/njc

Novel indenyl ligands bearing electron-withdrawing functional groups[†]

Iva Honzíčková,^a Jaromír Vinklárek,^a Carlos C. Romão,^b Zdeňka Růžičková^a and Jan Honzíček^{a*}

A series of molybdenum complexes bearing new ligands is reported. The study covers a series of molybdenum compounds with the η^5 -coordinated indenyl ligand substituted with acyl-, ester- and amide-functions. This portfolio was extended by adding one representative with a η^3 -coordinated ester-substituted indenyl ligand. The functionalized indenes, necessary for the assembly, were prepared by convenient routes starting from inexpensive and readily available materials, enabling their production on a multigram scale. All structural types presented in this experimental study were supported by X-ray crystallographic data.

Introduction

The attachment of functional groups at cyclopentadienyl (Cp) rings of transition metal complexes can change considerably their electronic properties as well as the range of potential applications.^{1,2} So far, many different substitution patterns have been developed for the Cp ligand but only a few of them cover electron-withdrawing substituents and are applicable for ligands with extended π -systems such as indenyl (Ind) or fluorenyl (Flu). These congeners of the Cp bearing annulated benzene rings show unique properties with consequent implications in the design of new catalytic systems.³ Hence, the replacement of the Cp ligand with a larger π -system often has a strong effect on reactivity.⁴ This so-called “indenyl effect” accelerates the reaction rates or switches the reaction pathway due to a lower energetic barrier of the haptotropic rearrangement of the π -ligand.⁵ Recent studies have further revealed that a subtle modification of the indenyl ligand (e.g. replacement of one hydrogen with a methyl group) may play a crucial role in activation of coordinated ligands.^{2,6,7}

The modification of the indenyl ligand with electron-withdrawing substituents is rather rare. In 2000, Deck *et al.* extended a synthetic route giving perfluoroaryl-functionalized cyclopentadienides⁸ on the indenes and described their rhenium complexes.⁹ Some other strong

electron-withdrawing substituents such as $-F$,¹⁰ $-CN$,¹¹ $-COOR$,^{12,13} $-CONHR$,^{14,15} and $-COR$,^{11,12,16} have been successfully attached on the Cp ring of various transition metal complexes using different strategies. However, the synthesis of the indenyl congeners has not been reported, although some of the suitable indene precursors are already known for several decades.¹⁷

The aim of this study is to extend a family of indenyl ligands with ester-, amide- and acyl-functionalized derivatives. It will cover a series of modified indenes and unprecedented indenyl complexes. It is expected that a strong electron-withdrawing power of the attached functional groups will lead to more electron deficient metal centers that should be beneficial for their future application in catalysis. We decided to start our investigations with a familiar and well defined fragment, $(\eta^3-C_3H_5)Mo(CO)_2$, before moving into unexplored areas. The allyl molybdenum scaffold is accessible from the halide precursor $[(\eta^3-C_3H_5)Mo(CO)_2(NCMe)_2X]$, which is an excellent starting material for the incorporation of a monoanionic π -ligand into the molybdenum coordination sphere.^{15,16,18-20}

Results and discussion

Ester-functionalized indenes

Three approaches for the synthesis of ester-functionalized indenes were examined. The obvious one using the reaction of sodium indenide with one equivalent of chloroformate was found to be ineffective since the 1,1-disubstituted derivative appears as a major product. In case of the methyl ester, 3-(MeOCO)C₉H₇ (2) and 1,1-(MeOCO)₂C₉H₆ (2a) were isolated in 2% and 15% yields, respectively (Scheme 1).

Alternatively, a series of ester-functionalized indenes (3-5) was prepared by an esterification of indene-3-carboxylic acid

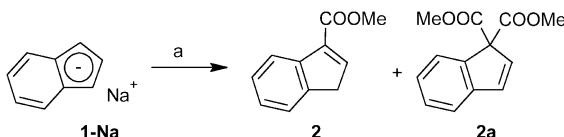
^a Department of General and Inorganic Chemistry, Faculty of Chemical Technology, University of Pardubice, Studentská 573, Pardubice, Czech Republic

^b Instituto de Tecnologia Química e Biológica António Xavier, Universidade Nova de Lisboa, Av. Da República, 2780-157 Oeiras, Portugal

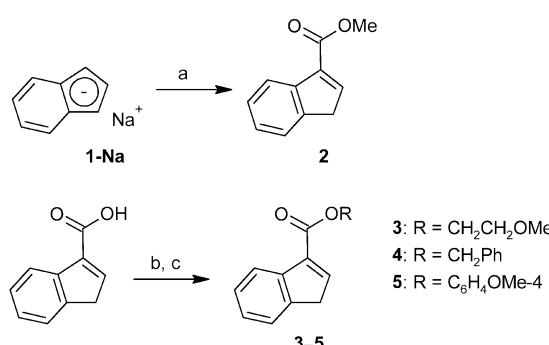
^c Institute of Chemistry and Technology of Macromolecular Materials Faculty of Chemical Technology, University of Pardubice, Studentská 573, Pardubice, Czech Republic. E-mail: jan.honzicek@upce.cz; Fax: +420 46603 7068

[†] CCDC 1416908–1416913. For crystallographic data in CIF or other electronic format see DOI: 10.1039/c5nj02406d





Scheme 1 Reaction of sodium indenide (**1-Na**) with chloroformate. Reagent: ClCOOMe.



Scheme 2 Synthesis of ester-functionalized indenes. Reagents: (a) OC(OMe)₂, (b) SOCl₂, (c) ROH.

according to a protocol reported for methyl ester **2**, see Scheme 2.²¹ Since availability of the starting 3-(HOCO)C₉H₇ is a limiting factor of the procedure, an alternative strategy was used for the preparation of 3-(MeOCO)C₉H₇ (**2**) on a larger scale. The reaction of sodium indenide (**1-Na**) with dimethyl carbonate gives the functionalized indene **2** in one step and about 41% isolated yield without the need of a chromatographic purification step (Scheme 2).

Ester-functionalized indenyl molybdenum compounds

The ability of ester-functionalized indenyl ligands to form η^5 -coordination compounds was evidenced for the following molybdenum species. The series of ester-substituted indenes (**3–5**) was deprotonated with *n*-butyl lithium. The reaction of indenides (**3–Li–5–Li**) formed *in situ* with the halide complex $[(\eta^3\text{-C}_3\text{H}_5)\text{Mo}(\text{CO})_2(\text{NCMe})_2\text{Cl}]$ (**6**), accompanied by a loss of the stabilizing MeCN ligands, resulted in the formation of η^5 -indenyl compounds $[(\eta^3\text{-C}_3\text{H}_5)\{\eta^5\text{-1-(ROCO)C}_9\text{H}_6\}\text{Mo}(\text{CO})_2]$ (**7–10**), see Scheme 3.

The infrared and Raman spectra of compounds **7–10** show two CO stretching bands in a range typical for terminal carbonyl ligands, see Table 1. The CO stretching bands of the ester groups vary between 1702 and 1722 cm^{−1}, thus revealing a very low

Table 1 Summary of the infrared and Raman data for the ester-functionalized molybdenum complexes^a

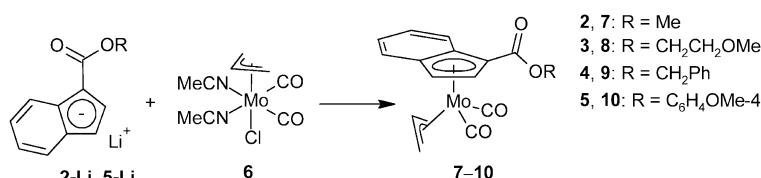
	Infrared		Raman	
	$\nu(\text{C}\equiv\text{O})$	$\nu(\text{C}=\text{O})$	$\nu(\text{C}\equiv\text{O})$	$\nu(\text{C}=\text{O})$
7	1934 1866	1714	1944 1861	1715
8	1947 1869	1712	— ^b	— ^b
9	1932 1865	1702	1942 1856	1705
10	1944 1865	1722	1946 1862	1714
12	1943 1876 1828	1694	— ^b	— ^b

^a The stretching frequencies are given in cm^{−1}. ^b The Raman spectrum was not obtained owing to luminescence.

delocalization of π -electrons of the C=O group and excluding an alternative κ -O-coordination mode of the functionalized indenyl ligand. The ¹H NMR spectra of compounds **7–10** show the presence of two conformers arising from a different orientation of the η^3 -bonded allyl ligand. The signals of the allyl ligand were assigned to a conformer with the allyl ligand eclipsed with OC-Mo-CO (*exo*) and that with a staggered conformation (*endo*) according to data published for the unsubstituted analogue.¹⁸ At room temperature, the *exo*-conformer predominates over the *endo*-conformer. The molar ratio (*exo/endo*) was found to be 3:1 for compounds **7–10** correlating well with data published for monosubstituted derivatives of $[(\eta^3\text{-C}_3\text{H}_5)(\eta^5\text{-Ind})\text{Mo}(\text{CO})_2]$.⁷

The solid state structure of compound **7** was determined by the single crystal X-ray analysis. The molecule has a distorted tetrahedral structure with allyl, indenyl and two carbonyl ligands around molybdenum in the formal oxidation state II, see Fig. 1. The geometric parameters describing the coordination sphere of molybdenum are listed in Table 2. The η^3 -coordinated allyl ligand is positionally disordered and splits into *exo* and *endo* conformations with an occupancy of about 7:3. The substituted indenyl ligand is η^5 -coordinated as evidenced by a low value of the envelope fold angle [$\Omega = 4.5(3)^\circ$] and also by $\Delta(\text{M}-\text{C})$ [0.119(3) Å]. The ester group is almost coplanar with the indenyl framework. The dihedral angle between the C₅ ring of indenyl and a plane defined by atoms C1, C10, O1 and O2 is 1.28(16)°.

Having obtained a series of molybdenum compounds with η^5 -bonded ester-substituted indenyl ligands, we sought to extend



Scheme 3 Synthesis of molybdenum complexes bearing ester-functionalized indenyl.



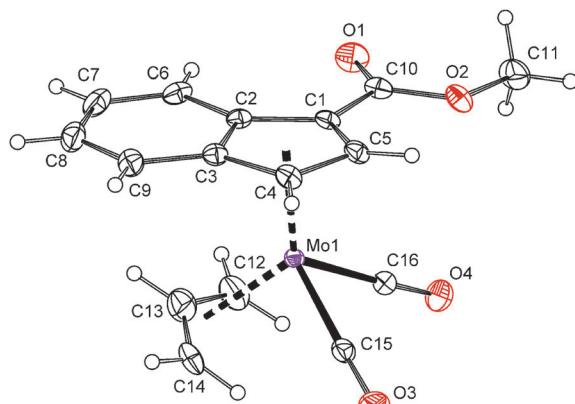
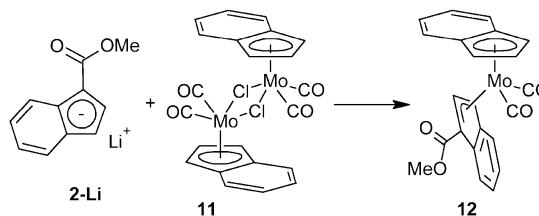


Fig. 1 ORTEP drawing of the molybdenum compound $[(\eta^3\text{-C}_3\text{H}_5)(\eta^5\text{-1-(MeOCO)C}_9\text{H}_6)\text{Mo}(\text{CO})_2]$ present in the crystal structure of 7. Thermal ellipsoids are drawn at the 30% probability level. Only the major conformation of the positionally disordered allyl ligand is shown for clarity.

the portfolio of such compounds by (i) adding a representative with a η^3 -coordinated ester-substituted indenyl ligand, (ii) introducing an acetyl substituent as a representative of a stronger electron-withdrawing substituent and (iii) developing a versatile route for amide-functionalized derivatives.

On the first count, we chose the mixed-indenyl species of type $[(\eta^3\text{-Ind})(\eta^5\text{-Ind})\text{Mo}(\text{CO})_2]$. The methyl ester derivative $[(\eta^3\text{-1-(MeOCO)C}_9\text{H}_6)(\eta^5\text{-Ind})\text{Mo}(\text{CO})_2]$ (**12**) was prepared by a reaction of **2-Li** with one equivalent of $[(\eta^5\text{-Ind})\text{Mo}(\text{CO})_2(\mu\text{-Cl})_2]$ (**11**) in a moderate isolated yield (43%), see Scheme 4. Coordination of the indenyl ligand was evidenced by infrared spectroscopy, which shows the stretching bands of the carbonyl ligands at frequencies (ν_a : 1943 cm^{-1} ; ν_s : 1876 , 1828 cm^{-1}) similar to those reported for the unsubstituted parent compound $[(\eta^3\text{-Ind})(\eta^5\text{-Ind})\text{Mo}(\text{CO})_2]$.²³ The appearance of two bands of the $\nu_s(\text{CO})$ is due to a vibration coupling of the carbonyl ligands in the crystal lattice. The CO stretching band of the ester group appears at a lower frequency (1694 cm^{-1}) than that of compound 7 thus implying a more electrophilic character of the molybdenum center. The ^1H NMR spectrum shows broadened signals indicating a fluxional structure in solution due to a fast hapticity



Scheme 4 Synthesis of a mixed indenyl molybdenum complex.

exchange of the indenyl rings. This observation correlates well with the properties of the unsubstituted analogue $[(\eta^3\text{-Ind})(\eta^5\text{-Ind})\text{Mo}(\text{CO})_2]$ that gives only one set of signals for both indenyl ligands.²⁴

The X-ray diffraction analysis reveals that the less donating ester-substituted indenyl ligand adopts the η^3 -coordination mode in the solid state, whereas the electron richer unsubstituted indenyl stays η^5 -coordinated, see Fig. 2. The hapticity of indenyl ligands is clearly elucidated from the slip parameters listed in Table 2. Hence, the substituted indenyl has considerably higher values of Ω and $\Delta(\text{M}-\text{C})$ than the unsubstituted one. Compound **12** adopts a conformation, similar to the unsubstituted counterpart,²³ with the η^3 -indenyl ligand in *exo*-conformation and the C₆-ring of the η^5 -indenyl facing away from the carbonyl ligands thereby avoiding repulsive interactions. The ester group is almost coplanar with the η^3 -coordinated π -system of the indenyl framework. The dihedral angle between a plane defined by three carbon atoms of Ind (C1, C4 and C5) and a plane defined by atoms C1, C10, O1 and O2 is $3.8(2)^\circ$.

The crystal structure of **12** is stabilized by a sandwich π - π stacking involving the unsubstituted indenyl ligands of two neighboring molecules. The distance between the centroid of the five-membered ring [Cg(C₁₂-C₁₆)] and a plane defined by the parallel five-membered ring [Pl(C_{12'}-C_{16'})] is $3.3075(10)\text{ \AA}$. A T-shaped interaction between the face of the six-membered ring of the substituted indenyl ligand (C₂-C₆) and the six-membered ring vertex of the unsubstituted indenyl (C_{17'}-H_{17'}) connects the molecules into zig-zag chains along the *b*-axis. The distance between the centroid Cg(C₂-C₆) and the carbon atom C_{17'} is $3.532(2)\text{ \AA}$.

Table 2 Geometric parameters of the molybdenum complexes^a

	7	12	14	20	22-MeOH
Mo-Cg(C ₅)	2.0358(12)	2.0203(10)	2.0366(11)	2.0229(10)	2.0369(11)
Mo-Cg(C ₃)	2.044(4)	2.1423(19)	2.053(3)	2.047(3)	2.049(3)
Mo-C(CO)	1.936(3)	1.943(2)	1.933(3)	1.931(2)	1.939(3)
	1.950(3)	1.952(2)	1.934(3)	1.954(2)	1.943(3)
Cg(C ₅)-Mo-Cg(C ₃)	126.06(13)	131.62(6)	127.88(10)	126.69(11)	127.09(10)
C(CO)-Mo-C(CO)	80.26(12)	79.22(9)	79.15(13)	82.79(9)	78.04(11)
Ω^b	4.5(3)	4.4(2) ^d	3.4(3)	4.5(2)	3.7(3)
$\Delta(\text{M}-\text{C})^c$	0.119(3)	0.114(2) ^d	0.106(3)	0.104(2)	0.105(3)
	0.765(2) ^e				

^a Distances are given in \AA ; angles and dihedral angles are given in $^\circ$. ^b Ω is the envelope fold angle defined for the indenyl ligand as the angle between planes defined by C1, C2 and C3 and that of C1, C3, C8 and C9.²² ^c $\Delta(\text{M}-\text{C})$ represents the differences in the metal–carbon bonds. It is defined for the indenyl compounds as the difference between the averages of the metal–carbon distances M–C₈ and M–C₉ and those of M–C₁, M–C₂, and M–C₃.²² ^d Data for Ind. ^e Data for 1-(MeOCO)C₉H₆.

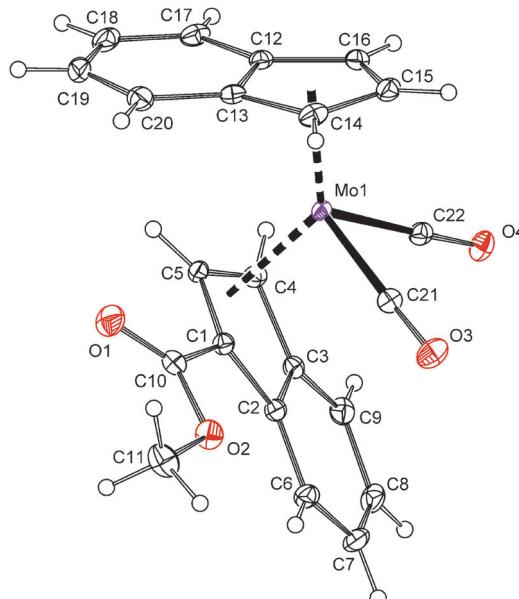
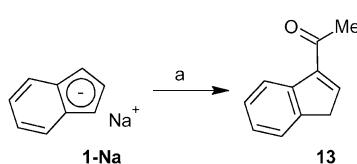


Fig. 2 ORTEP drawing of the molybdenum compound $[\eta^3\text{-}1\text{-(MeO-CO)C}_9\text{H}_6]\text{-(}\eta^5\text{-Ind)Mo(CO)}_2$ present in the crystal structure of **12**. Thermal ellipsoids are drawn at the 30% probability level.



Scheme 5 Synthesis of acetyl-functionalized indene **13**. Reagent: (a) MeCOOEt.

Acetyl-functionalized indenyl molybdenum compound

A similar strategy as described for indene **2** was utilized for the synthesis of the acetyl-functionalized derivative $3\text{-(MeCO)C}_9\text{H}_7$ (**13**). Hence, the reaction of sodium indenide with ethyl acetate produced indene **13** in 38% isolated yield including a vacuum distillation step (Scheme 5). The protocol utilized inexpensive and readily available starting materials providing the product on a multigram scale. The vibrational spectra show a strong band of CO stretching in a range typical for the keto-group (IR: 1669 cm^{-1} ; Raman: 1666 cm^{-1}). The ^1H and $^{13}\text{C}\{^1\text{H}\}$ NMR spectra reveal the appearance of an isomer with the acetyl function in the 3-position of the indene framework. This observation is in line with the X-ray analysis of a single crystal obtained by recrystallization from hexane at low temperature. Hence, the acetyl group is attached to the sp^2 carbon atom of the indene framework, see Fig. 3. The bond length between the carbon atom C1 and the oxygen atom O1 is $1.222(2)\text{ \AA}$ that is within a range typical for the CO double bond.

Deprotonation of indene **13** with *n*-butyl lithium followed by addition of the allyl complex $[(\eta^3\text{-C}_3\text{H}_5)\text{Mo}(\text{CO})_2(\text{NCMe})_2\text{Cl}]$ (**6**) yields the desired η^5 -indenyl complex $[(\eta^3\text{-C}_3\text{H}_5)\{\eta^5\text{-1-(MeCO)C}_9\text{H}_6\}\text{-Mo}(\text{CO})_2]$ (**14**), see Scheme 6.

Infrared, Raman and ^1H NMR spectroscopy confirmed the successful assembly of the acetyl-functionalized indenyl

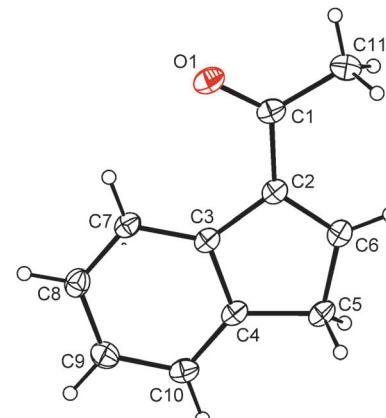
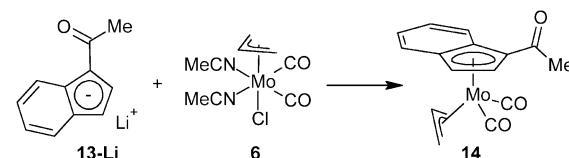


Fig. 3 ORTEP drawing of $3\text{-(MeCO)C}_9\text{H}_7$ present in the crystal structure of **13**. Thermal ellipsoids are drawn at the 30% probability level.



Scheme 6 Synthesis of an acetyl-functionalized indenyl molybdenum complex.

molybdenum framework. Hence, the vibrational spectra of compound **14** show, in addition to stretching bands of the carbonyl ligands, a characteristic band of the C=O stretching at similar frequencies as observed for indene precursor **13**, see Table 3. The ^1H NMR spectrum of compound **14** features a similar pattern as observed for the ester derivatives. The molar ratio of *exo*- and *endo*-conformers (3 : 1) is virtually the same as observed for the ester derivatives. This observation indicates that the abundance of given conformers is directed by the bulkiness of the modified indenyl ligand while electronic properties of the substituents play only a minor role.

X-ray crystallographic structure determination confirmed that the acetyl-substituted molybdenum compound **14** is isostructural with ester-derivative **7**. The acetyl function is coplanar

Table 3 Summary of the infrared and Raman data for the acyl- and amide-functionalized molybdenum complexes^a

	Infrared		Raman	
	$\nu(\text{C}\equiv\text{O})$	$\nu(\text{C=O})$	$\nu(\text{C}\equiv\text{O})$	$\nu(\text{C=O})$
14	1936 1858	1660	1932 1836	1666
20	1932 1848	1635	1931 1850	1637
21	1932 1859	1633	1933 1866	1635
22	1940 1852	1667	1948 1848	1664

^a The stretching frequencies are given in cm^{-1} .



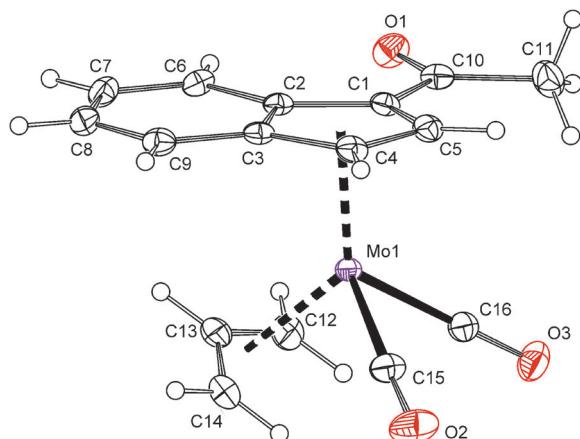
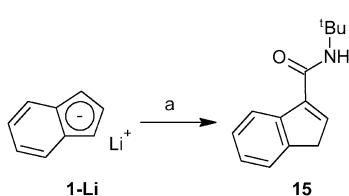
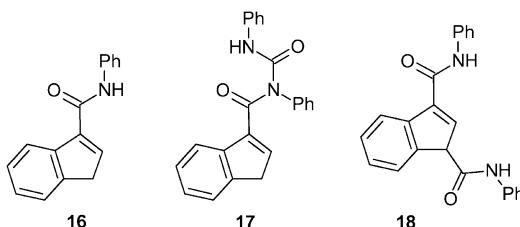


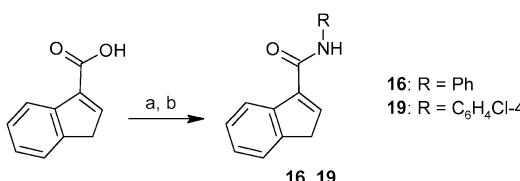
Fig. 4 ORTEP drawing of the molybdenum compound $[(\eta^3\text{-C}_3\text{H}_5)(\eta^5\text{-1-(MeCO)C}_9\text{H}_6)\text{Mo}(\text{CO})_2]$ present in the crystal structure of **14**. Thermal ellipsoids are drawn at the 30% probability level.



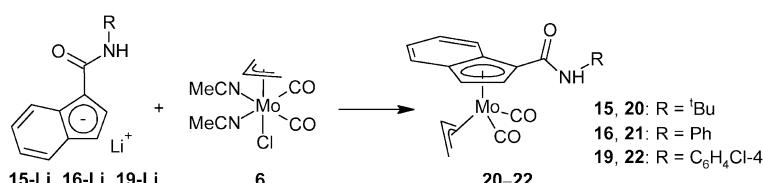
Scheme 7 Synthesis of carboxamide-functionalized indene **15**. Reagent: (a) $^t\text{BuNCO}$.



Scheme 8 Product of the reaction between **1-Li** and PhNCO.



Scheme 9 Synthesis of carboxamide-functionalized indenes **16** and **19**. Reagents: (a) SOCl_2 , (b) RNCO .



Scheme 10 Synthesis of amide-functionalized indenyl molybdenum complexes.

with the indenyl framework. The dihedral angle between the C5 ring of indenyl and a plane defined by atoms C1, C10, O1 and O2 is $2.15(17)^\circ$ (Fig. 4).

Amide-functionalized indenyl molybdenum compounds

Finally, we have also investigated the scope of our synthetic protocol for compounds with amide-functions. The starting amide-substituted indenes were synthesized using two strategies. *tert*-Butyl derivative **15** was prepared by a reaction of lithium indenide (**1-Li**) with *tert*-butyl isocyanate, see Scheme 7. Rather inexpensive starting materials and an acceptable isolated yield (65%) predestinate this procedure for the use on a multigram scale.

Unfortunately, the higher reactivity of aryl isocyanates precludes their use for the synthesis of aryl amides such as **16** and **19** (for structures, see Scheme 9). In fact, the reaction of phenyl isocyanate gives the acyl-substituted *N,N*-diphenyl urea **17** and the 1,3-disubstituted indene **18** as major outcomes in about 22% and 8% yields, respectively (based on indene). The desired 3-(PhNHCO)C₉H₇ (**16**) appears only as a minor product (in $\sim 4\%$ yield) that was separated from the reaction mixture by column chromatography (Scheme 8).

This led us to use 3-(ClCO)C₉H₇ prepared *in situ* for the synthesis of aryl amides **16** and **19**, see Scheme 9. The carboxylic acid, 3-(HOCO)C₉H₇, was treated with thionyl chloride and the product reacted with anilines to give carboxamides **16** and **19** in satisfactory isolated yields.

Indenyl molybdenum compounds bearing the amide function group are accessible using the aforementioned protocol successfully used for the ester-derivatives. Deprotonation with *n*-butyl lithium followed by a metathesis reaction gave indenyl molybdenum compounds **20–22** in moderate isolated yields, see Scheme 10. The compounds were characterized by infrared, Raman and ¹H NMR spectroscopy. The structures of compounds **20** and **22** were determined by X-ray diffraction analysis. The vibration spectra of compounds **20–22** show stretching bands of the carbonyl ligands at frequencies similar to those observed for ester-derivatives **7–10** (*cf.* data in Tables 1 and 3). Frequencies of N–H and C=O stretching bands of the amide functions are also consistent with the desired η^5 -coordination mode of the substituted indenyl ligands.

In case of compounds **20** and **22**, a successful assembly of the $[(\eta^3\text{-C}_3\text{H}_5)(\eta^5\text{-Ind})\text{Mo}(\text{CO})_2]$ moiety was further confirmed by the X-ray diffraction analysis, see Fig. 5 and 6. The carboxamide-functionalized indenyl ligands are η^5 -coordinated to the molybdenum as evidenced by ring slip parameters (Table 2). Surprisingly, only a very weak hydrogen bond (N1–H1 \cdots O1') was observed in the crystal lattice of

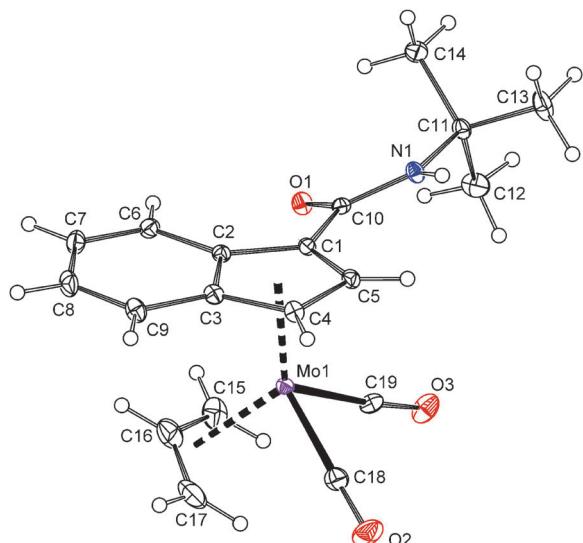


Fig. 5 ORTEP drawing of the molybdenum compound $[(\eta^3\text{-C}_3\text{H}_5)(\eta^5\text{-1-(BuNHCO)C}_9\text{H}_6)\text{Mo}(\text{CO})_2]$ present in the crystal structure of **20**. Thermal ellipsoids are drawn at the 30% probability level.

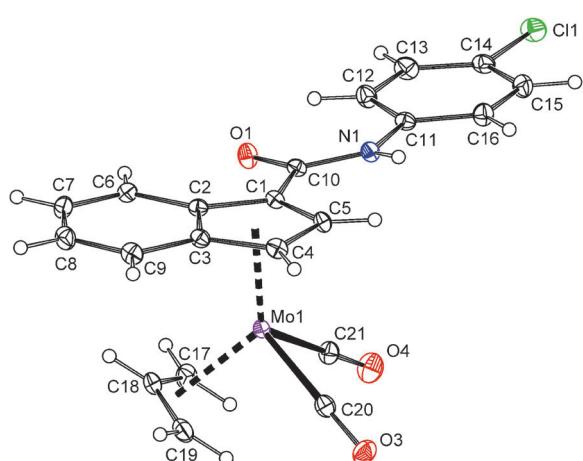


Fig. 6 ORTEP drawing of the molybdenum compound $[(\eta^3\text{-C}_3\text{H}_5)(\eta^5\text{-4-ClC}_6\text{H}_4\text{NHCO})\text{C}_9\text{H}_6)\text{Mo}(\text{CO})_2]$ present in the crystal structure of **22·MeOH**. Thermal ellipsoids are drawn at the 30% probability level.

compound **20** probably as a result of the steric hindrance of the bulky *t*-butyl group. The amide functions of neighboring molecules are connected into zig-zag chains along the *c*-axis. The distance between the nitrogen atom (N1) and the oxygen atom (O1') of the neighboring amide function is 3.295(2) Å. In case of **22·MeOH**, the amide functions and the hydroxyl group of methanol are connected into chains along the *a*-axis by considerably stronger hydrogen bonds N1–H1···O2 and O2–H2···O1'. The distances N1···O2 and O2···O1' are 2.936(3) and 2.714(3) Å, respectively.

Conclusions

The present study established a new family of ring-substituted indenyl complexes with an unprecedented substitution pattern.

The derivatives of $[(\eta^3\text{-C}_3\text{H}_5)(\eta^5\text{-Ind})\text{Mo}(\text{CO})_2]$ bearing a strong electron-withdrawing functional group attached to the indenyl framework were prepared by a convenient route starting from functionalized lithium indenides. Since the availability of the ligand precursor is often a limiting factor of a synthetic protocol and consequent applications, attention was further given to low-cost pathways giving the ester-, acyl- and amide-functionalized indenes without the necessity of a tedious chromatographic purification step. On that count, one representative from each group was synthesized on the 6–14 g scale starting from common and inexpensive starting materials.

The herewith established substitution of the indenyl ligands with polar functional groups opens a novel pathway for chemical modifications of transition metal complexes and may accelerate their use in organic synthesis or catalysis.

Experimental section

Methods and materials

All operations were performed under nitrogen using conventional Schlenk-line techniques. The solvents were purified and dried by standard methods.²⁵ The starting materials were available commercially or prepared according to literature procedures: 3-(HOOC)C₉H₇,²¹ $[(\eta^3\text{-C}_3\text{H}_5)\text{Mo}(\text{CO})_2(\text{NCMe})_2\text{Cl}]$ (**6**),¹⁸ $[(\eta^5\text{-Ind})\text{Mo}(\text{CO})_2(\mu\text{-Cl})_2]$ (**11**).²⁰

Measurements

Infrared and Raman spectra were measured on a Nicolet iS50 FTIR spectrometer equipped with a Raman module. The infrared spectra were recorded in the 4000–400 cm⁻¹ region (resolution 1 cm⁻¹) using a Diamond Smart Orbit ATR. Raman spectra were recorded in the 4000–100 cm⁻¹ region (resolution 2 cm⁻¹) in glass capillaries. The excitation source consisted of a Nd:YAG laser emitting at 1064 cm⁻¹. ¹H and ¹³C{¹H} NMR spectra were measured on a Bruker Avance 400 and a Bruker Avance 500 spectrometers, respectively, at room temperature. The chemical shifts are given in ppm relative to TMS.

Synthesis of 3-(MeOCO)C₉H₇ (**2**)

Sodium indenide (**1-Na**), freshly prepared from indene (**1**; 11.7 mL, 0.10 mol) and sodium hydride (2.4 g, 0.10 mmol) in THF (150 mL), was treated with dimethyl carbonate (8.4 mL, 0.10 mol) and heated under reflux overnight. After cooling to room temperature, the reaction mixture was poured on an ice/water mixture and extracted with diethyl ether. The combined organic phases were washed with water, dried with magnesium sulfate and volatiles were vacuum evaporated on a rotavapor. The crude product was vacuum distilled (120 °C, 660 Pa). Yield: 7.2 g (41 mmol, 41%). Pale yellow oil. Anal. Calc. for C₁₁H₁₀O₂: C: 75.84; H: 5.79. Found: C: 75.72; H: 5.85. ¹H NMR (CDCl₃; 400 MHz; δ ppm): 7.94 (d, ³J(¹H, ¹H) = 7.7 Hz, 1H, C₉H₇), 7.28 (d, ³J(¹H, ¹H) = 7.5 Hz, 1H, C₉H₇), 7.24 (s, 1H, C₉H₇), 7.21 (t, ³J(¹H, ¹H) = 7.5 Hz, 1H, C₉H₇), 7.10 (t, ³J(¹H, ¹H) = 7.5 Hz, 1H, C₉H₇), 3.73 (s, 3H, COOCH₃), 3.26 (s, 2H, C₉H₇). ¹³C{¹H} NMR (CDCl₃; 101 MHz; δ ppm): 164.3 (1C, C_q, COOMe), 144.4 (1C, CH, C₉H₇), 143.3,



140.6, 135.8 (3 \times 1C, C_q, C₉H₇), 126.5, 125.4, 123.6, 122.3 (4 \times 1C, CH, C₉H₇), 51.3 (1C, CH₃, COOCH₃), 38.2 (1C, CH₂, C₉H₇). IR (ATR, cm⁻¹): 1713s [ν (CO)_{C=O}]. Raman (capillary, cm⁻¹): 1715(4) [ν (CO)_{C=O}].

Reaction of 1-Na with ClCOOMe

Sodium indenide (**1-Na**), freshly prepared from indene (**1**, 11.7 mL, 0.10 mol) and sodium hydride (2.4 g, 0.10 mol) in THF (150 mL), was treated with methyl chloroformate (7.7 mL, 0.1 mol) and stirred at room temperature overnight. The reaction mixture was poured on an ice/water mixture and extracted with diethyl ether. The combined organic phases were dried with magnesium sulfate and volatiles were evaporated on a rotavapor. Fraction distillation of the crude product gave **2** as a minor product (yield: 0.4 g, 2.3 mmol, 2%) and **2a** as the major product (yield: 3.5 g, 15 mmol, 15%). 1,1-(MeOCO)₂C₉H₆ (**2a**): colorless crystals. Bp = 95 °C (10 Pa). Mp = 84 °C. Anal. Calc. for C₁₃H₁₂O₄: C: 67.23; H: 5.21. Found: C: 67.38; H: 5.14. ¹H NMR (CDCl₃; 400 MHz; δ ppm): 7.69 (d, ³J(1H, 1H) = 7.4 Hz, 1H, C₉H₆), 7.36–7.24 (m, 3H, C₉H₆), 6.91 (d, ³J(1H, 1H) = 5.5 Hz, 1H, C₉H₆), 6.56 (d, ³J(1H, 1H) = 5.5 Hz, 1H, C₉H₆), 3.73 (s, 6H, COOCH₃). ¹³C{¹H} NMR (CDCl₃; 101 MHz; δ ppm): 168.5 (2C, C_q, COOMe), 143.8, 139.9 (2 \times 1C, C_q, C₉H₆), 135.1, 133.5, 129.4, 126.6, 125.6, 121.9 (6 \times 1C, CH, C₉H₆), 53.5 (2C, CH₃, COOCH₃). IR (ATR, cm⁻¹): 1743s [ν _a(CO)_{C=O}], 1724s [ν (CO)_{C=O}]. Raman (capillary, cm⁻¹): 1740(2) [ν _a(CO)_{C=O}], 1724(2) [ν _s(CO)_{C=O}].

Synthesis of 3-(MeOCH₂CH₂OCO)C₉H₇ (**3**)

3-(HOCO)C₉H₇ (0.80 g; 5.0 mmol) was dissolved in the excess of thionyl chloride (5 mL) and stirred at room temperature for 1 h and then heated at 60 °C for 10 min. The volatiles were vacuum evaporated. The sticky solid was treated with the excess of MeOCH₂CH₂OH (3.8 g, 50 mmol) and stirred for 2 h. The reaction mixture was diluted with diethyl ether and the reaction was quenched with addition of aqueous solution sodium carbonate. The organic phase was separated and the water phase was washed with an additional portion of diethyl ether. The combined organic phases were washed with water, dried with magnesium sulfate. The volatiles were vacuum evaporated on a rotavapor and the crude product was purified by column chromatography on silica (diethyl ether/hexane = 1:9). Yield: 0.84 g (3.8 mmol, 77%). Pale yellow oil. Anal. Calc. for C₁₃H₁₄O₃: C: 71.54; H: 6.47. Found: C: 71.59; H: 6.45. ¹H NMR (CDCl₃; 400 MHz; δ ppm): 8.04 (d, ³J(1H, 1H) = 7.7 Hz, 1H, C₉H₇), 7.49 (t, ³J(1H, 1H) = 2.0 Hz, 1H, C₉H₇), 7.46 (d, ³J(1H, 1H) = 7.5 Hz, 1H, C₉H₇), 7.34 (t, ³J(1H, 1H) = 7.5 Hz, 1H, C₉H₇), 7.25 (td, ³J(1H, 1H) = 7.5 Hz, ⁴J(1H, 1H) = 1.2 Hz, 1H, C₉H₇), 4.45 (t, ³J(1H, 1H) = 4.7 Hz, 2H, CH₂), 3.72 (t, ³J(1H, 1H) = 4.7 Hz, 2H, CH₂), 3.51 (d, ³J(1H, 1H) = 2.0 Hz, 2H, C₉H₇), 3.42 (s, 3H, OCH₃). ¹³C{¹H} NMR (CDCl₃; 101 MHz; δ ppm): 164.2 (1C, C_q, COOMe), 145.0 (1C, CH, C₉H₇), 143.5, 140.9, 136.2 (3 \times 1C, C_q, C₉H₇), 126.9, 125.7, 124.0, 122.7 (4 \times 1C, CH, C₉H₇), 70.8, 63.7 (2 \times 1C, CH₂, CH₂), 59.2 (1C, CH₃, OCH₃), 38.6 (1C, CH₂, C₉H₇). IR (ATR, cm⁻¹): 1713s [ν (CO)_{C=O}]. Raman (capillary, cm⁻¹): 1717(3) [ν (CO)_{C=O}].

Synthesis of 3-(PhCH₂OCO)C₉H₇ (**4**)

The steps of synthesis followed the procedure for compound **3**. Reagents: 3-(HOCO)C₉H₇ (0.80 g, 5.0 mmol), PhCH₂OH (5.4 g, 50 mmol). The crude product was purified by column chromatography on silica (diethyl ether/hexane = 1:9). Yield: 1.0 g (4.0 mmol, 80%). Pale yellow oil. Anal. Calc. for C₁₇H₁₄O₂: C: 81.58; H: 5.64. Found: C: 81.51; H: 5.80. ¹H NMR (CDCl₃; 400 MHz; δ ppm): 8.06 (d, ³J(1H, 1H) = 7.7 Hz, 1H, C₉H₇), 7.69 (t, ³J(1H, 1H) = 1.8 Hz, 1H, C₉H₇), 7.49–7.32 (m, 2H of C₉H₇ and 5H of C₆H₅), 7.26 (t, ³J(1H, 1H) = 7.4 Hz, 1H, C₉H₇), 5.37 (s, 2H, CH₂Ph), 3.52 (d, ³J(1H, 1H) = 1.8 Hz, 2H, C₉H₇). ¹³C{¹H} NMR (CDCl₃; 101 MHz; δ ppm): 164.1 (1C, C_q, COOMe), 145.1 (1C, CH, C₉H₇), 143.5, 140.9, 136.3 (3 \times 1C, C_q, C₉H₇), 128.8 (2C, C₆H₅), 128.4 (1C, C₆H₅), 128.3 (2C, C₆H₅), 126.9, 125.8, 124.0, 122.7 (4 \times 1C, CH, C₉H₇), 66.4 (1C, CH₂, CH₂), 38.6 (1C, CH₂, C₉H₇). IR (ATR, cm⁻¹): 1713s [ν (CO)_{C=O}]. Raman (capillary, cm⁻¹): 1717(2) [ν (CO)_{C=O}].

Synthesis of 3-(4-MeOC₆H₄OCO)C₉H₇ (**5**)

The steps of synthesis followed the procedure for compound **3**. Reagents: 3-(HOCO)C₉H₇ (0.80 g, 5.0 mmol), 4-MeOC₆H₄OH (1.1 g, 9 mmol). The crude product was purified by column chromatography on silica (diethyl ether/hexane = 1:9). Yield: 0.72 g (2.7 mmol, 54%). Colorless crystals. Mp = 110 °C. Anal. Calc. for C₁₇H₁₄O₃: C: 76.68; H: 5.30. Found: C: 76.75; H: 5.33. ¹H NMR (CDCl₃; 400 MHz; δ ppm): 8.08 (d, ³J(1H, 1H) = 7.6 Hz, 1H, C₉H₇), 7.67 (t, ³J(1H, 1H) = 2.0 Hz, 1H, C₉H₇), 7.50 (d, ³J(1H, 1H) = 7.4 Hz, 1H, C₉H₇), 7.36 (t, ³J(1H, 1H) = 7.6 Hz, 1H, C₉H₇), 7.28 (td, ³J(1H, 1H) = 7.5 Hz, ⁴J(1H, 1H) = 1.2 Hz, 1H, C₉H₇), 7.13 (d, ³J(1H, 1H) = 9.1 Hz, 2H, C₆H₄), 7.93 (d, ³J(1H, 1H) = 9.1 Hz, 2H, C₆H₄), 3.81 (s, 3H, OCH₃), 3.60 (d, ³J(1H, 1H) = 2.0 Hz, 2H, C₉H₇). ¹³C{¹H} NMR (CDCl₃; 101 MHz; δ ppm): 162.9 (1C, C_q, COOMe), 157.6 (1C, C_q, C₆H₄), 146.3 (1C, CH, C₉H₇), 144.3 (1C, C_q, C₆H₄), 143.5, 140.7, 136.0 (3 \times 1C, C_q, C₉H₇), 127.0, 126.0, 124.1, 122.7 (4 \times 1C, CH, C₉H₇), 122.7, 114.8 (2 \times 2C, CH, C₆H₄), 55.9 (1C, CH₃, OCH₃), 38.9 (1C, CH₂, C₉H₇). IR (ATR, cm⁻¹): 1725s [ν (CO)_{C=O}]. Raman (capillary, cm⁻¹): 1727(8) [ν (CO)_{C=O}].

Synthesis of [(η^3 -C₃H₅) $\{\eta^5$ -1-(MeOCO)C₉H₆}Mo(CO)₂] (**7**)

3-(MeOCO)C₉H₇ (**2**; 0.87 g, 5 mmol) was dissolved with 30 mL of THF, cooled at 0 °C and treated dropwise with 3.1 mL of ⁷BuLi (1.6 mol L⁻¹). The reaction mixture was stirred for 1 h and then added dropwise to the THF solution of [(η^3 -C₃H₅)Mo(CO)₂-(NCMe)₂Cl] (**6**; 1.55 g, 5 mmol) precooled to -80 °C. The reaction mixture was stirred at room temperature overnight and then vacuum evaporated to dryness. The solid residue was washed with cold hexane (10 mL) and extracted several times with hot hexane. The volatiles were vacuum evaporated and product was vacuum dried. Yield: 1.24 g (3.4 mmol, 68%). Yellow powder. Mp = 89 °C. Anal. Calc. for C₁₆H₁₄MoO₄: C: 52.47; H: 3.85. Found: C: 52.29; H: 3.80. ¹H NMR (CDCl₃, 400 MHz, δ ppm; 3:1 mixture of **7a** (*exo*-C₃H₅) and **7b** (*endo*-C₃H₅)): 7.86–7.80 (m, 1H of **a** and 1H of **b**, H^{4,7} of C₉H₆), 7.30–7.05 (m, 3H of **a** and 3H of **b**, H^{4,7} of C₉H₆), 6.21 (s-br, 1H of **a**, H^{2,3} of C₉H₆), 6.11



(s-br, 1H of **b**, H^{2,3} of C₉H₆), 6.05 (s-br, 1H of **a**, H^{2,3} of C₉H₆), 5.98 (s-br, 1H of **b**, H^{2,3} of C₉H₆), 3.94 (s, 3H of **a** and 3H of **b**, C₃H₃), 3.50 (s-br, 1H of **b**, C₃H₅), 3.31 (s-br, 2H of **b**, C₃H₅), 2.33 (d, ³J(H, ¹H) = 6.0 Hz, 1H of **a**, *syn* of C₃H₅), 2.16 (d, ³J(H, ¹H) = 6.0 Hz, 1H of **a**, *syn* of C₃H₅), 1.03 (d, ³J(H, ¹H) = 10.8 Hz, 1H of **a**, *anti* of C₃H₅), 0.83 (d, ³J(H, ¹H) = 10.8 Hz, 1H of **a**, *anti* of C₃H₅), 0.72 (m, 1H of **a**, *meso* of C₃H₅), -0.11 (d, ³J(H, ¹H) = 8.4 Hz, 1H of **b**, *anti* of C₃H₅), -1.11 (d, ³J(H, ¹H) = 8.4 Hz, 1H of **b**, *anti* of C₃H₅). IR (ATR, cm⁻¹): 1934vs [ν_a(CO)_{c=O}], 1866vs [ν_s(CO)_{c=O}], 1714s [ν(CO)_{c=O}]. Raman (capillary, cm⁻¹): 1944(3) [ν_a(CO)_{c=O}], 1861(10) [ν_s(CO)_{c=O}], 1715(9) [ν(CO)_{c=O}]. Single crystals suitable for X-ray diffraction analysis were obtained by recrystallization of the product from hexane.

Synthesis of $[(\eta^3\text{-C}_3\text{H}_5)\{\eta^5\text{-1-(MeOCH}_2\text{CH}_2\text{OCO)C}_9\text{H}_6\}\text{Mo}(\text{CO})_2]$ (8)

The steps of synthesis followed the procedure for compound 7. Reagents: 3-(MeOCH₂CH₂OCO)C₉H₇ (3; 0.44 g, 2 mmol), 1.3 mL of ⁿBuLi (1.6 mol L⁻¹), $[(\eta^3\text{-C}_3\text{H}_5)\text{Mo}(\text{CO})_2(\text{NCMe})_2\text{Cl}]$ (6; 0.62 g, 2 mmol). Yield: 0.36 g (0.88 mmol, 44%). Yellow viscous oil. Anal. Calc. for C₁₈H₁₈MoO₅: C: 52.69; H: 4.42. Found: C: 52.65; H: 4.48. ¹H NMR (CDCl₃, 400 MHz, δ ppm; 3:1 mixture of **8a** (*exo*-C₃H₅) and **8b** (*endo*-C₃H₅)): 7.86–7.78 (m, 1H of **a** and 1H of **b**, H^{4,7} of C₉H₆), 7.40–7.00 (m, 3H of **a** and 3H of **b**, H^{4–7} of C₉H₆), 6.26 (s-br, 1H of **a**, H^{2,3} of C₉H₆), 6.16 (s-br, 1H of **b**, H^{2,3} of C₉H₆), 6.05 (s-br, 1H of **a**, H^{2,3} of C₉H₆), 5.98 (s-br, 1H of **b**, H^{2,3} of C₉H₆), 4.51 (m, 2H of **a** and 2H of **b**, CH₂), 3.73 (m, 2H of **a** and 2H of **b**, CH₂), 3.71 (s-br, 1H of **b**, C₃H₅), 3.59 (s-br, 2H of **b**, C₃H₅), 3.43 (s, 3H of **a** and 3H of **b**, CH₃), 2.36 (d, ³J(H, ¹H) = 5.7 Hz, 1H of **a**, *syn* of C₃H₅), 2.15 (d, ³J(H, ¹H) = 5.7 Hz, 1H of **a**, *syn* of C₃H₅), 1.03 (d, ³J(H, ¹H) = 10.8 Hz, 1H of **a**, *anti* of C₃H₅), 0.83 (d, ³J(H, ¹H) = 10.8 Hz, 1H of **a**, *anti* of C₃H₅), 0.75 (m, 1H of **a**, *meso* of C₃H₅), -0.03 (d, ³J(H, ¹H) = 8.8 Hz, 1H of **b**, *anti* of C₃H₅), -1.17 (d, ³J(H, ¹H) = 8.8 Hz, 1H of **b**, *anti* of C₃H₅). IR (ATR, cm⁻¹): 1947vs [ν_a(CO)_{c=O}], 1869vs [ν_s(CO)_{c=O}], 1712s [ν(CO)_{c=O}].

Synthesis of $[(\eta^3\text{-C}_3\text{H}_5)\{\eta^5\text{-1-(PhCH}_2\text{OCO)C}_9\text{H}_6\}\text{Mo}(\text{CO})_2]$ (9)

The steps of synthesis followed the procedure for compound 7. Reagents: 3-(PhCH₂OCO)C₉H₇ (4; 0.50 g, 2 mmol), 1.3 mL of ⁿBuLi (1.6 mol L⁻¹), $[(\eta^3\text{-C}_3\text{H}_5)\text{Mo}(\text{CO})_2(\text{NCMe})_2\text{Cl}]$ (6; 0.62 g, 2 mmol). Yield: 0.60 g (1.36 mmol, 68%). Yellow crystals. Mp = 101 °C. Anal. Calc. for C₂₂H₁₈MoO₄: C: 59.74; H: 4.10. Found: C: 59.79; H: 4.16. ¹H NMR (CDCl₃, 400 MHz, δ ppm; 3:1 mixture of **9a** (*exo*-C₃H₅) and **9b** (*endo*-C₃H₅)): 7.86–7.75 (m, 1H of **a** and 1H of **b**, H^{4,7} of C₉H₆), 7.52–7.00 (m, 9H of **a** and 9H of **b**, H^{4–7} of C₉H₆, C₆H₅), 6.25 (s-br, 1H of **a**, H^{2,3} of C₉H₆), 6.16 (s-br, 1H of **b**, H^{2,3} of C₉H₆), 6.03 (s-br, 1H of **a**, H^{2,3} of C₉H₆), 5.99 (s-br, 1H of **b**, H^{2,3} of C₉H₆), 5.40 (m, 2H of **a** and 2H of **b**, CH₂), 3.44 (s-br, 1H of **b**, C₃H₅), 3.29 (s-br, 2H of **b**, C₃H₅), 2.26 (s-br, 1H of **a**, *syn* of C₃H₅), 2.12 (s-br, 1H of **a**, *syn* of C₃H₅), 0.99 (s-br, 1H of **a**, C₃H₅), 0.81 (s-br, 2H of **a**, C₃H₅), -0.03 (s-br, 1H of **b**, *anti* of C₃H₅), -1.19 (s-br, 1H of **b**, *anti* of C₃H₅). IR (ATR, cm⁻¹): 1932vs [ν_a(CO)_{c=O}], 1865vs [ν_s(CO)_{c=O}], 1702s [ν(CO)_{c=O}]. Raman (capillary, cm⁻¹): 1942(6) [ν_a(CO)_{c=O}], 1856(10) [ν_s(CO)_{c=O}], 1705(5) [ν(CO)_{c=O}].

Synthesis of $[(\eta^3\text{-C}_3\text{H}_5)\{\eta^5\text{-1-(4-MeOC}_6\text{H}_4\text{OCO)C}_9\text{H}_6\}\text{Mo}(\text{CO})_2]$ (10)

The steps of synthesis followed the procedure for compound 7. Reagents: 3-(4-MeOC₆H₄OCO)C₉H₇ (5; 0.53 g, 2 mmol), 1.3 mL of ⁿBuLi (1.6 mol L⁻¹), $[(\eta^3\text{-C}_3\text{H}_5)\text{Mo}(\text{CO})_2(\text{NCMe})_2\text{Cl}]$ (6; 0.62 g, 2 mmol). Yield: 0.25 g (0.55 mmol, 27%). Orange crystals. Mp = 124 °C. Anal. Calc. for C₂₂H₁₈MoO₅: C: 57.65; H: 3.96. Found: C: 57.52; H: 3.80. ¹H NMR (CDCl₃, 400 MHz, δ ppm; 3:1 mixture of **10a** (*exo*-C₃H₅) and **10b** (*endo*-C₃H₅)): 7.90–7.80 (m, 1H of **a** and 1H of **b**, H^{4,7} of C₉H₆), 7.30–6.90 (m, 7H of **a** and 7H of **b**, H^{4–7} of C₉H₆ and C₆H₄), 6.37 (s-br, 1H of **a**, H^{2,3} of C₉H₆), 6.29 (s-br, 1H of **b**, H^{2,3} of C₉H₆), 6.13 (s-br, 1H of **a**, H^{2,3} of C₉H₆), 6.06 (s-br, 1H of **b**, H^{2,3} of C₉H₆), 3.82 (s, 3H of **a** and 3H of **b**, CH₃), 3.58 (s-br, 1H of **b**, C₃H₅), 3.35 (s-br, 2H of **b**, C₃H₅), 2.40 (d, ³J(H, ¹H) = 6.0 Hz, 1H of **a**, *syn* of C₃H₅), 2.24 (d, ³J(H, ¹H) = 6.1 Hz, 1H of **a**, *syn* of C₃H₅), 1.13 (d, ³J(H, ¹H) = 11.0 Hz, 1H of **a**, *anti* of C₃H₅), 0.89 (d, ³J(H, ¹H) = 11.0 Hz, 1H of **a**, *anti* of C₃H₅), 0.63 (m, 1H of **a**, *meso* of C₃H₅), 0.01 (d, ³J(H, ¹H) = 9.5 Hz, 1H of **b**, *anti* of C₃H₅), -1.13 (d, ³J(H, ¹H) = 9.6 Hz, 1H of **b**, *anti* of C₃H₅). IR (ATR, cm⁻¹): 1944vs [ν_a(CO)_{c=O}], 1865vs [ν_s(CO)_{c=O}], 1722s [ν(CO)_{c=O}]. Raman (capillary, cm⁻¹): 1946(3) [ν_a(CO)_{c=O}], 1862(7) [ν_s(CO)_{c=O}], 1714(9) [ν(CO)_{c=O}].

Synthesis of $[(\eta^3\text{-1-(MeOCO)C}_9\text{H}_6)\{\eta^5\text{-Ind}\text{Mo}(\text{CO})_2\}]$ (12)

3-(MeOCO)C₉H₇ (2; 0.17 g, 1 mmol) was dissolved with 20 mL of THF, cooled at 0 °C and treated dropwise with 0.6 mL of ⁿBuLi (1.6 mol L⁻¹). The reaction mixture was stirred for 1 h and then added dropwise to the THF solution of $[(\eta^5\text{-Ind})\text{Mo}(\text{CO})_2(\mu\text{-Cl})_2]$ (11; 0.30 g, 0.5 mmol) precooled to -80 °C. The reaction mixture was stirred at room temperature overnight and then vacuum evaporated to dryness. The solid residue was washed with cold hexane (10 mL) and extracted several times with diethyl ether. The volatiles were vacuum evaporated and product was vacuum dried. Yield: 0.19 g (0.43 mmol, 43%). Port red solid. Mp = 120 °C (dec). Anal. Calc. for C₂₂H₁₈MoO₄: C: 59.74; H: 4.10. Found: C: 59.87; H: 4.03. ¹H NMR (CDCl₃; 400 MHz; δ ppm): 7.52–6.65 (m, 9H, C₉H₆ and C₉H₇), 5.60 (m, 3H, C₉H₆ and C₉H₇), 4.73 (s-br, 1H, C₉H₇), 3.84 (s, 3H, (s, 3H, COOCH₃)). IR (ATR, cm⁻¹): 1943vs [ν_a(CO)_{c=O}], 1876vs [ν_s(CO)_{c=O}], 1828s [ν_s(CO)_{c=O}], 1694s [ν(CO)_{c=O}]. Single crystals suitable for X-ray diffraction analysis were obtained by recrystallization of the product from hot hexane.

Synthesis of 3-(MeCO)C₉H₇ (13)

The steps of synthesis followed the procedure for compound 2. Reagents: indene (1; 11.7 mL, 0.10 mol), sodium hydride (2.4 g; 0.10 mol), ethyl acetate (9.8 mL, 0.10 mol). The crude product was vacuum distilled (90 °C, 660 Pa). Yield: 6.0 g (38 mmol, 38%). Pale yellow solid. Mp = 58 °C. Anal. Calc. for C₁₁H₁₀O: C: 83.52; H: 6.37. Found: C: 83.44; H: 6.31. ¹H NMR (CDCl₃; 400 MHz; δ ppm): 8.19 (d, ³J(H, ¹H) = 7.7 Hz, 1H, C₉H₇), 7.41 (d, ³J(H, ¹H) = 7.4 Hz, 1H, C₉H₇), 7.30 (t, ³J(H, ¹H) = 7.4 Hz, 1H, C₉H₇), 7.27 (t, ³J(H, ¹H) = 1.8 Hz, 1H, C₉H₇), 7.22 (t, ³J(H, ¹H) = 7.2 Hz, 1H, C₉H₇), 3.47 (d, ³J(H, ¹H) = 1.8 Hz, 2H, C₉H₇), 2.46 (s, 3H, COCH₃). ¹³C{¹H} NMR (CDCl₃; 101 MHz; δ ppm): 196.2 (1C, C_q, COMe), 145.0 (1C, CH, C₉H₇), 143.5, 143.2, 140.8



(3×1 C, C_q, C₉H₇), 126.7, 125.8, 123.7, 123.5 (4×1 C, CH, C₉H₇), 38.6 (1C, CH₂, C₉H₇), 27.7 (1C, CH₃, COCH₃). IR (ATR, cm⁻¹): 1669s [ν (CO)_{c=O}]. Raman (capillary, cm⁻¹): 1666(8) [ν (CO)_{c=O}]. Single crystals suitable for X-ray diffraction analysis were obtained by recrystallization of the product from hexane.

Synthesis of $[(\eta^3\text{-C}_3\text{H}_5)\{\eta^5\text{-1-(MeCO)C}_9\text{H}_6\}\text{Mo}(\text{CO})_2]$ (14)

The steps of synthesis followed the procedure for compound 7. Reagents: 3-(MeCO)C₉H₇ (13; 0.79 g, 5 mmol), 3.1 mL of ⁷BuLi (1.6 mol L⁻¹), $[(\eta^3\text{-C}_3\text{H}_5)\text{Mo}(\text{CO})_2(\text{NCMe})_2\text{Cl}]$ (6; 1.55 g, 5 mmol). Yield: 1.1 g (3.1 mmol, 63%). Yellow powder. Mp = 124 °C. Anal. Calc. for C₁₆H₁₄MoO₃: C: 54.78; H: 4.03. Found: C: 54.91; H: 4.16. ¹H NMR (CDCl₃, 400 MHz, δ ppm; 3:1 mixture of 14a (*exo*-C₃H₅) and 14b (*endo*-C₃H₅)): 8.05–7.98 (m, 1H of a and 1H of b, H^{4,7} of C₉H₆), 7.32–7.05 (m, 3H of a and 3H of b, H^{2,3} of C₉H₆), 6.05 (s-br, 2H of a and 2H of b, H^{2,3} of C₉H₆), 3.50 (s-br, 1H of b, C₃H₅), 3.29 (s-br, 2H of b, C₃H₅), 2.54 (s, 3H of a and 3H of b, CH₃), 2.25 (s-br, 1H of a, *syn* of C₃H₅), 2.14 (s-br, 1H of a, *syn* of C₃H₅), 1.09 (d, $^3J(\text{H}, \text{H})$ = 9.3 Hz, 1H of a, *anti* of C₃H₅), 0.85 (d, $^3J(\text{H}, \text{H})$ = 9.5 Hz, 1H of a, *anti* of C₃H₅), 0.64 (s-br, 1H of a, *meso* of C₃H₅), 0.06 (s-br, 1H of b, *anti* of C₃H₅), -1.33 (s-br, 1H of b, *anti* of C₃H₅). IR (ATR, cm⁻¹): 1936vs [ν_a (CO)_{c=O}], 1859vs [ν_s (CO)_{c=O}], 1660s [ν (CO)_{c=O}]. Raman (capillary, cm⁻¹): 1932(5) [ν_a (CO)_{c=O}], 1836(10) [ν_s (CO)_{c=O}], 1666(7) [ν (CO)_{c=O}]. Single crystals suitable for X-ray diffraction analysis were obtained by recrystallization of the product from hexane.

Synthesis of 3-(⁷BuNHCO)C₉H₇ (15)

Lithium indenide (1-Li), freshly prepared from indene (1; 11.7 mL, 0.10 mol) and 62.5 mL of ⁷BuLi (1.6 mol L⁻¹) in THF (150 mL), was cooled at -80 °C, treated with ⁷BuNCO (11.4 mL, 0.10 mol), slowly warmed at room temperature and stirred overnight. The reaction mixture was poured on an ice/water mixture. The pale yellow precipitate was filtered on a glass frit and washed with hexane. The crude product was dissolved in CH₂Cl₂ and water. The organic phase was separated, dried with magnesium sulfate and volatiles were evaporated on a rotavapor. The final product was washed with hexane on a glass frit and vacuum dried. Yield: 14.0 g (65 mmol, 65%). Colorless crystals. Mp = 122 °C. Anal. Calc. for C₁₄H₁₇NO: C: 78.10; H: 7.96; N: 6.51. Found: C: 78.22; H: 8.04; N: 6.67. ¹H NMR (CDCl₃, 400 MHz, δ ppm): 7.89 (d, $^3J(\text{H}, \text{H})$ = 7.7 Hz, 1H, C₉H₇), 7.49 (d, $^3J(\text{H}, \text{H})$ = 7.4 Hz, 1H, C₉H₇), 7.36 (t, $^3J(\text{H}, \text{H})$ = 7.5 Hz, 1H, C₉H₇), 7.28 (t, $^3J(\text{H}, \text{H})$ = 7.4 Hz, 1H, C₉H₇), 6.90 (s, 1H, C₉H₇), 5.89 (s, 1H, NH⁷Bu), 3.48 (s, 2H, C₉H₇), 1.51 (s, 9H, C(CH₃)₃). ¹³C{¹H} NMR (CDCl₃, 101 MHz, δ ppm): 164.7 (1C, C_q, CONH), 143.9, 141.6 (2 \times 1C, C_q, C₉H₇), 136.7, 126.7, 125.7, 124.1, 121.9 (5 \times 1C, CH, C₉H₇), 51.7 (1C, C_q, C(CH₃)₃), 38.2 (1C, CH₂, C₉H₇), 29.1 (3C, CH₃, C_q, C(CH₃)₃). IR (ATR, cm⁻¹): 3286m [ν (NH)], 1637s [ν (CO)_{c=O}]. Raman (capillary, cm⁻¹): 1638(8) [ν (CO)_{c=O}].

Synthesis of 3-(PhNHCO)C₉H₇ (16)

3-(HOCO)C₉H₇ (0.80 g; 5.0 mmol) was dissolved in the excess of thionyl chloride (5 mL) and stirred at room temperature for 1 h and then heated at 60 °C for 10 min. The volatiles were vacuum evaporated. The sticky solid was dissolved in CH₂Cl₂, cooled at

-80 °C, treated with the excess of PhNH₂ (2.7 mL, 30 mmol) and stirred at room temperature for 2 h. The volatiles were vacuum evaporated and the solid product was washed with diethyl ether. The crude product was purified by column chromatography on silica (hexane/ethyl acetate = 7:3). Yield: 0.62 g (2.6 mmol, 53%). Colorless crystals. Mp = 155 °C. R_f(TLC; hexane/ethyl acetate = 7:3) = 0.44. Anal. Calc. for C₁₆H₁₃NO: C: 81.68; H: 5.57; N: 5.95. Found: 81.52; H: 5.55; N: 5.84. ¹H NMR (CDCl₃, 400 MHz, δ ppm): 7.94 (d, $^3J(\text{H}, \text{H})$ = 7.7 Hz, 1H, C₉H₇), 7.81 (s, 1H, NHPh), 7.63 (d, $^3J(\text{H}, \text{H})$ = 8.6 Hz, 2H, C₆H₅), 7.48 (d, $^3J(\text{H}, \text{H})$ = 7.4 Hz, 1H, C₉H₇), 7.37–7.32 (m, 1H of C₉H₇ and 2H of C₆H₅), 7.27 (td, $^3J(\text{H}, \text{H})$ = 7.4 Hz, $^4J(\text{H}, \text{H})$ = 1.2 Hz, 1H, C₉H₇), 7.13 (tt, $^3J(\text{H}, \text{H})$ = 7.5 Hz, $^4J(\text{H}, \text{H})$ = 1.0 Hz, 1H, C₆H₅), 7.06 (t, $^3J(\text{H}, \text{H})$ = 2.0 Hz, 1H, C₉H₇), 3.50 (d, $^3J(\text{H}, \text{H})$ = 2.0 Hz, 2H, C₉H₇). ¹³C{¹H} NMR (CDCl₃, 101 MHz, δ ppm): 163.3 (1C, C_q, CONH), 143.7, 141.2, 140.9, 137.9 (4 \times 1C, C_q, C₉H₇ and C₆H₅), 137.0 (1C, CH, C₉H₇), 129.3 (2C, CH, C₆H₅), 127.0, 126.0 (2 \times 1C, CH, C₉H₇), 124.7 (2C, CH, C₆H₅), 124.1, 122.2 (2 \times 1C, CH, C₉H₇), 120.3 (2C, CH, C₆H₅), 38.6 (1C, CH₂, C₉H₇). IR (ATR, cm⁻¹): 3284s [ν (NH)], 1648s [ν (CO)_{c=O}]. Raman (capillary, cm⁻¹): 1650(9) [ν (CO)_{c=O}].

Reaction of 1-Na with PhNCO

Lithium indenide (1-Li), freshly prepared from indene (1; 11.7 mL, 0.10 mol) and 62.5 mL of ⁷BuLi (1.6 mol L⁻¹) in THF (150 mL), was cooled at -80 °C, treated with PhNCO (10.9 mL, 0.10 mol), slowly warmed at room temperature and stirred overnight. The reaction mixture was poured on an ice/water mixture, treated with CH₂Cl₂ and neutralized with hydrochloric acid. The aqueous phase was separated and disposed. The organic phase was filtered on a glass frit. The collected solid was recrystallized from acetone to give colorless crystals of 18 (yield: 2.9 g, 8.2 mmol, 8%). The volatiles from the filtrate were vacuum evaporated and the product was washed with diethyl ether to give 9 g of a mixture of 16 and 17 in a molar ratio of 1:5 (according to ¹H NMR). Analytically pure samples of 16 and 17 were obtained by column chromatography on silica (hexane/ethyl acetate = 7:3). 1,3-(PhNHCO)₂C₉H₆ (18): white solid. Mp = 240 °C (dec.). Anal. Calc. for C₂₃H₁₈N₂O₂: C: 77.95; H: 5.12; N: 7.90. Found: C: 77.90; H: 5.04; N: 7.96. ¹H NMR (acetone-d₆; 400 MHz, δ ppm): 9.66 (s, 1H, NHPh), 9.14 (s, 1H, NHPh), 8.03 (d, $^3J(\text{H}, \text{H})$ = 7.6 Hz, 1H, C₉H₆), 7.85 (d, $^3J(\text{H}, \text{H})$ = 8.2 Hz, 2H, C₆H₅), 7.68–7.63 (m, 1H of C₉H₆ and 2H of C₆H₅), 7.42–7.27 (m, 3H of C₉H₆ and 4H of C₆H₅), 7.12 (tt, $^3J(\text{H}, \text{H})$ = 7.3 Hz, $^4J(\text{H}, \text{H})$ = 1.1 Hz, 1H, C₆H₅), 7.08 (tt, $^3J(\text{H}, \text{H})$ = 7.3 Hz, $^4J(\text{H}, \text{H})$ = 1.1 Hz, 1H, C₆H₅), 4.71 (d, $^3J(\text{H}, \text{H})$ = 2.1 Hz, H, C₉H₆). IR (ATR, cm⁻¹): 3236m [ν (NH)], 1662s [ν (CO)_{c=O}], 1646s [ν (CO)_{c=O}]. Raman (capillary, cm⁻¹): 1647(9) [ν (CO)_{c=O}]. 3-(PhNHCONPhCO)C₉H₇ (17): colorless crystals. Mp = 116 °C. R_f(TLC; hexane/ethyl acetate = 7:3) = 0.53. Anal. Calc. for C₂₃H₁₈N₂O₂: C: 77.95; H: 5.12; N: 7.90. Found: C: 77.84; H: 5.18; N: 7.79. ¹H NMR (CDCl₃, 400 MHz, δ ppm): 11.60 (s, 1H, NHPh), 7.75 (d, $^3J(\text{H}, \text{H})$ = 7.7 Hz, 1H, C₉H₇), 7.66 (d, $^3J(\text{H}, \text{H})$ = 8.2 Hz, 2H, C₆H₅), 7.43–7.25 (m, 3H of C₉H₇ and 7H of C₆H₅), 7.16 (tt, $^3J(\text{H}, \text{H})$ = 7.4 Hz, $^4J(\text{H}, \text{H})$ = 1.1 Hz, 1H, C₆H₅), 6.07 (t, $^3J(\text{H}, \text{H})$ = 2.1 Hz, 1H, C₉H₇), 3.25 (d, $^3J(\text{H}, \text{H})$ = 2.0 Hz, 2H,



C_9H_7). $^{13}C\{^1H\}$ NMR ($CDCl_3$; 101 MHz; δ ppm): 170.0, 152.2 ($2 \times 1C$, C_q , CO), 142.5, 141.9, 138.9, 138.7, 137.9 ($5 \times 1C$, C_q , C_9H_7 and C_6H_5), 139.0 ($1C$, CH , C_9H_7), 129.8, 129.2, 129.1 ($3 \times 2C$, CH , C_6H_5), 128.9 ($1C$, CH , C_6H_5), 126.9, 126.0 ($2 \times 1C$, CH , C_9H_7), 124.5, 124.0 ($2 \times 1C$, CH , C_9H_7 and C_6H_5), 121.5 ($1C$, CH , C_9H_7), 120.6 ($2C$, CH , C_6H_5), 39.2 ($1C$, CH_2 , C_9H_7). IR (ATR, cm^{-1}): 3214m [$\nu(NH)$], 1646s [$\nu(CO)C=O$]. Raman (capillary, cm^{-1}): 1723(1) [$\nu(CO)C=O$], 1648(9) [$\nu(CO)C=O$].

Synthesis of 3-(4-ClC₆H₄NHCO)C₉H₇ (19)

The steps of synthesis followed the procedure for compound **16**. Reagents: 3-(HOCO)C₉H₇ (0.80 g, 5.0 mmol), 4-ClC₆H₄NH₂ (2.6 g, 20 mmol). The crude product was washed with ether and purified by column chromatography on silica (hexane/ethyl acetate = 7 : 3). Yield: 0.60 g (2.2 mmol, 44%). Colorless crystals. $M_p = 172$ $^{\circ}C$. R_f (TLC; hexane/ethyl acetate = 7 : 3) = 0.42. Anal. Calc. for C₁₆H₁₂ClNO: C: 71.25; H: 4.48; N: 5.19. Found: C: 71.35; H: 4.46; N: 5.12. 1H NMR ($CDCl_3$; 400 MHz; δ ppm): 7.91 (d, $^3J(^1H, ^1H)$ = 7.5 Hz, 1H, C_9H_7), 7.80 (s, 1H, $NHPh$), 7.57 (d, $^3J(^1H, ^1H)$ = 8.8 Hz, 2H, C_6H_4), 7.48 (d, $^3J(^1H, ^1H)$ = 7.4 Hz, 1H, C_9H_7), 7.34 (t, $^3J(^1H, ^1H)$ = 7.5 Hz, 1H, C_9H_7), 7.29 (d, $^3J(^1H, ^1H)$ = 8.8 Hz, 2H, C_6H_4), 7.27 (td, $^3J(^1H, ^1H)$ = 7.4 Hz, $^4J(^1H, ^1H)$ = 1.1 Hz, 1H, C_9H_7), 7.05 (t, $^3J(^1H, ^1H)$ = 2.0 Hz, 1H, C_9H_7), 3.50 (d, $^3J(^1H, ^1H)$ = 2.0 Hz, 2H, C_9H_7). $^{13}C\{^1H\}$ NMR ($CDCl_3$; 101 MHz; δ ppm): 163.2 ($1C$, C_q , $CONH$), 143.7, 141.1, 140.7, 136.5, 127.9 ($5 \times 1C$, C_q , C_9H_7 and C_6H_4), 137.3 ($1C$, CH , C_9H_7), 129.3 ($2C$, CH , C_6H_5), 127.0, 126.2, 124.2, 122.1, ($4 \times 1C$, CH , C_9H_7), 121.6 ($2C$, CH , C_6H_5), 38.6 ($1C$, CH_2 , C_9H_7). IR (ATR, cm^{-1}): 3284m [$\nu(NH)$], 1655s [$\nu(CO)C=O$]. Raman (capillary, cm^{-1}): 1657(10) [$\nu(CO)C=O$].

Synthesis of $[(\eta^3\text{-}C_3H_5)\{\eta^5\text{-}1\text{-}(^t\text{BuNHCO})C_9H_6\}Mo(CO)_2]$ (20)

The steps of synthesis followed the procedure for compound **7**. Reagents: 3-(t BuNHCO)C₉H₇ (**15**; 0.43 g, 2 mmol), 1.3 mL of n BuLi (1.6 mol L^{-1}), $[(\eta^3\text{-}C_3H_5)Mo(CO)_2(NCMe)_2Cl]$ (**6**; 0.62 g, 2 mmol). Yield: 0.50 g (1.23 mmol, 61%). Yellow powder. $M_p = 190$ $^{\circ}C$ (dec.). Anal. Calc. for C₁₉H₂₁MoNO₃: C: 56.03; H: 5.20; N: 3.44. Found: C: 56.18; H: 5.33; N: 3.51. 1H NMR ($CDCl_3$, 400 MHz, δ ppm; 3 : 1 mixture of **20a** (*exo*-C₃H₅) and **20b** (*endo*-C₃H₅)): 8.00–7.91 (m, 1H of **a** and 1H of **b**, $H^{4,7}$ of C_9H_6), 7.21–6.98 (m, 3H of **a** and 3H of **b**, $H^{4,7}$ of C_9H_6), 5.98 (d, $^3J(^1H, ^1H)$ = 3.0 Hz, 1H of **a**, $H^{2,3}$ of C_9H_6), 5.91 (d, $^3J(^1H, ^1H)$ = 2.5 Hz, 1H of **b**, $H^{2,3}$ of C_9H_6), 5.86 (d, $^3J(^1H, ^1H)$ = 3.0 Hz, 1H of **a**, $H^{2,3}$ of C_9H_6), 5.79 (d, $^3J(^1H, ^1H)$ = 2.5 Hz, 1H of **b**, $H^{2,3}$ of C_9H_6), 5.68 (s, 1H of **a**, NH), 5.62 (s, 1H of **b**, NH), 3.54 (s-br, 1H of **b**, C_3H_5), 3.33 (s-br, 2H of **b**, C_3H_5), 2.44 (d, $^3J(^1H, ^1H)$ = 6.7 Hz, 1H of **a**, *syn* of C_3H_5), 2.11 (d, $^3J(^1H, ^1H)$ = 6.6 Hz, 1H of **a**, *syn* of C_3H_5), 1.48 (s, 9H of **a** and 9H of **b**, $C(CH_3)_3$), 1.06 (d, $^3J(^1H, ^1H)$ = 10.7 Hz, 1H of **a**, *anti* of C_3H_5), 0.85 (d, $^3J(^1H, ^1H)$ = 10.8 Hz, 1H of **a**, *anti* of C_3H_5), 0.78 (m, 1H of **a**, *meso* of C_3H_5), -0.06 (d, $^3J(^1H, ^1H)$ = 9.6 Hz, 1H of **b**, *anti* of C_3H_5), -1.09 (d, $^3J(^1H, ^1H)$ = 9.7 Hz, 1H of **b**, *anti* of C_3H_5). IR (ATR, cm^{-1}): 3372m [$\nu(NH)$], 1932vs [$\nu_a(CO)C=O$], 1848vs [$\nu_s(CO)C=O$], 1635s [$\nu(CO)C=O$]. Raman (capillary, cm^{-1}): 1931(6) [$\nu_a(CO)C=O$], 1850(10) [$\nu_s(CO)C=O$], 1637(4) [$\nu(CO)C=O$]. Single crystals of **20** suitable to X-ray

diffraction analysis were prepared by slow evaporation of MeOH solution.

Synthesis of $[(\eta^3\text{-}C_3H_5)\{\eta^5\text{-}1\text{-}(PhNHCO)C_9H_6\}Mo(CO)_2]$ (21)

The steps of synthesis followed the procedure for compound **7**. Reagents: 3-(PhNHCO)C₉H₇ (**16**; 0.47 g, 2 mmol), 1.3 mL of n BuLi (1.6 mol L^{-1}), $[(\eta^3\text{-}C_3H_5)Mo(CO)_2(NCMe)_2Cl]$ (**6**; 0.62 g, 2 mmol). Yield: 0.45 g (1.05 mmol, 53%). Yellow powder. $M_p = 180$ $^{\circ}C$ (dec.). Anal. Calc. for C₂₁H₁₇MoNO₃: C: 59.03; H: 4.01; H: 3.28. Found: C: 58.91; H: 4.08; H: 3.21. 1H NMR (acetone- d^6 , 400 MHz, δ ppm; 4 : 1 mixture of **21a** (*exo*-C₃H₅) and **21b** (*endo*-C₃H₅)): 9.24 (1H of **a**, NH), 9.13 (1H of **b**, NH), 8.16–6.95 (m, 9H of **a** and 9H of **b**, $H^{4,7}$ of C_9H_6 , C_6H_5), 6.71 (d, $^3J(^1H, ^1H)$ = 3.2 Hz, 1H of **a**, $H^{2,3}$ of C_9H_6), 6.61 (s-br, 1H of **b**, $H^{2,3}$ of C_9H_6), 6.32 (d, $^3J(^1H, ^1H)$ = 3.2 Hz, 1H of **a**, $H^{2,3}$ of C_9H_6), 6.28 (s-br, 1H of **b**, $H^{2,3}$ of C_9H_6), 3.50 (s-br, 1H of **b**, C_3H_5), 3.36 (s-br, 2H of **b**, C_3H_5), 2.36 (d, $^3J(^1H, ^1H)$ = 7.2 Hz, 1H of **a**, *syn* of C_3H_5), 2.14 (d, $^3J(^1H, ^1H)$ = 7.0 Hz, 1H of **a**, *syn* of C_3H_5), 1.15 (m, 1H of **a**, *meso* of C_3H_5), 0.99 (d, $^3J(^1H, ^1H)$ = 11.3 Hz, 1H of **a**, *anti* of C_3H_5), 0.82 (d, $^3J(^1H, ^1H)$ = 11.4 Hz, 1H of **a**, *anti* of C_3H_5), -0.09 (d, $^3J(^1H, ^1H)$ = 10.7 Hz, 1H of **b**, *anti* of C_3H_5), -0.94 (d, $^3J(^1H, ^1H)$ = 10.8 Hz, 1H of **b**, *anti* of C_3H_5). IR (ATR, cm^{-1}): 3307m [$\nu(NH)$], 1932vs [$\nu_a(CO)C=O$], 1859vs [$\nu_s(CO)C=O$], 1633s [$\nu(CO)C=O$]. Raman (capillary, cm^{-1}): 1933(5) [$\nu_a(CO)C=O$], 1866(9) [$\nu_s(CO)C=O$], 1635(8) [$\nu(CO)C=O$].

Synthesis of $[(\eta^3\text{-}C_3H_5)\{\eta^5\text{-}1\text{-}(4-ClC_6H_4NHCO)C_9H_6\}Mo(CO)_2]$ (22)

The steps of synthesis followed the procedure for compound **7**. Reagents: 3-(4-ClC₆H₄NHCO)C₉H₇ (**19**; 0.54 g, 2 mmol), 1.3 mL of n BuLi (1.6 mol L^{-1}), $[(\eta^3\text{-}C_3H_5)Mo(CO)_2(NCMe)_2Cl]$ (**6**; 0.62 g, 2 mmol). Yield: 0.55 g (1.19 mmol, 60%). Yellow powder. $M_p = 185$ $^{\circ}C$ (dec.). Anal. Calc. for C₂₁H₁₆ClMoNO₃: C: 54.62; H: 3.49; N: 3.03. Found: C: 54.70; H: 3.52; N: 3.08. 1H NMR ($CDCl_3$, 400 MHz, δ ppm; 3 : 1 mixture of **23a** (*exo*-C₃H₅) and **23b** (*endo*-C₃H₅)): 7.98 (d, $^3J(^1H, ^1H)$ = 8.8 Hz, 1H of **a** and 1H of **b**, $H^{4,7}$ of C_9H_6), 7.60–7.05 (m, 8H of **a** and 8H of **b**, $H^{4,7}$ of C_9H_6 , C_6H_4 , NH), 6.10 (d, $^3J(^1H, ^1H)$ = 2.9 Hz, 1H of **a**, $H^{2,3}$ of C_9H_6), 6.05 (d, $^3J(^1H, ^1H)$ = 2.9 Hz, 1H of **a**, $H^{2,3}$ of C_9H_6), 6.03 (d, $^3J(^1H, ^1H)$ = 2.8 Hz, 1H of **b**, $H^{2,3}$ of C_9H_6), 5.98 (d, $^3J(^1H, ^1H)$ = 2.8 Hz, 1H of **b**, $H^{2,3}$ of C_9H_6), 3.62 (s-br, 1H of **b**, C_3H_5), 3.39 (s-br, 2H of **b**, C_3H_5), 2.47 (d, $^3J(^1H, ^1H)$ = 6.7 Hz, 1H of **a**, *syn* of C_3H_5), 2.21 (d, $^3J(^1H, ^1H)$ = 6.7 Hz, 1H of **a**, *syn* of C_3H_5), 1.14 (d, $^3J(^1H, ^1H)$ = 11.1 Hz, 1H of **a**, *anti* of C_3H_5), 0.90 (d, $^3J(^1H, ^1H)$ = 11.6 Hz, 1H of **a**, *anti* of C_3H_5), 0.64 (m, 1H of **a**, *meso* of C_3H_5), -0.06 (d, $^3J(^1H, ^1H)$ = 9.8 Hz, 1H of **b**, *anti* of C_3H_5), -1.00 (d, $^3J(^1H, ^1H)$ = 9.6 Hz, 1H of **b**, *anti* of C_3H_5). IR (ATR, cm^{-1}): 3424m [$\nu(NH)$], 1940vs [$\nu_a(CO)C=O$], 1852vs [$\nu_s(CO)C=O$], 1667s [$\nu(CO)C=O$]. Raman (capillary, cm^{-1}): 1948(3) [$\nu_a(CO)C=O$], 1848(8) [$\nu_s(CO)C=O$], 1664(10) [$\nu(CO)C=O$]. Single crystals of **23**·MeOH suitable to X-ray diffraction analysis were prepared by slow evaporation of MeOH solution.

X-ray crystallography

The X-ray data for the crystals of compounds **7**, **12**, **13**, **14**, **20** and **22**·MeOH were obtained at 150 K using an Oxford Cryostream



low-temperature device on a Nonius KappaCCD diffractometer with Mo K α radiation ($\lambda = 0.71073$ Å) and a graphite monochromator. Data reductions were performed using DENZO-SMN.²⁶ The structures were solved by direct methods (Sir92)²⁷ and refined by full-matrix least squares based on F^2 (SHELXL).²⁸ Hydrogen atoms were mostly localized on a difference Fourier map. However, to ensure uniformity of the treatment of the crystals, all hydrogen atoms were recalculated into idealized positions (riding model) and assigned temperature factors $U_{\text{iso}}(\text{H}) = 1.2[U_{\text{eq}}(\text{pivot atom})]$ or $1.5U_{\text{eq}}$ for the methyl moiety with C–H = 0.96, 0.97, and 0.93 Å for methyl, methylene, and hydrogen atoms in aromatic rings or the allyl moiety, respectively. The structure of 7 contains a disorder of the allyl group which, is positionally disordered on one of the carbon atoms (C13) and splits into two positions with an occupancy of about 7 : 3; this disorder was treated using SHELXL software.²⁸

Acknowledgements

The NMR spectrometers at ITQB are part of the National NMR Facility, supported by Fundação para a Ciência e a Tecnologia (RECI/BBB-BQB/0230/2012). We thank University of Pardubice for the Erasmus mobility fellowship (Erasmus+ 2014/2015).

References

- (a) T. Liu, X. Wang, C. Hoffmann, D. L. DuBois and M. R. Bullock, *Angew. Chem., Int. Ed.*, 2014, **53**, 5300–5304; (b) M. Fang, E. S. Wiedner, W. G. Dougherty, W. S. Kassel, T. Liu, D. L. DuBois and M. R. Bullock, *Organometallics*, 2014, **33**, 5820–5833; (c) X. Wang, D. Li, W. Deuther-Conrad, J. Lu, Y. Xie, B. Jia, M. Cui, J. Steinbach, P. Brust, B. Liu and H. Jia, *J. Med. Chem.*, 2014, **57**, 7113–7125; (d) S. Sulieman, D. Can, J. Mertens, H. W. P. N'Dongo, Y. Liu, P. Schmutz, M. Bauwens, B. Spingler and R. Alberto, *Organometallics*, 2012, **31**, 6880–6886; (e) D. Can, B. Spingler, P. Schmutz, F. Mendes, P. Raposo, C. Fernandes, F. Carta, A. Innocenti, I. Santos, C. T. Supuran and R. Alberto, *Angew. Chem., Int. Ed.*, 2012, **51**, 3354–3357; (f) E. Hillard, A. Vessieres, L. Thouin, G. Jaouen and C. Amatore, *Angew. Chem., Int. Ed.*, 2006, **45**, 285–290; (g) C. Ornelas, *New J. Chem.*, 2011, **35**, 1973–1985; (h) J. H. Scarborough, K. Brusoski, S. Brewer, S. Rodich, K. S. Chatley, T. Nguyen and K. N. Green, *Organometallics*, 2015, **34**, 918–925; (i) Y. Yan, T. M. Deaton, J. Zhang, H. He, J. Hayat, P. Pageni, K. Matyjaszewski and C. Tang, *Macromolecules*, 2015, **48**, 1644–1650; (j) K. Strohfeldt and M. Tacke, *Chem. Soc. Rev.*, 2008, **37**, 1174–1187; (k) G. Erker, *Dalton Trans.*, 2011, **40**, 7475–7483; (l) S. S. Braga and A. M. S. Silva, *Organometallics*, 2013, **32**, 5626–5639; (m) S. Ursillo, D. Can, H. W. P. N'Dongo, P. Schmutz, B. Spingler and R. Alberto, *Organometallics*, 2014, **33**, 6945–6952.
- P. J. Chirik, *Organometallics*, 2010, **29**, 1500–1517.
- S. Manzini, J. A. Fernández-Salas and S. P. Nolan, *Acc. Chem. Res.*, 2014, **47**, 3089–3101.
- (a) J. M. O'Connor and C. P. Casey, *Chem. Rev.*, 1987, **87**, 307–318; (b) H. Bang, T. J. Lynch and F. Basolo, *Organometallics*, 1992, **11**, 40–48; (c) C. C. Romão, *Appl. Organomet. Chem.*, 2000, **14**, 539–548.
- (a) M. J. Calhorda, C. C. Romão and L. F. Veiros, *Chem. – Eur. J.*, 2002, **8**, 868–875; (b) M. J. Calhorda and L. F. Veiros, *Coord. Chem. Rev.*, 1999, **185–186**, 37–51.
- G. P. McGovern, F. Hung-Low, J. W. Tye and C. A. Bradley, *Organometallics*, 2012, **31**, 3865–3879.
- J. Honzíček, C. C. Romão, M. J. Calhorda, A. Mukhopadhyay, J. Vinklárek and Z. Padělková, *Organometallics*, 2011, **30**, 717–725.
- P. A. Deck, W. F. Jackson and F. R. Fronczek, *Organometallics*, 1996, **15**, 5287–5291.
- P. A. Deck and F. R. Fronczek, *Organometallics*, 2000, **19**, 327–333.
- K. Sünkel, S. Weigand, A. Hoffmann, S. Blomeyer, C. G. Reuter, Y. V. Vishnevskiy and N. W. Mitzel, *J. Am. Chem. Soc.*, 2015, **137**, 126–129.
- P. J. Graham, V. Lindsey, G. W. Parshall, M. L. Peterson and G. M. Whitman, *J. Am. Chem. Soc.*, 1957, **79**, 3416–3419.
- W. P. Hart, D. W. Macomber and M. D. Rausch, *J. Am. Chem. Soc.*, 1980, **102**, 1196–1198.
- (a) L. Busetto, C. Cassani, V. Zanotti, V. G. Albano and P. Sabatino, *Organometallics*, 2001, **20**, 282–288; (b) J. Honzíček, A. Mukhopadhyay, T. S. Silva, M. J. Romão and C. C. Romão, *Organometallics*, 2009, **28**, 2871–2879; (c) A. R. Petrov, K. Jess, M. Freytag, P. G. Jones and M. Tamm, *Organometallics*, 2013, **32**, 5946–5954.
- (a) M. Oberhoff, L. Duda, J. Karl, R. Mohr, G. Erker, R. Fröhlich and M. Grehl, *Organometallics*, 1996, **15**, 4005–4011; (b) K. Klaß, R. Fröhlich and G. Erker, *J. Chem. Soc., Dalton Trans.*, 1999, 4457–4461; (c) H. Goitia, Y. Nieto, M. D. Villacampa, C. Kasper, A. Laguna and M. C. Gimeno, *Organometallics*, 2013, **32**, 6069–6078.
- J. Honzíček, P. Kratochvíl, J. Vinklárek, A. Eisner and Z. Padělková, *Organometallics*, 2012, **31**, 2193–2202.
- J. Schejbal, J. Honzíček, J. Vinklárek, M. Erben and Z. Růžičková, *Eur. J. Inorg. Chem.*, 2014, 5895–5907.
- (a) W. E. Noland, L. L. Landucci and V. Kameswaran, *J. Org. Chem.*, 1980, **45**, 3456–3461; (b) T. Takahashi, H. Kameda, T. Kamei and M. Ishizaki, *J. Fluorine Chem.*, 2006, **127**, 760–768; (c) G. R. Clemo, L. H. Groves, L. Munday and G. A. Swan, *J. Chem. Soc.*, 1951, 863–867.
- J. W. Faller, C. C. Chen, M. J. Mattina and A. Jakubowski, *J. Organomet. Chem.*, 1973, **52**, 361–386.
- (a) P. Neves, C. C. L. Pereira, F. A. A. Paz, S. Gago, M. Pillinger, C. M. Silva, A. A. Valente, C. C. Romão and I. S. Gonçalves, *J. Organomet. Chem.*, 2010, **695**, 2311–2319; (b) F. Pammer, Y. Sun and W. R. Thiel, *Organometallics*, 2008, **27**, 1015–1018; (c) J. Honzíček, J. Vinklárek, M. Erben, Z. Padělková, L. Šebestová and M. Řezáčová, *J. Organomet. Chem.*, 2014, **749**, 387–393; (d) J. Honzíček, J. Vinklárek, Z. Padělková, L. Šebestová, K. Foltánová and M. Řezáčová, *J. Organomet. Chem.*, 2012, **716**, 258–268.
- J. Honzíček, J. Vinklárek, M. Erben, J. Lodinský, L. Dostál and Z. Padělková, *Organometallics*, 2013, **32**, 3502–3511.



21 J. Pietruszka, R. C. Simon, F. Kruska and M. Braun, *Eur. J. Org. Chem.*, 2009, 6217–6224.

22 J. W. Faller, R. H. Crabtree and A. Habib, *Organometallics*, 1985, **4**, 929–935.

23 M. G. B. Drew, V. Félix, I. S. Gonçalves, C. C. Romão and B. Royo, *Organometallics*, 1998, **17**, 5782–5788.

24 J. R. Ascenso, C. G. de Azevedo, I. S. Gonçalves, E. Herdtweck, D. S. Moreno, M. Pessanha and C. C. Romão, *Organometallics*, 1995, **14**, 3901–3919.

25 W. L. F. Armarego and D. D. Perrin, *Purification of Laboratory Chemicals*, Oxford, 1996.

26 Z. Otwinowski and W. Minor, *Methods Enzymol.*, 1997, **276**, 307–326.

27 A. Altomare, G. Cascarano, C. Giacovazzo, A. Guagliardi, M. C. Burla, G. Polidori and M. Camalli, *J. Appl. Crystallogr.*, 1994, **27**, 435–436.

28 G. M. Sheldrick, *SHELXL97*, University of Göttingen, Germany, 2008.

