Palladium-Catalyzed Cross-Coupling Reactions of Amines with Alkenyl Bromides: A New Method for the Synthesis of Enamines and Imines

José Barluenga,* M. Alejandro Fernández, Fernando Aznar, and Carlos Valdés[a]

Abstract: The palladium-catalyzed cross-coupling reaction of alkenyl bromides with secondary and primary amines gives rise to enamines and imines, respectively. This new transformation expands the applicability of palladium-catalyzed C–N bond forming reactions (the Buchwald–Hartwig amination), which have mostly been applied to aryl halides. After screening of different ligands, bases, and solvents, the catalytic combination $[Pd_2(dba)_3]$/BINAP in the presence of NaO*t*Bu in toluene gave the best results in the cross-coupling of secondary amines with 1-bromostyrene (dba = dibenzylideneacetone, BINAP = 2,2′-bis(diphenylphosphino)-1,1′-binaphthyl). The corresponding enamines are obtained cleanly and in nearly quantitative yields. However, steric hindrance seems to be a limitation of the reaction, as amines carrying large substituents are not well converted. The same methodology can be applied to the coupling of secondary amines with 2-bromostyrene. Moreover, the reaction with substituted 2-bromopropenes allows regioselective synthesis of isomerizable terminal enamines without isomerization of the double bond. The best catalytic conditions for the cross-coupling of 1-bromostyrene with primary amines include again the use of the Pd^0/BINAP/NaO*t*Bu system. The reaction gives rise to the expected imines in very short times and with low catalyst loadings. A set of structurally diverse imines can be prepared by this methodology through variations in the structure of both coupling partners. However, 2-bromostyrene failed to give good results in this coupling reaction, probably due to product inhibition of the catalytic cycle. Competition experiments of vinyl versus aryl amination reveal that the reaction occurs preferentially on vinyl bromides.

Keywords: alkenes · amination · amines · cross-coupling · palladium

Introduction

The C–N bond can be found in a great number of organic compounds of major importance, such as biologically active natural products, pharmaceuticals, and dyes. Imines and enamines are among the most useful intermediates for introducing a nitrogen-containing fragment in a synthetic sequence due to their versatile reactivity.[1] For this reason, the development of new methods to selectively prepare these systems is of great interest.

The standard procedure to synthesize imines and enamines is the condensation of an amine with the appropriate carbonyl compound, usually in the presence of an acid catalyst and a water scavenger.[2] While this approach is fairly general, it presents several limitations, such as harsh reaction conditions and low functional group tolerance. Moreover, no real control of the regiochemistry and stereochemistry can be expected in the synthesis of enamines from a nonsymmetric ketone (Scheme 1).

Enamines have also been prepared by alternative approaches, for instance, by olefination strategies involving amine-substituted Wadsworth–Emmons reagents[3] or methylenation of amides.[4] Another appealing and atom-economical approach to enamines and imines is the metal-catalyzed hydroamination of alkynes. This method, pioneered by our group several years ago,[5] is currently an area of active research.[6,7]

On the other hand, in the recent years, the palladium-catalyzed cross-coupling reaction of aryl halides with amines, known as the Buchwald–Hartwig reaction,[8] has emerged as a very powerful procedure for the creation of C–N bonds (Scheme 2 A). Over the last few years, the work of the Buchwald and Hartwig groups, and others, has led to the development of very efficient catalytic systems for this transformation. In fact, very active catalysts have been devised for the amination not only of aryl bromides[9] but also for the less reactive aryl chlorides[10] and sulfonates.[11] Further-

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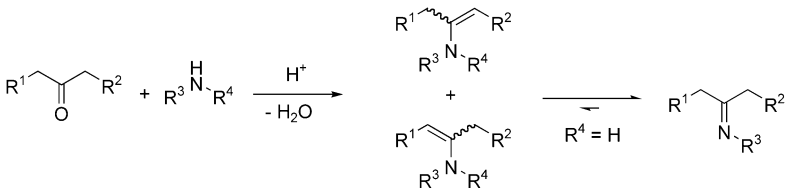
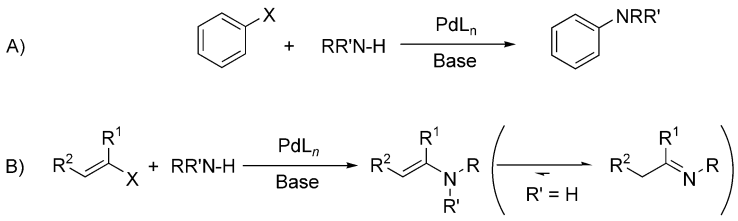


Scheme 1. Synthesis of enamines and imines by condensation of an amine with a carbonyl compound: the classical approach.



Scheme 2. a) Buchwald–Hartwig amination. b) Amination of vinyl halides.

Abstract in Spanish: *La reacción de acoplamiento cruzado de bromuros de alquenilo con aminas secundarias y primarias da lugar a enaminas e iminas respectivamente. Esta nueva transformación expande las aplicaciones de la reacción de formación de enlaces C–N catalizada por paladio (amination Buchwald–Hartwig), que se había limitado fundamentalmente a haluros de arilo. Después de un estudio de diferentes ligandos. bases y disolventes, los mejores resultados en la reacción de acoplamiento cruzado de aminas secundarias con 1-bromoestireno, se obtuvieron para el catalizador constituido por la combinación Pd/BINAP en presencia de NaOtBu en tolueno. Las correspondientes enaminas se obtienen limpiamente y con rendimientos prácticamente cuantitativos. Sin embargo, los impedimentos estéricos en la amina parecen ser una limitación de la reacción, puesto que aminas con sustituyentes voluminosos proporcionan conversiones bajas. La misma metodología puede aplicarse al acoplamiento de aminas secundarias con 2-bromoestireno. Además, la reacción con 2-bromopropenos sustituidos permite obtener de forma regioselectiva enaminas terminales isomerizables, sin que la isomerización del doble enlace tenga lugar. Las mejores condiciones catalíticas para el acoplamiento de aminas primarias con 1-bromoestireno incluyen de nuevo la utilización del sistema Pd(0)/BINAP/NaOtBu. La reacción proporciona las iminas esperadas en tiempos de reacción muy cortos y con baja carga del catalizador. Mediante esta metodología pueden prepararse un conjunto de iminas de gran diversidad estructural, permitiendo variaciones en ambos reactivos de acoplamiento. Sin embargo, la reacción con 2-bromoestireno no produce buenos resultados en este acoplamiento, probablemente debido a inhibición del ciclo catalítico por parte del producto de reacción. Finalmente, experimentos de competencia de aminación vinílica frente a aminación arílica, ponen de manifiesto que esta reacción se produce de forma preferente sobre los bromuros de vinilo.*

more, the reaction has been applied to many N–H-containing species other than amines.[12]

The application of the same catalytic process to alkenyl halides should provide enamines and imines (Scheme 2B). However, in spite of the great interest that this reaction has attracted in the recent years, its application to vinyl halides instead of aryl halides has hardly been studied.

To the best of our knowledge, only two contributions, prior to our previous communication,[13] had described palladium-catalyzed C–N bond-forming reactions with vinyl halides: the synthesis of *N*-vinyl azoles from vinyl bromides[14] and the palladium-catalyzed intramolecular cyclization of a β-lactam and a vinyl bromide as the key step in the synthesis of carbapenem derivatives.[15] More recently, the palladium-catalyzed amination of vinyl sulfonates has also been reported.[16]

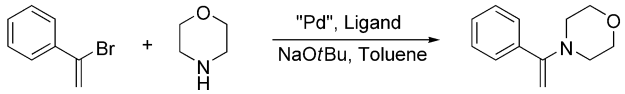
A major research theme in our group over the years has been the synthesis and applications of simple and cross-conjugated enamines (2-amino-1,3-dienes). We uncovered several years ago a very efficient method for the synthesis of enamines by hydroamination of terminal acetylenes catalyzed by thalium or mercury salts.[5] The enamines resulting from this approach are very versatile intermediates, for instance, as dienes in cycloaddition reactions,[17] substrates for Claisen rearrangements,[18] and chameleon linkers in solid-phase organic synthesis.[19] However, the use of highly toxic salts and the sometimes sluggish purification methods required prompted us to search for alternative synthetic routes to these types of enamines.

In a previous communication we disclosed the cross-coupling reaction of vinyl bromides with secondary amines, which can be regarded as a new alternative for the synthesis of enamines.[13] In this paper we wish to report a detailed study of the scope and limitations of this particular transformation oriented toward the preparation of imines and enamines by coupling of vinyl bromides with primary or secondary amines, respectively.

Results and Discussion

Coupling of vinyl halides with secondary amines: Synthesis of enamines from vinyl bromides: In our initial experiments we chose the reaction of 1-bromostyrene (**1a**) with morpholine (**2a**) as a model to develop suitable reaction conditions (Table 1). The reaction was studied in the presence of different palladium sources and ligands,[20] with NaO*t*Bu, the standard base for amination of aryl halides, being used as an additive. The reactions were carried out in toluene at 90 °C for 6 h. The coupling took place under several of the reaction conditions to furnish enamine **3a**. As presented in Table 1, complete conversion (based on 1-bromostyrene) was achieved with several different catalytic combinations. However, the best yields of **3a** were obtained in the reactions that

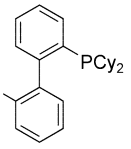
Table 1. Influence of the ligand and the temperature in the synthesis of enamine **3a** by the cross-coupling reaction of 1-bromostyrene (**1a**) with morpholine (**2a**) in toluene.[a]



1a **2a** **3a**

Entry	Pd source (mol%)	Ligand	t [h]	T [°C]	Conversion[b] [%]
1	$[Pd_2(dba)_3]$[c] (1)	P(*o*-Tol)$_3$[d]	6	90	100 (78)
2	$[Pd_2(dba)_3]$ (1)	BINAP[e]	6	90	100 (96)
3	$Pd(OAc)_2$ (1)	BINAP	6	90	100 (91)
4	$[Pd_2(dba)_3]$ (1)	PPh_3	6	90	100 (85)
5	$[Pd_2(dba)_3]$ (1)	DPPF[f]	6	90	100 (69)
6	$[Pd_2(dba)_3]$ (1)	**4**[g]	6	90	100 (95)
7	$[Pd_2(dba)_3]$ (1)	P*t*Bu$_3$[h]	6	90	100 (85)
8	$[Pd_2(dba)_3]$ (0.5)	BINAP	6	90	100 (69)
9	$[Pd_2(dba)_3]$ (0.05)	BINAP	6	90	<1
10	$[Pd_2(dba)_3]$ (1)	BINAP	6	40	100 (89)
11	$[Pd_2(dba)_3]$ (1)	BINAP	6	20	22
12	$[Pd_2(dba)_3]$ (1)	**4**	16	20	19[i]
13	$[Pd_2(dba)_3]$ (1)	P*t*Bu$_3$[h]	6	20	2

[a] Reaction conditions: 1 equivalent of **1a**, 1.1 equivalents of **2a**, 1:3 Pd:Ligand molar ratio, 1.4 equivalents of NaO*t*Bu, 4 mL of toluene per mmol of **1a**, 90 °C. [b] Determined by GC. Yields are indicated in parentheses. [c] dba = dibenzylideneacetone. [d] *o*-Tol = *ortho*-Tolyl. [e] BINAP = 2,2′-bis(diphenylphosphino)-1,1′-binaphthyl. [f] DPPF = 1,1′-bis(diphenylphosphino)ferrocene. [g] **4** = 2-dicyclohexylphosphino-2′-dimethylaminobiphenyl. [h] A 1:0.8 Pd:ligand molar ratio was used.



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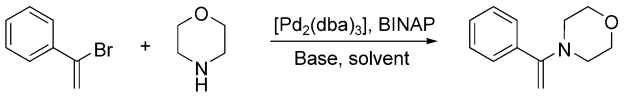
employed either BINAP or **4** as the ligand. Further experiments with lower catalyst loadings and temperatures (Table 1, entries 8–13) revealed $[Pd_2(dba)_3]$/BINAP[21] as the more active catalytic combination. Interestingly, bulky and electron-rich ligands such as **4** and P*t*Bu$_3$, which are able to catalyze the amination of aryl bromides at room temperature, did not perform better than BINAP in this reaction at RT or at higher temperatures. Presumably, the kinetics in this process are different from the amination of aryl halides and the oxidative addition is not the rate-determining step. For these reasons, we carried out the following studies by using the Pd/BINAP combination.

First, we examined different reaction conditions, solvents, and bases (Table 2). No particular improvement was found by changing to more polar solvent such as dioxane, while the reaction in DMF and the presence of water led to very low conversion. The reactions in the presence of milder bases were also assayed. However, the most common bases used in aminations of aryl halides (Cs_2CO_3, K_3PO_4, and NaOH) did not provide complete conversion under the reaction conditions studied. These preliminary results established the Pd/BINAP/NaO*t*Bu catalytic combination in toluene as the most appropriate. Therefore, we set out to investigate the scope of this transformation regarding both coupling partners, the amine and the alkenyl bromide.

The results of the reaction of 1-bromostyrene (**1a**) with a set of structurally diverse secondary amines **2** are presented in Table 3. Excellent yields are obtained for a cyclic amine such as morpholine (**2a**), an aliphatic acyclic amine such *N*-methylbenzylamine (**2b**), and an aromatic amine such as *N*-methylaniline (**2c**). However, the reaction is very sensitive to the bulkiness of the substituents, and a slight increase in their size, from methyl to ethyl (compare entries 3 and 6 in Table 3) or benzyl (compare entries 2 and 7 in Table 3), gives rise to a dramatic decrease in the conversion of the reaction. For instance, under the conditions described complete conversion is achieved with *N*-methylaniline (**2c**) and only 50 % is converted with *N*-ethylaniline (**2e**). Unfortunately, conversions and yields could not be improved by raising the temperature or increasing the catalyst loading. However, an increase in the catalyst loading remarkably accelerates the cross-coupling reaction with unhindered amines. As shown in entry 4 in Table 3, complete conversion is achieved for the coupling of *N*-methylaniline (**2c**) in only 1 hour when the reaction is conducted with 3 mol% of Pd. In fact, faster reaction rates are important when potentially sensitive functional groups are present. For example, functionalized piperidines **2g** and **2h**

Table 2. Influence of the solvent and base in the synthesis of enamine **3a** by the cross-coupling reaction of 1-bromostyrene (**1a**) with morpholine (**2a**) in the presence of the Pd/BINAP catalytic system.[a]

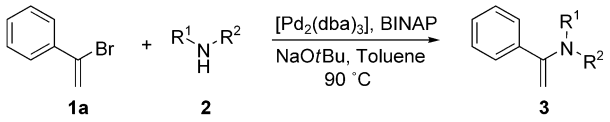


1a **2a** **3a**

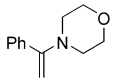
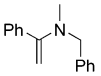
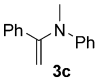
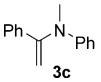
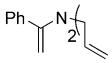
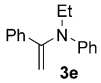
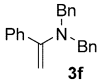
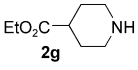
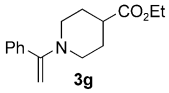
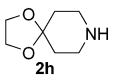
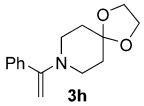
Entry	Base	Solvent	t [h]	Conversion[b] [%]
1	NaO*t*Bu	toluene	1	65
2	NaO*t*Bu	toluene	6	100 (96)
3	NaO*t*Bu	dioxane	6	100 (94)
4	NaO*t*Bu	DMF[c]	24	>5
5	NaO*t*Bu	toluene/H_2O (1:1)	24	16
6	Cs_2CO_3	toluene	6	20
7	Cs_2CO_3	toluene	24	45
8	K_3PO_4	toluene	6	>5
9	K_3PO_4	toluene	24	10
10	Na_2CO_3	toluene	24	>5
11	NaOH	toluene	6	65
12	NaOH	toluene	24	87
13	Cs_2CO_3	dioxane	6	40
14	Cs_2CO_3	dioxane	24	60
15	K_3PO_4	dioxane	6	10
16	K_3PO_4	dioxane	24	18

[a] Reaction conditions: 1 equivalent of **1a**, 1.1 equivalents of **2a**, 1 mol % of $[Pd_2(dba)_3]$, 3 mol% of BINAP, 1.4 equiv of base, 4 mL of solvent per mmol of **1a**, 90 °C. [b] Determined by GC. Yields indicated in parentheses in specific cases.[c] DMF = *N*,*N*-Dimethylformamide.

Table 3. Reaction of 1-bromostyrene (**1a**) with secondary amines **2** catalyzed by the Pd/BINAP system in toluene at 90 °C.[a]



1a **2** **3**

Entry	Amine **2**	Pd source (mol %)	*t* [h]	Enamine **3**	Yield [%]
1	 **2a**	$[Pd_2(dba)_3]$ (1)	6	 **3a**	96
2	 **2b**	$[Pd_2(dba)_3]$ (1)	6	 **3b**	95
3	 **2c**	$[Pd_2(dba)_3]$ (1)	6	 **3c**	97
4[b]	 **2c**	$Pd(OAc)_2$ (3)	1	 **3c**	98
5	 **2d**	$Pd(OAc)_2$ (1)	12	 **3d**	75
6[c]	 **2e**	$[Pd_2(dba)_3]$ (1)	20	 **3e**	50[d]
7[c]	 **2f**	$Pd(OAc)_2$ (1)	20	 **3f**	35[d]
8[b]	 **2g**	$Pd(OAc)_2$ (3)	1	 **3g**	90
9[b]	 **2h**	$Pd(OAc)_2$ (3)	1	 **3h**	90

[a] Reaction conditions: 1 equivalent of **1a**, 1.1 equivalents of amine, 1–3 mol % Pd, 3 mol % BINAP, 1.4 equivalents of base, 4 mL of toluene per mmol of **1a**, 90 °C. [b] Carried out at 80 °C with 6 mol % BINAP and 1 equiv of amine. [c] Carried out at 100 °C. [d] Conversion (%) determined by GC and ^{1}H NMR spectroscopy of the crude reaction mixture.

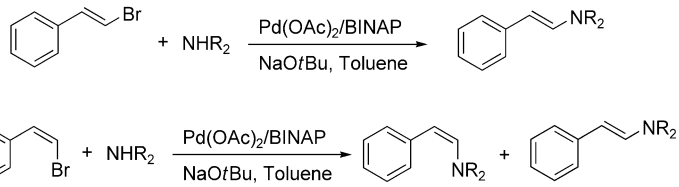
(Table 3, entries 8 and 9) were successfully coupled with **1a** in 1 hour in the presence of 3 mol % of Pd without formation of any of the side products that may have been produced with longer reaction times.

In all cases the enamines were isolated as pure compounds (as judged by ^{1}H and ^{13}C NMR spectroscopy) after dilution with dry hexanes, filtration through celite, evaporation of the solvents, and removal of the slight excess of amine under high vacuum. This is an important feature, as aqueous work-up and chromatographic techniques are not suitable for the purification of enamines because of their water sensitivity whereas high-vacuum distillation is only possible for systems with reasonably low boiling points.

The same reaction was then studied with *trans*-2-bromostyrene (**1b**), a typical β-substituted vinyl bromide. The results are summarized in Table 4. Again, very high yields are obtained for the coupling with morpholine (**2a**) and *N*-methylaniline (**2c**). Contrary to the case of 1-bromostyrene (**1a**), high conversions were also achieved for reactions of **1b** with bulkier amines such as **2e**, **2f**, and **2i** (compare entries 3–5 in Table 4 against entries 6 and 7 in Table 3). An acceptable yield was obtained even for branched amine **2j** (Table 4, entry 6). Clearly, the diminished steric hindrance around the vinyl bromide in **1b** in comparison to that in **1a** allows for easier participation of amines bearing large substituents in the reaction.

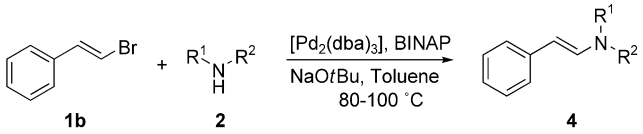
The reactions described in Table 4, carried out with *trans*-2-bromostyrene, furnished exclusively the *trans* isomer of the enamine. However, when the same reactions were conducted with *cis*-2-bromostyrene a mixture of both isomers was obtained under all the reaction conditions examined, even when the catalyst loading was increased substantially in order to reduce the reaction times (Scheme 3). This lack of stereospecificity differs from the observations of Voskoboynikov and co-workers,[14] who reported the palladium-catalyzed stereospecific vinylation of azoles. Nevertheless, this different behavior is not surprising, as the isomerization of the enamines can take place easily by a tautomerism, which is not likely to happen in the case of the vinyl azoles.

Alkenyl bromides with the general structure **5** (3-substituted-2-bromopropenes) are particularly challenging substrates (Scheme 4). The amination reaction of **5** gives rise to terminal enamines **6**, which may undergo a very easy isomerization to the more substituted internal enamine **7**. In fact, when the coupling reactions are conducted under the standard reaction conditions described above, a mixture of both enamines is obtained. For instance, the reaction of 2-bromo-4-phenyl-1-butene (**5a**) with *N*-methylaniline (**2c**) under those conditions (1 mol % $Pd(OAc)_2$, BINAP, 80 °C, 6 h) produces a 1:2 mixture of the terminal and the internal en-

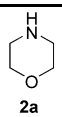
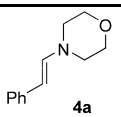
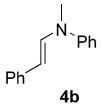
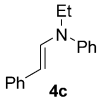
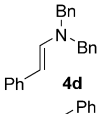
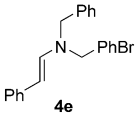
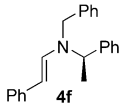
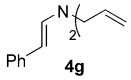
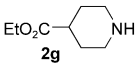
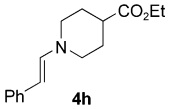
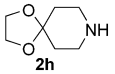
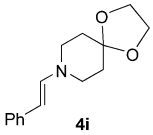


Scheme 3. Stereoselectivity in the amination of *cis*- and *trans*-2-bromostyrene.

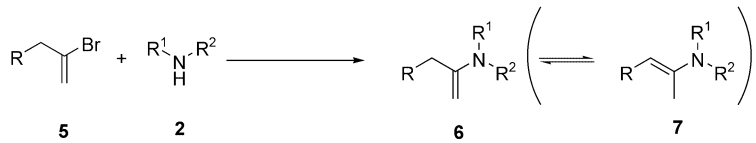
Table 4. Synthesis of enamines **4** by reaction of *trans*-2-bromostyrene (**1b**) with secondary amines **2** catalyzed by the Pd/BINAP system.[a]



1b **2** **4**

Entry	Amine	Pd source (mol %)	t [h][b]	Product	Yield [%]
1[c]	 **2a**	$[Pd_2(dba)_3]$ (1)	6	 **4a**	95
2[c]	 **2c**	$[Pd_2(dba)_3]$ (1)	6	 **4b**	96
3	 **2e**	$[Pd_2(dba)_3]$ (1)	20	 **4c**	80
4[d]	 **2f**	$[Pd_2(dba)_3]$ (2)	20	 **4d**	90
5	 **2i**	$[Pd_2(dba)_3]$ (1)	20	 **4e**	70
6[d]	 **2j**	$Pd(OAc)_2$ (2)	20	 **4f**	64
7[e]	 **2d**	$Pd(OAc)_2$ (3)	1	 **4g**	97
8[e]	 **2g**	$Pd(OAc)_2$ (3)	1	 **4h**	95
9[e]	 **2h**	$Pd(OAc)_2$ (3)	1	 **4i**	97

[a] Reaction conditions: 1 equivalent of **1b**, 1.1 equivalents of amine, 1.4 equivalents of NaO*t*Bu, 1–3 mol % Pd, 2–6 mol % BINAP, 4 mL of toluene per mmol of **1b**, 100 °C. [b] Reaction times have not been optimized. [c] Reaction carried out at 90 °C. [d] Ligand = P(*o*-tol)$_3$. [e] Reaction carried out at 80 °C with 6 mol % of BINAP and 1 equiv of amine.



R = Ph
R^1 = Me, R^2 = Ph

1 mol % $Pd(OAc)_2$, BINAP 80 °C, 6 h	1	:	2
3 mol % $Pd(OAc)_2$, BINAP 80 °C, 1.5 h	> 95	:	< 5

Scheme 4. Regioselectivity in the synthesis of terminal isomerizable enamines **6**.

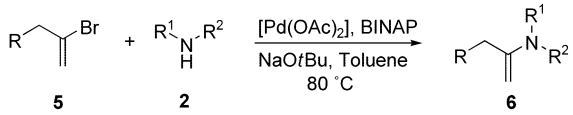
amines, **6a** and **7a**, respectively (Scheme 2). Nevertheless, it is possible to obtain exclusively the terminal enamine **6a** by increasing the catalyst loading and, therefore, reducing the reaction time. Thus, when the same reaction is carried out with 3 mol % of Pd, complete conversion is achieved in 1.5 hours and the terminal enamine **6a** is isolated without formation of the internal isomer **7a**, as determined from ^{1}H and ^{13}C NMR spectra.

The regioselective formation of terminal enamines **6** was extended to several different substrates, including functionalized bromoolefins (Table 5). In all cases, the terminal regioisomers were cleanly obtained after purification by dilution of the reaction mixture with dry hexanes, filtration through celite, and removal of the solvents. However, most of the terminal enamines undergo spontaneous isomerization upon standing.

It is worth noting that, with the exception of some particular examples,[22] to the best of our knowledge no general method for the preparation of these terminal isomerizable enamines has been described previously. Moreover, the bromides required for the amination reaction are very easily accessible from commercial 2,3-dibromopropene. Therefore, the present method constitutes a unique and very convenient procedure for accessing this type of system.

Coupling of vinyl bromides with primary amines: Synthesis of imines: We next turned our attention to the coupling reaction of vinyl bromides with primary amines, which gives rise to imines after tautomerization of the initially formed enamine. The synthesis of imine **9a** from 1-bromostyrene (**1a**) and *p*-anisidine (**8a**) was selected as a representative example to develop suitable reaction condi-

Table 5. Regioselective synthesis of terminal isomerizable enamines **6**.[a]



5 **2** **6**

Entry	Bromide	Amine	Pd source (mol%)	t [h][b]	Product	Yield [%]
1[c]	**5a**	**2a**	$Pd(OAc)_2$ (3)	0.5	**6b**	86
2	**5a**	**2c**	$Pd(OAc)_2$ (3)	1.5	**6a**	90
3	**5b**	**2a**	$Pd(OAc)_2$ (3)	1	**6c**	96
4	**5b**	**2c**	$Pd(OAc)_2$ (3)	1.5	**6d**	95
5	**5c**	**2a**	$Pd(OAc)_2$ (3)	1	**6e**	96
6	**5c**	**2c**	$Pd(OAc)_2$ (3)	1.5	**6f**	95
7	**5d**	**2a**	$Pd(OAc)_2$ (3)	1	**6g**	96
8	**5d**	**2c**	$Pd(OAc)_2$ (3)	1.5	**6h**	95

[a] Reaction conditions: 1 equivalent of vinyl bromide **5**, 1 equivalents of amine **2**, 1.4 equivalents of NaO*t*Bu, 3 mol% Pd, 6 mol% BINAP, 4 mL of toluene per mmol of **5**, 80°C. [b] Reaction times have not been optimized. [c] Reaction carried out at 65°C.

tions. The activities of different ligands in toluene with NaO*t*Bu as the base are represented in Table 6. BINAP and phosphine **4** were the best ligands for this transformation. The reaction proceeds much faster and requires lower catalyst loading than the coupling with secondary amines. For instance, complete conversions are achieved with 1 mol% of Pd and 3 mol% of BINAP, **4**, or DPPF in only 15 min at 90°C, to provide quantitative yields of imine **9a** (Table 6, entries 1,3, and 8, respectively). Moreover, the reaction can be carried out also with almost quantitative yields in 45 min by using as little as 0.1 mol% of Pd at 90°C (Table 6, entry 12).

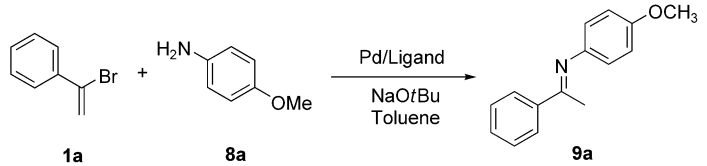
The influence of the solvent and the base was also studied (Table 7). As in the reaction with secondary amines, toluene performed better than more polar solvents such as dioxane or DMF. Moreover, NaO*t*Bu was the most effective base, and again, in our hands, milder bases such as Cs_2CO_3 and K_3PO_4 were not able to provide complete conversion at 1 mol% Pd loading (Table 7).

Therefore, the scope of the reaction was studied with the Pd/BINAP/NaO*t*Bu catalytic system (1 mol% of Pd) in toluene at 90°C as the typical experimental conditions. Representative examples of the coupling with different amines are presented in Table 8. The coupling proceeds with excellent yields with all types of aromatic amines carrying electron-donating substituents, such as OMe and Me (Table 8, entries 1,6 and 2,5, respectively), or electron-withdrawing substituents, such as CN and NO_2 (Table 8, entries 3 and 4), although the latter required longer reaction times. Moreover, steric hindrance is not a serious limitation for this reaction, as *ortho*-substituted aromatic amines react readily (Table 8, entries 5–7) and even the very hindered 2,4,6-trimethylaniline (Table 8, entry 10) was coupled quantitatively in 90 min. Only for 2,6-dibromoaniline (Table 8, entry 11) was a lower yield (50%) obtained. It is interesting to note the chemoselectivity of the reaction (vinyl amination versus aromatic amination), as no homocoupling by aromatic amination was observed when bromoanilines were employed (Table 8, entries 7–9). Aliphatic, allylic, and benzylic amines were also coupled equally effectively (Table 8, entries 12–15). Linear and also branched (Table 8, entry 15) amines were employed, with nearly quantitative yields, which shows that the steric effects are not as important as in the synthesis of enamines by coupling of secondary amines as discussed before.

Excellent results were also obtained with a set of structurally diverse 3-substituted-2-bromopropenes **5**. The expected imines **10** were obtained in very high yields under the same reaction conditions (Table 9). Again, both aromatic (Table 9, entries 1–4) and benzylic (Table 9, entries 5 and 6) amines were successfully coupled.

Following the same sequence as for the secondary amines, we next examined the coupling with 2-bromostyrene (**1b**). Unexpectedly, the reactions of *p*-anisidine (**8a**) or 4-methoxybenzylamine (**8n**) with 2-bromostyrene (**1b**) failed to proceed with high conversion (Scheme 5). Several reaction conditions and catalytic systems were tested in this particular coupling, and in the best cases the crude reaction mixture consisted of starting reagents and the enamine coming from the amination reaction, with conversions of around 50%.

Table 6. Optimization of the catalyst for the synthesis of imine **9a** by the cross-coupling reaction of 1-bromostyrene (**1a**) with *p*-anisidine (**8a**) in toluene with NaO*t*Bu as the base.[a]



1a **8a** **9a**

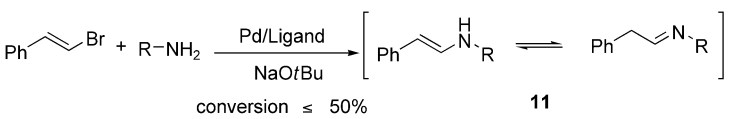
Entry	Pd source (mol%)	Ligand	*t* [min]	*T* [°C]	Conversion[b] [%]
1	$[Pd_2(dba)_3]$ (1)	BINAP	15	90	100 (98)
2	$Pd(OAc)_2$ (1)	BINAP	15	90	100 (98)
3	$[Pd_2(dba)_3]$ (1)	**4**	15	90	100 (98)
4	$[Pd_2(dba)_3]$ (1)	DTPB[c]	15	90	70
5	$[Pd_2(dba)_3]$ (1)	DTPB	24 h	90	85
6	$[Pd_2(dba)_3]$ (1)	P(*o*-Tol)$_3$	15	90	26
7	$[Pd_2(dba)_3]$ (1)	P(*o*-Tol)$_3$	24 h	90	63
8	$[Pd_2(dba)_3]$ (1)	DPPF	15	90	100 (97)
9	$[Pd_2(dba)_3]$ (1)	XANTPHOS[d]	15	90	94
10	$[Pd_2(dba)_3]$ (1)	P*t*Bu$_3$[e]	180	90	60
11	$[Pd_2(dba)_3]$ (0.5)	BINAP	15	90	100 (95)
12	$[Pd_2(dba)_3]$ (0.1)	BINAP	45	90	100 (94)
13	$[Pd_2(dba)_3]$ (1)	BINAP	150	45	100 (95)
14	$[Pd_2(dba)_3]$ (1)	BINAP	180	20[f]	15
15	$[Pd_2(dba)_3]$ (1)	none	180	90	–
16	none	none	180	90	–

[a] Reaction conditions: 1 equivalent of **1a**, 1.1 equivalents of **8a**, 1.4 equivalents of NaO*t*Bu, 1 mol% Pd (unless stated otherwise), 3 mol% ligand, 4 mL of toluene per mmol of **1a**. [b] Determined by GC and ^{1}H NMR spectroscopy of the crude reaction mixture. Yields are indicated in parentheses. [c] DTPB = 2-Di-*tert*-butylphosphinobiphenyl. [d] XANTPHOS = 9,9-Dimethyl-4,5-bis-(diphenylphosphino)xanthene. [e] 1 mol% of ligand was used.

Table 7. Optimization of the reaction conditions for the reaction of **1a** and **8a** with 1 mol% $[Pd_2(dba)_3]$ and 3 mol% BINAP at 90°C.

Entry	Base	Solvent	*t* [h]	Conversion[a] [%]
1	NaO*t*Bu	toluene	15 min	100
2	NaO*t*Bu	dioxane	15 min	75
3	NaO*t*Bu	DMF	15 min	8
4	NaO*t*Bu	DME	15 min	6
5	NaO*t*Bu	toluene/H_2O (1:1)	3	–
6	Cs_2CO_3	toluene	1	–
7	Cs_2CO_3	toluene	24	25
8	K_3PO_4	toluene	1	–
9	Na_2CO_3	toluene	1	–
10	KOH	toluene	1	–
11	NaOH	toluene	1	–
12	NaOH	toluene	24	20
13	Cs_2CO_3	DME	1	–
14	Cs_2CO_3	DME	24	40
15	K_3PO_4	DME	1	11
16	K_3PO_4	DME	24	47
17	Cs_2CO_3	dioxane	1	7
18	Cs_2CO_3	dioxane	24	57
19	K_3PO_4	dioxane	1	4
20	K_3PO_4	dioxane	24	27

[a] Determined by GC and ^{1}H NMR spectroscopy of the crude reaction mixture.



1b **8**

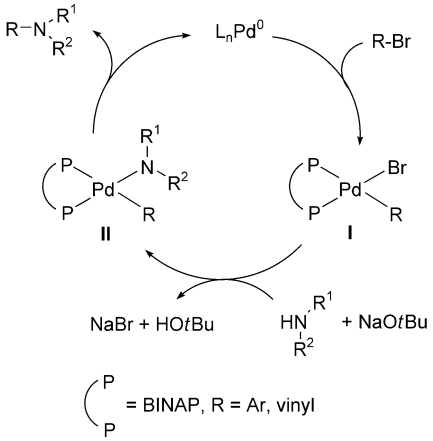
R= *p*-MeO-Ph, *p*-MeO-Ph-CH_2-

Scheme 5. Amination of 2-bromostyrene (**1b**) with primary amines.

No improvement in conversion was achieved by increasing the catalyst loading. Moreover, addition of more Pd species or more Pd and ligand once the 50% conversion had been reached did not increase the conversion of the reaction. These observations point to an interruption of the catalytic cycle by product inhibition.[23]

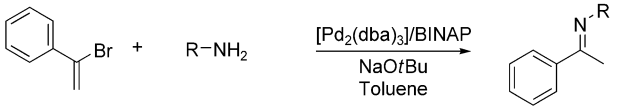
Alkenyl amination versus aryl amination: The cross-coupling reaction of amines with alkenyl bromides discussed herein is an extension of the well-known Buchwald–Hartwig amination of aryl halides. The conventional mechanism accepted for this reaction catalyzed by the Pd/BINAP system is shown in Scheme 6. The catalytic cycle involves three main steps:[9b,24] 1) the oxidative addition of the aryl halide to generate aryl palladium bromide complex **I**;[25] 2) coordination of the amine to give rise to amido complex **II** after abstraction of a proton by the base present;[26] 3) reductive elimination to release the aryl amine and regenerate the Pd(0) catalyst.[27]

The same catalytic cycle can be proposed for the amination of alkenyl bromides discussed in this paper, simply by replacing the aryl with a vinyl bromide. As both types of bromides share a common mechanism, we found it interesting to compare their relative reactivities. From a synthetic point of view, it is interesting to study the relative rates, in order to carry out chemoselective aminations of alkenyl bromides in the presence of aryl bromides, or vice versa. In fact, we had already observed very high chemoselectivity in

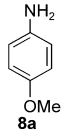
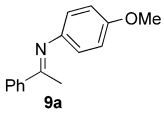
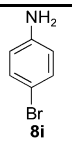
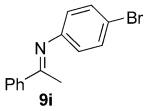
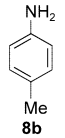
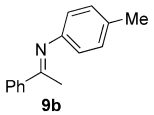
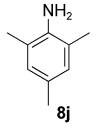
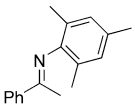
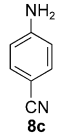
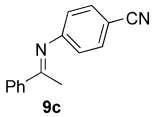
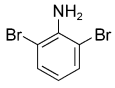
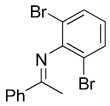
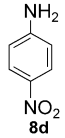
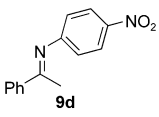
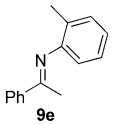
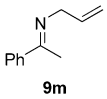
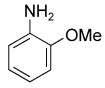
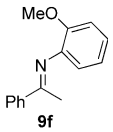
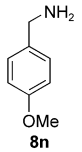
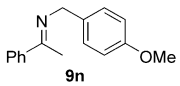
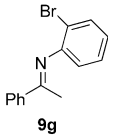
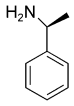
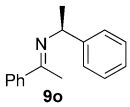
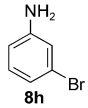
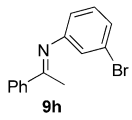


Scheme 6. Proposed mechanism for palladium-catalyzed aryl and vinyl aminations.

Table 8. Synthesis of imines **9** by coupling of primary amines **8** with 1-bromostyrene (**1a**).[a]



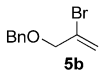
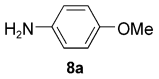
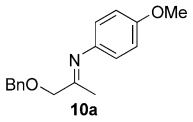
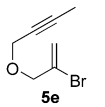
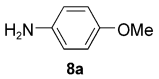
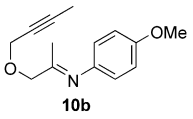
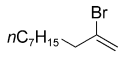
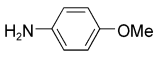
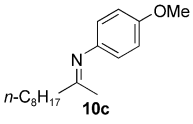
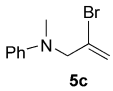
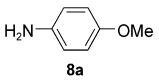
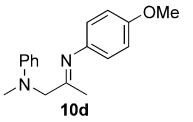
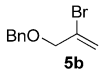
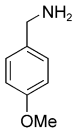
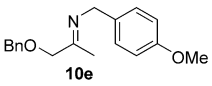
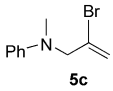
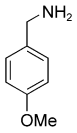
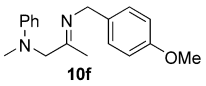
1a **8** **9**

Entry	Amine	*t* [min]	Product	Yield [%]	Entry	Amine	*t* [min]	Product	Yield [%]
1	 **8a**	15	 **9a**	98	9	 **8i**	45	 **9i**	98
2	 **8b**	15	 **9b**	98	10	 **8j**	90	 **9j**	90
3	 **8c**	20 h	 **9c**	86	11[c]	 **8k**	6 h	 **9k**	50[d]
4[b]	 **8d**	4 h	 **9d**	86	12	Bu-NH$_2$	3 h	 **9l**	88
	8l								
5	 **8e**	15	 **9e**	98	13	 **8m**	15	 **9m**	98
6	 **8f**	15	 **9f**	98	14	 **8n**	15	 **9n**	96
7	 **8g**	15	 **9g**	98	15	 **8o**	15	 **9o**	94
8	 **8h**	25	 **9h**	98					

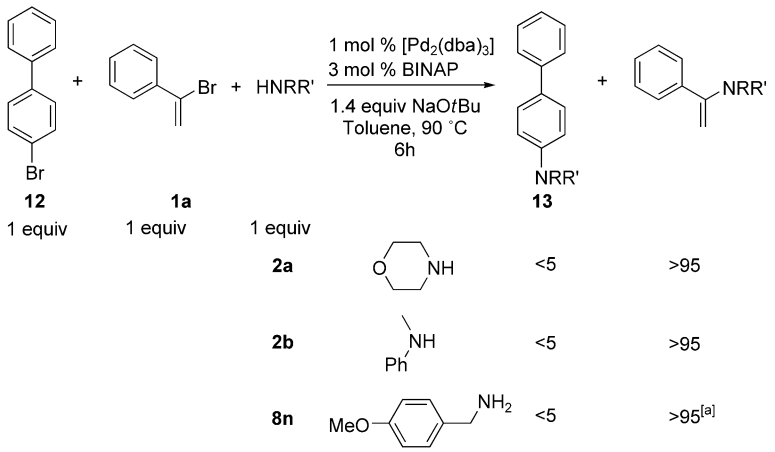
[a] Reaction conditions: 1 equivalent of **1a**, 1.1 equivalents of amine **8**, 1.4 equivalents of NaO*t*Bu, 1 mol% of [Pd$_2$(dba)$_3$], 3 mol% of BINAP, 4 mL of toluene per mmol of **1a**, 90 °C. [b] Reaction carried out with 2 mol% of [Pd$_2$(dba)$_3$] and 6 mol% of BINAP in dioxane. [c] Reaction carried out with 2 mol% of [Pd$_2$(dba)$_3$] and 6 mol% of BINAP. [d] Determined by GC.

the coupling of primary amines (Table 8, entries 7, 8, 9, and 11). For these reasons, we decided to undertake a more detailed study to confirm the preference of vinyl versus aryl amination. With this purpose, competition experiments were conducted in which equimolar amounts of 4-bromobiphenyl (**12**) and 1-bromostyrene (**1a**) were reacted with 1 equiv of morpholine (**2a**), *N*-methylaniline (**2b**), and 4-methoxybenzylamine (**8n**), respectively (Scheme 7). The reactions were monitored by GC and by NMR spectroscopic analysis of the crude reaction mixture. As represented in Scheme 7, in the three examples examined, the compound coming from the vinyl amination was the only product formed and in no case were the aromatic amines **13** detected. It is apparent from these results that in the absence of additional steric effects the vinyl amination occurs preferentially to the aryl amination. The oxidative addition probably occurs faster for the vinyl bromide **1a** and, as an irreversible step, drives the reaction exclusively to the vinyl amination. This is an interesting observation that may allow sequential catalytic events in cascade or step-by-step synthetic processes to be programed. We are currently investigating different applications of this selective reactivity.

Table 9. Synthesis of imines **10** by the cross-coupling reaction of vinyl bromides **5** with primary amines **8**.[a]

Entry	Bromide	Amine	*t* [min]	Imine	Yield [%]
1	 **5b**	 **8a**	15	 **10a**	90
2	 **5e**	 **8a**	15	 **10b**	94
3	 **5d**	 **8a**	15	 **10c**	95
4	 **5c**	 **8a**	20	 **10d**	92
5	 **5b**	 **8n**	25	 **10e**	94
6	 **5c**	 **8n**	45	 **10f**	93

[a] Reaction conditions: 1 equivalent of **5**, 1 equivalent of amine, 1.4 equivalents of NaO*t*Bu, 1 mol% of $[Pd_2(dba)_3]$, 3 mol% of BINAP, 4 mL of toluene per mmol of **5**, 90 °C.



Scheme 7. Competition experiments of amination of alkenyl versus aryl bromides. [a] Obtained as the imine tautomer

Conclusion

In summary, we have demonstrated that the palladium-catalyzed amination of alkenyl bromides constitutes a very efficient method for the preparation of imines and enamines and that it expands the applicability of the palladium-catalyzed C–N bond forming cross-coupling reaction. The catalytic system Pd/BINAP/NaO*t*Bu has been found to be a very suitable combination for the reaction with both primary and secondary amines. The reaction with secondary amines provides a new method for the preparation of enamines, and in particular, the present methodology constitutes the first general method for the preparation of terminal isomerizable enamines. Moreover, the reaction with primary amines gives rise to imines in very reduced times and with lower catalyst loadings than other methods. Among the main limitations of the reaction at this point of development are the sensitivity to steric hindrance in both coupling partners in the synthesis of enamines and the low conversions achieved in the reactions of primary amines with 2-bromostyrenes. Nevertheless, taking into account the wide scope of the reaction and the synthetic versatility of enamines and imines, we believe this reaction will become a very useful transformation in synthetic organic chemistry.

Experimental Section

General: All reactions were carried out under a nitrogen atmosphere. Toluene and hexane solvents were continuously refluxed and freshly distilled over sodium/benzophenone under nitrogen. NMR spectra were recorded at 300 or 200 MHz for ^{1}H and 75 or 50.3 MHz for ^{13}C spectra, with tetramethylsilane as the internal standard for ^{1}H and the residual solvent signals as the standard for ^{13}C spectra. Chemical shifts are given in ppm. Mass spectra were obtained by EI (70 eV). $Pd(OAc)_2$ and $Pd_2(dba)_3$ were purchased from Strem Chemical Co. and used without further purification. All phosphine ligands used are commercially available from Strem or Aldrich and were used without further purification. NaO*t*Bu was purchased from Aldrich, stored in a flask purged with nitrogen, and weighed in air. (2-Bromobut-3-enyl)benzene (**5a**),[28] (2-bromoallyloxymethyl)benzene (**5b**),[29] (2-bromoallyl)methylphenylamine (**5c**),[30] 2-bromodec-1-ene (**5d**),[31] and 1-(2-bromoallyloxy)-but-2-yne (**5e**)[29] were all prepared according to literature procedures. All other chemicals were used as received from commercial suppliers.

General procedure for palladium-catalyzed amination of vinyl bromides with $[Pd_2(dba)_3]$ (Method A): A Schlenk flask under a nitrogen atmosphere was charged with (±)-BINAP (0.03 mmol, 3 mol%), tris(dibenzylideneacetone)dipalladium(0) (0.005 mmol, 1 mol%), sodium *tert*-butoxide (1.4 mmol), and toluene (4 mL). After 1 min the vinyl bromide (1 mmol)

and the amine (1.1 mmol) were added under nitrogen and the flask was immersed in an oil bath and heated to 90 °C with stirring until the starting vinyl bromide had been completely consumed as judged by GC analysis. The mixture was allowed to cool to room temperature, taken up in hexanes (15 mL), and filtered through celite. The solvents were evaporated under reduced pressure. The residue was redissolved in hexanes (15 mL), filtered again through celite, concentrated under reduced pressure, and dried under high vacuum to remove the excess of amine. This afforded a residue which consisted of the essentially pure enamine. The enamines can be purified by Kugelrohr distillation under high vacuum (dependent on the boiling point).

General procedure for palladium-catalyzed amination of vinyl bromides with $Pd(OAc)_2$ (Method B): A Schlenk flask was charged with (±)-BINAP (0.06 mmol, 6 mol %) under a nitrogen atmosphere and toluene (2 mL) was added. The mixture was heated to 80 °C with stirring until the BINAP was dissolved (≈1 min). The solution was cooled to room temperature and $Pd(OAc)_2$ (0.03 mmol, 3 mol %) was added. Toluene (1 mL) was added to rinse the Pd from the sides of the flask. The mixture was stirred at room temperature for approximately 2 min, and the vinyl bromide (1 mmol) and the amine (1.1 mmol) were added. After 2 min, the sodium *tert*-butoxide (1.4 mmol) was added under nitrogen and additional toluene (1 mL) was added. The flask was immersed in an oil bath and heated to 80 °C with stirring until the starting vinyl bromide had been completely consumed as judged by GC analysis. The mixture was allowed to cool to room temperature, taken up in hexanes (15 mL), and filtered through celite. The solvents were evaporated under reduced pressure. The residue was redissolved in hexanes (15 mL), filtered again through celite, concentrated under reduced pressure, and dried under high vacuum to remove the excess of amine. This afforded a residue which consisted of the essentially pure enamine. The enamines can be purified by Kugelrohr distillation under high vacuum (dependent on the boiling point).

4-(1-Phenylvinyl)morpholine (3a): The general procedure A with 1 mol % of $[Pd_2(dba)_3]$, 3 mol % of (±)-BINAP, and a reaction temperature of 90 °C gave **3a** in 96 % yield as a light yellow oil after distillation in a Kugelrohr apparatus (150 °C) at 10^{-2} Torr. ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 2.85–2.82 (t, ^3J = 4.8 Hz, 4H), 3.78–3.75 (t, ^3J = 4.8 Hz, 4H), 4.21 (s, 1H), 4.35 (s, 1H), 7.34–7.30 (m, 3H), 7.48–7.46 (m, 2H) ppm; ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 49.6 ($2CH_2$), 66.7 ($2CH_2$), 90.9 (CH_2), 127.6 (2CH), 127.9 (CH), 128.0 (2CH), 138.9 (C), 156.9 (C) ppm; HRMS: *m*/*z* calcd for $C_{12}H_{15}NO$: 189.11481; found: 189.11456.

Benzylmethyl(1-phenylvinyl)amine (3b): The general procedure A with 1 mol % of $[Pd_2(dba)_3]$, 3 mol % of (±)-BINAP, and a reaction temperature of 90 °C gave **3b** in 95 % yield as a yellow oil after distillation in a Kugelrohr apparatus (180 °C) at 10^{-2} Torr. ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 2.67 (s, 3H), 4.08 (s, 2H), 4.19 (s, 1H), 4.31 (s, 1H), 7.43–7.32 (m, 8H), 7.65–7.62 (m, 2H) ppm; ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 38.4 (CH_3), 57.3 (CH_2), 90.6 (CH_2), 127.4 (CH), 128.4 (2CH), 128.5 (2CH), 128.6 (2CH), 128.7 (3CH), 139.2 (C), 140.5 (C), 157.2 (C) ppm; HRMS: *m*/*z* calcd for $C_{16}H_{17}N$: 223.13555; found: 223.13586.

Methylphenyl(1-phenylvinyl)amine (3c): The general procedure A with 1 mol % of $[Pd_2(dba)_3]$, 3 mol % of (±)-BINAP, and a reaction temperature of 90 °C gave **3c** in 97 % yield as a yellow oil after distillation in a Kugelrohr apparatus (160 °C) at 10^{-2} Torr. ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 3.36 (s, 3H), 4.94 (s, 1H), 5.13 (s, 1H), 6.97–6.92 (m, 1H), 7.08–7.04 (m, 1H), 7.37–7.25 (m, 6H), 7.61–7.58 (m, 2H) ppm; ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 40.8 (CH_3), 100.5 (CH_2), 120.1 (2CH), 120.2 (CH), 127.1 (2CH), 127.7 (CH), 128.0 (2CH), 128.5 (2CH), 139.0 (C), 148.7 (C), 153.4 (C) ppm; HRMS: *m*/*z* calcd for $C_{15}H_{15}N$: 209.11990; found: 209.12035.

Diallyl(1-phenylvinyl)amine (3d): The general procedure A with 1 mol % of $[Pd_2(dba)_3]$, 3 mol % of (±)-BINAP, and a reaction temperature of 90 °C gave **3d** in 75 % yield as a yellow oil after distillation in a Kugelrohr apparatus (170 °C) at 10^{-2} Torr. ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 3.62–3.60 (d, ^3J = 5.9 Hz, 4H), 4.16 (s, 1H), 4.23 (s, 1H), 5.22–5.16 (m, 4H), 5.89–5.78 (m, 2H), 7.37–7.34 (m, 3H), 7.51–7.46 (m, 2H) ppm; ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 51.9 ($2CH_2$), 90.6 (CH_2), 116.8 ($2CH_2$), 127.8 (2CH), 127.9 (2CH), 134.4 (CH), 140.2 (C), 154.8 (C) ppm; HRMS: *m*/*z* calcd for $C_{14}H_{17}N$: 199.13555; found: 199.13567.

Ethylphenyl(1-phenylvinyl)amine (3e): The general procedure A with 1 mol % of $[Pd_2(dba)_3]$, 3 mol % of (±)-BINAP, and a reaction temperature of 100 °C gave **3e** in 50 % yield as a yellow oil after distillation in a Kugelrohr apparatus (190 °C) at 10^{-2} Torr. ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 1.30–1.25 (t, ^3J = 7.1 Hz, 3H), 3.75–3.69 (q, ^3J = 7.1 Hz, 2H), 4.91 (s, 1H), 5.06 (s, 1H), 7.14–6.80 (m, 3H), 7.49–7.20 (m, 7H) ppm; ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 12.6 (CH_3), 46.2 (CH_2), 102.3 (CH_2), 119.5 (2CH), 127.2 (2CH), 127.8 (CH), 128.1 (2CH), 128.3 (CH), 128.6 (2CH), 139.4 (C), 147.6 (C), 151.8 (C) ppm; HRMS: *m*/*z* calcd for $C_{16}H_{17}N$: 233.13555; found: 233.13580.

Dibenzyl(1-phenylvinyl)amine (3f): The general procedure A with 1 mol % of $Pd(OAc)_2$, 3 mol % of (±)-BINAP, and a reaction temperature of 100 °C gave **3f** in 35 % yield as a yellow oil after distillation in a Kugelrohr apparatus (240 °C) at 10^{-2} Torr. ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 4.11 (s, 4H), 4.16 (s, 1H), 4.39 (s, 1H), 7.40–7.32 (m, 15H) ppm; ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 53.22 ($2CH_2$), 93.3 (CH_2), 126.8 (2CH), 128.0 (3CH), 128.1 (3CH), 128.2 (3CH), 128.3 (2CH), 128.5 (2CH), 138.2 (2C), 139.5 (C), 154.8 (C) ppm; HRMS: *m*/*z* calcd for $C_{22}H_{21}N$: 299.16685; found: 299.16666.

1-(1-Phenylvinyl)piperidine 4-carboxylic acid ethyl ester (3g): The general procedure B with 3 mol % of $Pd(OAc)_2$, 6 mol % of (±)-BINAP, and a reaction temperature of 80 °C gave **3g** in 90 % yield as a yellow syrup after distillation in a Kugelrohr apparatus (190 °C) at 10^{-2} Torr. ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 1.30–1.26 (t, ^3J = 7.2 Hz, 3H), 1.95–1.83 (m, 4H), 2.53–2.41 (m, 3H), 3.30–3.26 (m, 2H), 4.19–4.15 (m, 3H), 4.31 (s, 1H), 7.34–7.30 (m, 3H), 7.48–7.45 (m, 2H) ppm; ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 14.1 (CH_3), 28.2 ($2CH_2$), 41.2 (CH), 48.9 ($2CH_2$), 60.3 (CH_2), 90.8 (CH_2), 127.5 (2CH), 127.9 (CH), 128.1 (2CH), 139.8 (C), 157.3 (C), 175.0 (C) ppm; HRMS: *m*/*z* calcd for $C_{16}H_{21}NO_2$: 259.15668; found: 259.15642.

8-(1-Phenylvinyl)-1,4-dioxa-8-aza-spiro[4,5]decane (3h): The general procedure B with 3 mol % of $Pd(OAc)_2$, 6 mol % of (±)-BINAP, and a reaction temperature of 80 °C gave **3h** in 90 % yield as a yellow syrup after distillation in a Kugelrohr apparatus (200 °C) at 10^{-2} Torr. ^{1}H NMR ($CDCl_3$, 200 MHz): δ = 1.82–1.76 (t, ^3J = 5.9, 4H), 3.02–2.96 (t, ^3J = 5.9, 4H), 3.98 (s, 4H), 4.22 (s, 1H), 4.32 (s, 1H), 7.35–7.31 (m, 3H), 7.57–7.47 (m, 2H) ppm; ^{13}C NMR ($CDCl_3$, 50.3 MHz): δ = 34.6 ($2CH_2$), 47.2 ($2CH_2$), 64.1 ($2CH_2$), 91.1 (CH_2), 107.2 (C), 127.4 (2CH), 127.8 (CH), 128.0 (2CH), 139.8 (C), 156.6 (C) ppm; HRMS: *m*/*z* calcd for $C_{15}H_{19}NO_2$: 245.14103; found: 245.14142.

4-Styrylmorpholine (4a): The general procedure A with 1 mol % of $[Pd_2(dba)_3]$, 3 mol % of (±)-BINAP, and a reaction temperature of 90 °C gave **4a** in 95 % yield as a yellow solid after distillation in a Kugelrohr apparatus (160 °C) at 10^{-2} Torr. M.p.: 78–80 °C; ^{1}H NMR ($CDCl_3$, 200 MHz): δ = 3.07–3.03 (t, ^3J = 4.8 Hz, 4H), 3.82–3.77 (t, ^3J = 4.8 Hz, 4H), 5.52–5.45 (d, ^3J = 14.1 Hz, 1H), 6.69–6.62 (d, ^3J = 14.1 Hz, 1H), 7.29–7.26 (m, 5H) ppm; ^{13}C NMR ($CDCl_3$, 50.3 MHz): δ = 48.7 ($2CH_2$), 66.2 ($2CH_2$), 101.1 (CH), 124.0 (2CH), 124.2 (CH), 128.3 (2CH), 138.5 (C), 139.4 (CH) ppm; HRMS: *m*/*z* calcd for $C_{12}H_{15}NO$: 189.11481; found: 189.11468.

Methylphenylstyrylamine (4b): The general procedure A with 1 mol % of $[Pd_2(dba)_3]$, 3 mol % of (±)-BINAP, and a reaction temperature of 90 °C gave **4b** in 96 % yield as a yellow oil after distillation in a Kugelrohr apparatus (180 °C) at 10^{-2} Torr . ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 3.39 (s, 3H), 5.86–5.81 (d, ^3J = 15 Hz, 1H), 7.27–7.12 (m, 4H), 7.56–7.41 (m, 7H) ppm; ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 35.2 (CH_3), 103.4 (CH), 117.6 (2CH), 121.2 (CH), 124.1 (2CH), 124.2 (CH), 128.4 (2CH), 129.1 (2CH), 133.8 (CH), 138.7 (C), 147.4 (C) ppm; HRMS: *m*/*z* calcd for $C_{15}H_{15}N$: 209.11990; found: 209.12039.

Ethylphenylstyrylamine (4c): The general procedure A with 1 mol % of $[Pd_2(dba)_3]$, 3 mol % of (±)-BINAP, and a reaction temperature of 100 °C gave **4c** in 80 % yield as a yellow oil after distillation in a Kugelrohr apparatus (200 °C) at 10^{-2} Torr. ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 1.55–1.49 (t, ^3J = 7.2 Hz, 3H), 4.06–3.95 (q, ^3J = 7.2 Hz, 2H), 6.01–5.93 (d, ^3J = 14.2 Hz, 1H), 7.55–7.27 (m, 10H) ppm; ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 11.6 (CH_3), 42.5 (CH_2), 103.2 (CH), 117.5 (2CH), 121.1 (CH), 124.1 (CH), 124.2 (CH), 128.4 (3CH), 129.2 (2CH), 131.9 (CH), 138.8 (C), 146.2 (C) ppm; HRMS: *m*/*z* calcd for $C_{16}H_{17}N$: 233.13555; found: 233.13775.

Dibenzylstyrylamine (4d): The general procedure A with 1 mol % of $[Pd_2(dba)_3]$, 3 mol % of P(*o*-tol)$_3$, and a reaction temperature of 100 °C gave **4d** in 90 % yield as a yellow solid after distillation in a Kugelrohr apparatus (210 °C) at 10^{-2} Torr. M.p.: 120–122 °C; ^{1}H NMR ($CDCl_3$,

300 MHz): $\delta = 4.37$ (s, 4H), 5.43–5.39 (d, $^3J = 13.9$ Hz, 1H), 7.18–7.13 (d, $^3J = 13.9$ Hz, 1H), 7.42–7.26 (m, 15H) ppm; ^{13}C NMR ($CDCl_3$, 75 MHz): $\delta = 54.6$ ($2CH_2$), 98.2 (CH), 123.3 (CH), 123.4 (2CH), 127.1 (2CH), 127.4 (3CH), 128.4 (4CH), 128.5 (3CH), 137.8 (2C), 138.9 (CH), 139.4 (C) ppm; HRMS: *m*/*z* calcd for $C_{22}H_{21}N$: 299.16685; found: 299.16733.

Benzyl(3-bromobenzyl)styrylamine (4e): The general procedure A with 1 mol% of [$Pd_2(dba)_3$], 3 mol% of (±)-BINAP, and a reaction temperature of 100°C gave **4e** in 70% yield as a yellow solid. ^{1}H NMR ($CDCl_3$, 200 MHz): $\delta = 4.48$ (s, 4H), 5.39–5.34 (d, $^3J = 13.9$ Hz, 1H), 7.5–7.2 (m, 15 H) ppm; ^{13}C NMR ($CDCl_3$, 50.3 MHz): $\delta = 54.7$ (CH_2), 55.5 (CH_2), 98.6 (CH), 122.9 (C), 123.4 (CH), 123.5 (CH), 127.2 (2CH), 127.3 (CH), 127.4 (CH), 128.1 (CH), 128.2 (CH), 128.3 (CH), 128.5 (2CH), 128.6 (2CH), 132.7 (CH), 136.4 (C), 137.7 (C), 138.3 (CH), 139.2 (C) ppm.

Benzyl(1-phenylethyl)styrylamine (4f): The general procedure A with 1 mol% of $Pd(OAc)_2$, 3 mol% of (±)-BINAP, and a reaction temperature of 100°C gave **4f** in 64% yield as a yellow solid after distillation in a Kugelrohr apparatus (220°C) at 10^{-2} Torr. M.p.: 122–125°C; ^{1}H NMR ($CDCl_3$, 200 MHz): $\delta = 1.86$–1.83 (d, $^3J = 6.9$ Hz, 3H), 4.59–4.35 (q, $^3J = 14.2$ Hz, 2H), 4.86–4.76 (q, $^3J = 6.9$ Hz, 1H), 5.59–5.53 (d, $^3J = 13.8$ Hz, 1 H), 7.58–7.22 (m, 16H) ppm; ^{13}C NMR ($CDCl_3$, 50.3 MHz): $\delta = 19.0$ (CH_3), 51.1 (CH_2), 60.6 (CH), 98.8 (CH), 123.1 (CH), 123.4 (2CH), 126.6 (2CH), 126.7 (3CH), 126.8 (2CH), 127.1 (CH), 128.3 (4CH), 136.1 (CH), 138.4 (C), 139.7 (C), 142.4 (C) ppm; HRMS: *m*/*z* calcd for $C_{23}H_{23}N$: 313.18250; found: 313.18301.

Diallylstyrylamine (4g): The general procedure B with 3 mol% of $Pd(OAc)_2$, 6 mol% of (±)-BINAP, and a reaction temperature of 80°C gave **4g** in 97% yield as a yellow oil after distillation in a Kugelrohr apparatus (160°C) at 10^{-2} Torr. ^{1}H NMR ($CDCl_3$, 300 MHz): $\delta = 3.77$–3.75 (d, $^3J = 5.7$ Hz, 4H), 5.33–5.22 (m, 5H), 5.94–5.82 (m, 2H), 6.88–6.83 (d, $^3J = 14.2$ Hz, 1H), 7.05–7.00 (m, 1H), 7.25–7.22 (m, 4H) ppm; ^{13}C NMR ($CDCl_3$, 75 MHz): $\delta = 53.5$ ($2CH_2$), 97.8 (CH), 116.8 ($2CH_2$), 123.1 (CH), 123.3 (2CH), 128.4 (2CH), 133.8 (CH), 137.8 (2CH), 139.6 (C) ppm; HRMS: *m*/*z* calcd for $C_{14}H_{17}N$: 199.13555; found: 199.13574.

1-Styrylpiperidine 4-carboxylic acid ethyl ester (4h): The general procedure B with 3 mol% of $Pd(OAc)_2$, 6 mol% of (±)-BINAP, and a reaction temperature of 80°C gave **4h** in 95% yield as a yellow solid after distillation in a Kugelrohr apparatus (190°C) at 10^{-2} Torr. M.p.: 62–65 °C; ^{1}H NMR ($CDCl_3$, 300 MHz): $\delta = 1.30$–1.25 (t, $^3J = 7.1$ Hz, 3H), 1.84–1.71 (m, $^3J = 4.2$, 11.1 Hz, 2H), 1.99–1.93 (m, 2H), 2.46–2.36 (tt, $^3J = 3.7$, 11.1 Hz, 1H), 2.79–2.70 (td, $^3J = 12.8$, 11.6, 3.1 Hz, 2H), 3.44–3.38 (dt, $^3J = 3.7$, 12.8 Hz, 2H), 4.20–4.13 (q, $^3J = 7.1$ Hz, 2H), 5.42–5.38 (d, $^3J = 14.2$ Hz, 1H), 6.67–6.63 (d, $^3J = 14.2$ Hz, 1H), 7.05–7.00 (m, 1H), 7.21–7.18 (m, 4H) ppm; ^{13}C NMR ($CDCl_3$, 75 MHz): $\delta = 14.1$ (CH_3), 27.4 (2 CH_2), 40.9 (CH), 48.1 ($2CH_2$), 60.3 (CH_2), 100.3 (CH), 123.8 (2CH), 128.3 (2CH), 138.9 (C), 139.4 (CH), 174.5 (C) ppm; HRMS: *m*/*z* calcd for $C_{16}H_{21}NO_2$: 259.15668; found: 259.15677.

8-Styryl-1,4-dioxa-8-aza-spiro[4,5]decane (4i): The general procedure B with 3 mol% of $Pd(OAc)_2$, 6 mol% of (±)-BINAP, and a reaction temperature of 80°C gave **4i** in 97% yield as a yellow solid after distillation in a Kugelrohr apparatus (190°C) at 10^{-2} Torr. M.p.: 65–68°C; ^{1}H NMR ($CDCl_3$, 300 MHz): $\delta = 3.01$–2.97 (t, $^3J = 5.8$ Hz, 4H), 4.42–4.38 (t, $^3J = 5.8$ Hz, 4H), 5.18 (s, 4H), 6.64–6.59 (d, $^3J = 14.1$ Hz, 1H), 7.90–7.86 (d, $^3J = 14.1$ Hz, 1H), 8.27–8.24 (m, 1H), 8.44–8.42 (m, 4H) ppm; ^{13}C NMR ($CDCl_3$, 75 MHz): $\delta = 33.9$ ($2CH_2$), 46.6 ($2CH_2$), 64.1 ($2CH_2$), 100.4 (CH), 106.9 (C), 123.7 (2CH), 128.3 (2CH), 128.4 (CH), 138.8 (C), 139.0 (C) ppm; HRMS: *m*/*z* calcd for $C_{15}H_{19}NO_2$: 245.14103; found: 245.14170.

Methyl(1-methylene-3-phenylpropyl)phenylamine (6a): The general procedure B with 3 mol% of $Pd(OAc)_2$, 6 mol% of (±)-BINAP, and a reaction temperature of 80°C gave **6b** in 90% yield as an orange oil. ^{1}H NMR ($CDCl_3$, 300 MHz): $\delta = 2.76$–2.71 (m, 2H), 3.00–2.90 (m, 2H), 3.34 (s, 3H), 4.54 (s, 1H), 4.61 (s,1H), 7.55–7.30 (m, 10H) ppm; ^{13}C NMR ($CDCl_3$, 75 MHz): $\delta = 34.7$ (CH_2), 36.1 (CH_2), 41.4 (C), 92.4 (CH_2), 122.1 (CH), 123.6 (CH), 125.4(CH), 127.9 (CH), 128.1 (2CH), 128.1 (2CH), 128.7 (2CH), 141.6 (C), 148.4 (C), 152.4 (C) ppm.

4-(1-Methylene-3-phenylpropyl)morpholine (6b): The general procedure B with 3 mol% of $Pd(OAc)_2$, 6 mol% of (±)-BINAP, and a reaction temperature of 65°C gave **6a** in 90% yield as an orange oil . ^{1}H NMR ($CDCl_3$, 300 MHz): $\delta = 2.53$–2.59 (m, 2H), 2.86–2.81 (m, 2H), 2.93–2.90 (t, $^3J = 4.8$ Hz, 4H), 3.85–3.82 (t, $^3J = 4.8$ Hz, 4H), 4.01 (s, 1H), 4.09 (s, 1 H), 7.30–7.40 (m, 5H) ppm; ^{13}C NMR ($CDCl_3$, 75 MHz): $\delta = 34.6$ (CH_2), 35.1 (CH_2), 47.9 ($2CH_2$), 66.5 ($2CH_2$), 86.9 (CH_2), 125.7 (CH), 128.0 (CH), 128.1 (CH), 128.2 (CH), 128.4 (CH), 141.5 (C), 154.4 (C) ppm.

4-(1-Benzyloxymethylvinyl)morpholine (6c): The general procedure B with 3 mol% of $Pd(OAc)_2$, 6 mol% of (±)-BINAP, and a reaction temperature of 80°C gave **6c** in 96% yield as an orange oil. ^{1}H NMR ($CDCl_3$, 300 MHz): $\delta = 3.00$–2.97 (t, $^3J = 4.8$ Hz, 4H), 3.78–3.75 (t, $^3J = 4.8$ Hz, 4H), 4.00 (s, 1H), 4.09 (s, 2H), 4.11 (s, 1H), 4.54 (s, 2H), 7.40–7.37 (m, 5H) ppm; ^{13}C NMR ($CDCl_3$, 75 MHz): $\delta = 47.4$ ($2CH_2$), 66.4 (2 CH_2), 70.3 (CH_2), 71.2 (CH_2), 88.4 (CH_2), 127.4 (2CH), 127.8 (2CH), 128.1 (CH), 137.9 (C), 150.4 (C) ppm; HRMS: *m*/*z* calcd for $C_{14}H_{19}NO_2$: 233.14103; found: 233.13994.

(1-Benzyloxymethylvinyl)methylphenylamine (6d): The general procedure B with 3 mol% of $Pd(OAc)_2$, 6 mol% of (±)-BINAP, and a reaction temperature of 80°C gave **6d** in 95% yield as an orange oil. ^{1}H NMR ($CDCl_3$, 200 MHz): $\delta = 3.23$ (s, 3H), 4.11 (s, 2H), 4.50 (s, 1H), 4.55 (s, 2H), 4.66 (s, 1H), 7.24–7.19 (m, 2H), 7.44–7.36 (m, 8H) ppm; ^{13}C NMR ($CDCl_3$, 50.3 MHz): $\delta = 40.9$ (CH_3), 69.9 (CH_2), 71.7 (CH_2), 93.4 (CH_2), 112.1 (CH), 123.1 (CH), 123.6 (2CH), 127.5 (2CH), 128.1 (2 CH), 128.8 (2CH), 138.1 (C), 148.1 (C), 149.4 (C) ppm; HRMS: *m*/*z* calcd for $C_{17}H_{19}NO$: 253.14734; found: 253.14611.

Methyl(2-morpholin-4-ylallyl)phenylamine (6e): The general procedure B with 3 mol% of $Pd(OAc)_2$, 6 mol% of (±)-BINAP, and a reaction temperature of 80°C gave **6e** in 96% yield as an orange oil. ^{1}H NMR ($CDCl_3$, 300 MHz): $\delta = 2.97$–2.94 (t, $^3J = 4.8$ Hz, 4H), 3.00 (s, 3H), 3.78–3.75 (t, $^3J = 4.8$ Hz, 4H), 3.98 (s, 2H), 4.05 (s, 1H), 4.14 (s, 1H), 6.80–6.78 (m, 2H), 7.30–7.26 (m, 3H) ppm; ^{13}C NMR ($CDCl_3$, 75 MHz): $\delta = 37.4$ (CH_3), 48.1 ($2CH_2$), 54.6 (CH_2), 66.6 ($2CH_2$), 87.4 (CH_2), 112.2 (2CH), 116.4 (CH), 128.8 (2CH), 149.4 (C), 150.3 (C) ppm; HRMS: *m*/*z* calcd for $C_{14}H_{20}N_2O$: 232.15701; found: 232.15743.

***N,N′*-dimethyl-1-methylene-*N,N′*-diphenyl-1,2-ethanediamine (6f)**: The general procedure B with 3 mol% of $Pd(OAc)_2$, 6 mol% of (±)-BINAP, and a reaction temperature of 80°C gave **6f** in 95% yield as an orange oil. ^{1}H NMR ($CDCl_3$, 300 MHz): $\delta = 3.01$ (s, 3H), 3.21 (s, 3H), 4.00 (s, 2 H), 4.56 (s, 1H), 4.61 (s, 1H), 6.86–6.77 (m, 2H), 7.20–7.14 (m, 2H), 7.46–7.32 (m, 5H) ppm; ^{13}C NMR ($CDCl_3$, 75 MHz): $\delta = 37.9$ (CH_3), 41.5 (CH_3), 55.2 (CH_2), 93.5 (CH_2), 111.8 (2CH), 115.9 (CH), 122.9 (CH), 123.0 (CH), 128.7 (2CH), 128.8 (CH), 128.9 (2CH), 148.2 (C), 148.9 (C), 149.2 (C) ppm; HRMS: *m*/*z* calcd for $C_{17}H_{20}N_2$: 252.16210; found: 252.16314.

4-(1-methylenenonyl)morpholine (6g): The general procedure B with 3 mol% of $Pd(OAc)_2$, 6 mol% of (±)-BINAP, and a reaction temperature of 80°C gave **6g** in 96% yield as an orange oil. ^{1}H NMR ($CDCl_3$, 300 MHz): $\delta = 0.89$–0.85 (t, $^3J = 6.7$ Hz, 3H), 1.29–1.21 (m, 12H), 2.13–2.08 (t, $^3J = 7.6$ Hz, 2H), 2.85–2.82 (t, $^3J = 4.8$ Hz, 4H), 3.73–3.69 (t, $^3J = 4.8$ Hz, 4H), 3.79 (s, 1H), 3.89 (s, 1H) ppm; ^{13}C NMR ($CDCl_3$, 75 MHz): $\delta = 13.9$ (CH_3), 22.5 (CH_2), 24.3 (CH_2), 29.1 (CH_2), 29.2 (CH_2), 29.3 (CH_2), 31.7 (CH_2), 33.4 (CH_2), 48.1 ($2CH_2$), 66.7 ($2CH_2$), 85.9 (CH_2), 155.4 (C) ppm; HRMS: *m*/*z* calcd for $C_{14}H_{27}NO$: 210.18793; found: 210.18741.

Methyl(1-methylenenonyl)phenylamine (6h): The general procedure B with 3 mol% of $Pd(OAc)_2$, 6 mol% of (±)-BINAP, and a reaction temperature of 80°C gave **6h** in 95% yield as an orange oil. ^{1}H NMR ($CDCl_3$, 300 MHz): $\delta = 0.97$–0.91 (t, $^3J = 6.7$ Hz, 3H), 1.43–1.26 (m, 12H), 2.19–2.14 (t, $^3J = 7.5$ Hz, 2H), 3.11 (s, 3H), 4.28 (s, 1H), 4.35 (s, 1H), 7.08–7.05 (m, 3H), 7.37–7.29 (m, 2H) ppm; ^{13}C NMR ($CDCl_3$, 75 MHz): $\delta = 14.0$ (CH_3), 22.6 (CH_2), 28.3 (CH_2), 29.0 (CH_2), 29.1 (CH_2), 29.3 (CH_2), 31.5 (CH_2), 34.1 (CH_2), 41.4 (CH_2), 92.4 (CH_2), 122.4 (CH), 123.3 (2CH), 128.7 (2CH), 148.8 (C), 153.8 (C) ppm; HRMS: *m*/*z* calcd for $C_{17}H_{27}N$: 245.21380; found: 245.21334.

General procedure for palladium-catalyzed amination of vinyl bromides with primary amines by using [$Pd_2(dba)_3$]: A Schlenk flask was charged with (±)-BINAP (0.03 mmol, 3 mol%), tris(dibenzylideneacetone)dipalladium(0) (0.005 mmol, 1 mol%), sodium *tert*-butoxide (1.4 mmol), and toluene (2 mL) under a nitrogen atmosphere. After 1 min, the vinyl bromide (1 mmol) and the amine (1.1 mmol) were added under nitrogen and the flask was immersed in an oil bath and heated to 90°C with stirring until the starting vinyl bromide had been completely consumed as judged by GC analysis. The mixture was allowed to cool to room temperature, taken up in hexanes (15 mL), and filtered through celite. The solvents were evaporated under reduced pressure. The residue was redissolved in

hexanes (15 mL), filtered again through celite, concentrated under reduced pressure, and dried under high vacuum to remove the excess of amine. This afforded a residue which consisted of the essentially pure imine. The imines can be purified by Kugelrohr distillation under high vacuum (dependent on the boiling point).

(4-Methoxyphenyl)(1-phenylethylidene)amine (9a): The general procedure with 1 mol% of $[Pd_2(dba)_3]$, 3 mol% of (±)-BINAP, and a reaction temperature of 90°C gave **9a** in 98% yield as a light yellow oil after distillation in a Kugelrohr apparatus (180°C) at 10^{-2} Torr. ^{1}H NMR ($CDCl_3$, 300 MHz): $\delta = 2.27$ (s, 3H), 3.62 (s, 3H), 6.80–6.78 (d, $^3J = 8.6$ Hz, 2H), 6.95–6.92 (d, $^3J = 8.6$ Hz, 2H), 7.47–7.43 (m, 3H), 8.01–7.98 (m, 2H) ppm; ^{13}C NMR ($CDCl_3$, 75 MHz): $\delta = 17.1$ (CH_3), 55.2 (CH_3), 114.1 (2CH), 120.6 (2CH), 126.9 (2CH), 128.2 (2CH), 130.1 (CH), 139.6 (C), 144.6 (C), 155.8 (C), 165.5 (C) ppm; HRMS: *m/z* calcd for $C_{15}H_{15}NO$: 225.11481; found: 225.11505.

(1-Phenylethylidene)*p*-tolylamine (9b): The general procedure with 1 mol% of $[Pd_2(dba)_3]$, 3 mol% of (±)-BINAP, and a reaction temperature of 90°C gave **9b** in 98% yield as a light yellow oil after distillation in a Kugelrohr apparatus (170°C) at 10^{-2} Torr. ^{1}H NMR ($CDCl_3$, 200 MHz): $\delta = 2.32$ (s, 3H), 2.45 (s, 3H), 6.84 (d, $^3J = 8$ Hz, 2H), 7.28–7.24 (d, $^3J = 8$ Hz, 2H), 7.55–7.52 (m, 3H), 8.10–8.05 (m, 2H) ppm; ^{13}C NMR ($CDCl_3$, 50.3 MHz): $\delta = 17.0$ (CH_3), 20.6 (CH_3), 119.2 (2CH), 126.9 (2CH), 128.1 (2CH), 129.3 (2CH), 130.1 (CH), 132.3 (C), 139.4 (C), 148.9 (C), 165.1 (C) ppm; HRMS: *m/z* calcd for $C_{15}H_{15}N$: 209.11990; found: 209.11962.

4-(1-Phenylethylideneamino)benzonitrile (9c): The general procedure with 1 mol% of $[Pd_2(dba)_3]$, 3 mol% of (±)-BINAP, and a reaction temperature of 90°C gave **9c** in 86% yield as a yellow solid. ^{1}H NMR ($CDCl_3$, 300 MHz): $\delta = 0.22$ (s, 3H), 6.86–6.83 (d, $^3J = 8.5$ Hz, 2H), 7.48–7.45 (m, 3H), 7.61–7.58 (d, $^3J = 8.3$ Hz, 2H), 7.98–7.95 (m, 2H) ppm; ^{13}C NMR ($CDCl_3$, 75 MHz): $\delta = 17.6$ (CH_3), 106.2 (C), 119.2 (C), 119.8 (2CH), 127.1 (2CH), 128.4 (2CH), 131.0 (CH), 133.1 (2CH), 138.2 (C), 155.6 (C), 166.1 (C) ppm; HRMS: *m/z* calcd for $C_{15}H_{12}N_2$: 220.0995; found: 220.10012.

(4-Nitrophenyl)(1-phenylethylidene)amine (9d): The general procedure with 2 mol% of $[Pd_2(dba)_3]$, 6 mol% of (±)-BINAP, and a reaction temperature of 90°C gave **9d** in 86% yield as a yellow solid after distillation in a Kugelrohr apparatus (190°C) at 10^{-2} Torr. M.p.: 125–128°C; ^{1}H NMR ($CDCl_3$, 300 MHz): $\delta = 2.26$ (s, 3H), 6.89–6.86 (d, $^3J = 8.5$ Hz, 2H), 7.49–7.46 (m, 3H), 7.98–7.96 (d, $^3J = 7.4$ Hz, 2H), 8.24–8.21 (d, $^3J = 8.5$ Hz, 2H) ppm; ^{13}C NMR ($CDCl_3$, 75 MHz): $\delta = 17.7$ (CH_3), 119.4 (2CH), 124.9 (2CH), 127.2 (2CH), 128.4 (2CH), 131.1 (CH), 138.1 (C), 143.5 (C), 157.6 (C), 166.1 (C) ppm; HRMS: *m/z* calcd for $C_{14}H_{12}N_2O_2$: 240.08932; found: 240.09015.

(1-Phenylethylidene)-*o*-tolylamine (9e): The general procedure with 1 mol% of $[Pd_2(dba)_3]$, 3 mol% of (±)-BINAP, and a reaction temperature of 90°C gave **9e** in 98% yield as a yellow oil after distillation in a Kugelrohr apparatus (170°C) at 10^{-2} Torr. ^{1}H NMR ($CDCl_3$, 200 MHz): $\delta = 2.16$ (s, 3H), 2.23 (s, 3H), 6.72–6.69 (d, $^3J = 7.9$ Hz, 1H), 7.08–7.03 (t, $^3J = 7.7$ Hz, 1H), 7.29–7.21 (m, 2H), 7.52–7.50 (m, 3H), 8.08–8.05 (m, 2H) ppm; ^{13}C NMR ($CDCl_3$, 50.3 MHz): $\delta = 17.3$ (CH_3), 17.6 (CH_3), 118.3 (CH), 123.1 (CH), 126.3 (CH), 127.0 (2CH), 128.3 (2CH), 130.2 (CH), 130.3 (CH), 139.3 (2C), 150.2 (C), 164.8 (C) ppm; HRMS: *m/z* calcd for $C_{15}H_{15}N$: 209.11990; found: 209.11950.

(2-Methoxyphenyl)(1-phenylethylidene)amine (9f): The general procedure with 1 mol% of $[Pd_2(dba)_3]$, 3 mol% of (±)-BINAP, and a reaction temperature of 90°C gave **9f** in 98% yield as a yellow oil after distillation in a Kugelrohr apparatus (180°C) at 10^{-2} Torr. ^{1}H NMR ($CDCl_3$, 200 MHz): $\delta = 2.25$ (s, 3H), 3.82 (s, 3H), 6.87–6.82 (m, 1H), 7.1–6.98 (m, 3H), 7.51–7.48 (m, 3H), 8.09–8.0 (m, 2H); ^{13}C NMR ($CDCl_3$, 50.3 MHz): $\delta = 17.6$ (CH_3), 55.4 (CH_3), 111.4 (CH), 120.4 (CH), 120.7 (CH), 123.9 (CH), 127.1 (2CH), 128.1 (2CH), 130.2 (CH), 139.2 (C), 140.4 (C), 148.7 (C), 16.8 (C) ppm; HRMS: *m/z* calcd for $C_{15}H_{15}NO$: 225.11481; found: 225.11464.

(2-Bromophenyl)(1-phenylethylidene)amine (9g): The general procedure with 1 mol% of $[Pd_2(dba)_3]$, 3 mol% of (±)-BINAP, and a reaction temperature of 90°C gave **9g** in 98% yield as a yellow oil after distillation in a Kugelrohr apparatus (190°C) at 10^{-2} Torr. ^{1}H NMR ($CDCl_3$, 300 MHz): $\delta = 2.23$ (s, 3H), 6.88–6.83 (dd, $^3J = 1.4$, 7.7 Hz, 1H), 7.35–7.30 (t, $^3J = 7.7$ Hz, 1H), 7.52–7.49 (m, 3H), 7.66–7.63 (dd, $^3J = 1.1$, 7.9 Hz, 1H), 8.06–8.04 (m, 2H) ppm; ^{13}C NMR ($CDCl_3$, 75 MHz): $\delta = 17.9$ (CH_3), 113.6 (C), 120.2 (CH), 124.3 (CH), 127.3 (2CH), 127.8 (CH), 128.2 (CH), 128.3 (CH), 130.7 (CH), 132.7 (CH), 138.7 (C), 149.8 (C), 167.3 (C) ppm; HRMS: *m/z* calcd for $C_{14}H_{12}BrN$: 273.01476; found: 273.01371.

(3-Bromophenyl)(1-phenylethylidene)amine (9h): The general procedure with 1 mol% of $[Pd_2(dba)_3]$, 3 mol% of (±)-BINAP, and a reaction temperature of 90°C gave **9h** in 98% yield as a yellow oil after distillation in a Kugelrohr apparatus (190°C) at 10^{-2} Torr. ^{1}H NMR ($CDCl_3$, 200 MHz): $\delta = 2.28$ (s, 3H), 6.79–6.76 (m, 1H), 7.03–7.02 (m, 1H), 7.26–7.24 (m, 2H), 7.51–7.48 (m, 3H), 8.02–7.99 (m, 2H) ppm; ^{13}C NMR ($CDCl_3$, 50.3 MHz): $\delta = 17.4$ (CH_3), 118.0 (CH), 122.2 (CH), 122.3 (C), 125.9 (CH), 127.1 (2CH), 128.3 (2CH), 130.2 (CH), 130.7 (CH), 138.8 (C), 152.9 (C), 166.2 (C) ppm; HRMS: *m/z* calcd for $C_{14}H_{12}BrN$: 273.01476; found: 273.01454.

(4-Bromophenyl)(1-phenylethylidene)amine (9i): The general procedure with 1 mol% of $[Pd_2(dba)_3]$, 3 mol% of (±)-BINAP, and a reaction temperature of 90°C gave **9i** in 98% yield as a yellow oil after distillation in a Kugelrohr apparatus (190°C) at 10^{-2} Torr. ^{1}H NMR ($CDCl_3$, 300 MHz): $\delta = 2.24$ (s, 3H), 6.72–6.69 (d, $^3J = 8.5$ Hz, 2H), 7.49–7.46 (m, 5H), 8.01–7.97 (m, 2H) ppm; ^{13}C NMR ($CDCl_3$, 75 MHz): $\delta = 17.2$ (CH_3), 115.9 (C), 121.1 (2CH), 127.0 (2CH), 128.2 (2CH), 130.5 (2CH), 131.8 (CH), 138.9 (C), 150.5 (C), 165.9 (C) ppm; HRMS: *m/z* calcd for $C_{14}H_{12}BrN$: 273.01476; found: 273.01444.

(1-Phenylethylidene)(2,4,6-trimethylphenyl)amine (9j): The general procedure with 1 mol% of $[Pd_2(dba)_3]$, 3 mol% of (±)-BINAP, and a reaction temperature of 90°C gave **9j** in 92% yield as a yellow oil after distillation in a Kugelrohr apparatus (190°C) at 10^{-2} Torr. ^{1}H NMR ($CDCl_3$, 300 MHz): $\delta = 2.06$ (s, 6H), 2.12 (s, 3H), 2.35 (s, 3H), 6.94 (s, 2H), 7.53–7.51 (m, 3H), 8.09–8.07 (m, 2H) ppm; ^{13}C NMR ($CDCl_3$, 75 MHz): $\delta = 17.3$ (CH_3), 17.8 (CH_3), 20.6 (CH_3), 125.4 (C), 126.9 (2CH), 128.3 (2CH), 128.4 (2CH), 130.2 (CH), 131.7 (C), 139.1 (C), 146.3 (C), 165.3 (C) ppm; HRMS: *m/z* calcd for $C_{17}H_{19}N$: 237.15120; found: 237.15218.

(2,6-Dibromophenyl)(1-phenylethylidene)amine (9k): The general procedure with 2 mol% of $[Pd_2(dba)_3]$, 6 mol% of (±)-BINAP, and a reaction temperature of 90°C gave **9k** in 50% conversion as an orange solid. ^{1}H NMR ($CDCl_3$, 300 MHz): $\delta = 0.19$ (s, 3H), 6.85–6.80 (t, $^3J = 7.9$ Hz, 1H), 7.58–7.49 (m, 5H), 8.01–8.06 (m, 2H) ppm; ^{13}C NMR ($CDCl_3$, 75 MHz): $\delta = 18.7$ (CH_3), 113.8 (C), 124.8 (CH), 127.5 (2CH), 128.4 (2CH), 131.1 (CH), 131.6 (2CH), 131.7 (CH), 138.2 (C), 148.2 (C), 164.4 (C) ppm; HRMS: *m/z* calcd for $C_{14}H_{11}Br_2N$: 350.92527; found: 350.92542.

Butyl(1-phenylethylidene)amine (9l): The general procedure with 1 mol% of $[Pd_2(dba)_3]$, 3 mol% of (±)-BINAP, and a reaction temperature of 90°C gave **9l** in 88% yield as a yellow oil after distillation in a Kugelrohr apparatus (150°C) at 10^{-2} Torr. ^{1}H NMR ($CDCl_3$, 300 MHz): $\delta = 1.09–1.04$ (t, $^3J = 7.3$ Hz, 3H), 1.64–1.49 (m, $^3J = 7.3$ Hz, 2H), 1.87–1.77 (q, $^3J = 7.3$ Hz, 2H), 2.26 (s, 3H), 3.57–3.52 (t, $^3J = 7.3$ Hz, 2H), 7.43–7.40 (m, 3H), 7.88–7.83 (m, 2H) ppm; ^{13}C NMR ($CDCl_3$, 75 MHz): $\delta = 13.8$ (CH_3), 15.1 (CH_3), 20.6 (CH_2), 32.9 (CH_2), 51.7 (CH_2), 126.3 (2CH), 127.9 (2CH), 128.9 (CH), 141.2 (C), 164.4 (C) ppm; HRMS: *m/z* calcd for $C_{12}H_{17}N$: 175.12772; found: 175.12773.

Allyl(1-phenylethylidene)amine (9m): The general procedure with 1 mol% of $[Pd_2(dba)_3]$, 3 mol% of (±)-BINAP, and a reaction temperature of 90°C gave **9m** in 98% yield as a yellow oil after distillation in a Kugelrohr apparatus (140°C) at 10^{-2} Torr. ^{1}H NMR ($CDCl_3$, 300 MHz): $\delta = 2.24$ (s, 3H), 4.19–4.18 (d, $^3J = 4.4$ Hz, 2H), 5.18–5.14 (dd, $^3J = 1.7$, 10.5 Hz, 1H), 5.30–5.24 (dd, $^3J = 1.7$, 17.1 Hz, 1H), 6.20–6.07 (m, 1H), 7.39–7.37 (m, 3H), 7.83–7.80 (m, 2H) ppm; ^{13}C NMR ($CDCl_3$, 75 MHz): $\delta = 15.4$ (CH_3), 54.4 (CH_2), 114.9 (CH_2), 126.5 (2CH), 128.1 (2CH), 129.4 (CH), 135.8 (CH), 140.9 (C), 166.1 (C) ppm.

4-Methoxybenzyl(1-phenylethylidene)amine (9n): The general procedure with 1 mol% of $[Pd_2(dba)_3]$, 3 mol% of (±)-BINAP, and a reaction temperature of 90°C gave **9n** in 96% yield as a yellow oil after distillation in a Kugelrohr apparatus (200°C) at 10^{-2} Torr. ^{1}H NMR ($CDCl_3$, 200 MHz): $\delta = 2.36$ (s, 3H), 3.84 (s, 3H), 4.73 (s, 2H), 6.97–6.93 (d, $^3J = 8.7$ Hz, 2H), 7.45–7.38 (m, 5H), 7.91–7.88 (m, 2H) ppm; ^{13}C NMR ($CDCl_3$, 50.3 MHz): $\delta = 15.6$ (CH_3), 54.9 (CH_2), 55.4 (CH_3), 113.6 (2CH), 126.6 (2CH), 128.1 (2CH), 128.6 (2CH), 129.4 (CH), 132.5 (C), 140.9 (C), 158.2 (C), 165.5 (C) ppm; HRMS: *m/z* calcd for $C_{16}H_{17}NO$: 239.13046; found: 239.13018.

(1-Phenylethyl)(1-phenylethylidene)amine (9o): The general procedure with 1 mol% of $[Pd_2(dba)_3]$, 3 mol% of (±)-BINAP, and a reaction temperature of 90°C gave **9o** in 94% yield as a yellow oil after distillation in a Kugelrohr apparatus (200°C) at 10^{-2} Torr. ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 1.65–1.63 (d, ^3J = 6.5 Hz, 3H), 2.33 (s, 3H), 4.95–4.81 (q, ^3J = 6.5 Hz, 1H), 7.55–7.30 (m, 8H), 7.57–7.55 (m, 2H) ppm; ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 15.4 (CH_3), 24.9 (CH_3), 59.7 (CH), 126.4 (CH), 126.5 (2CH), 126.6 (2CH), 128.1 (2CH), 128.2 (2CH), 129.2 (CH), 141.3 (C), 146.1 (C), 163.3 (C) ppm; HRMS: *m*/*z* calcd for $C_{16}H_{17}N$: 223.13555; found: 223.15517.

(2-Benzyloxy-1-methylethylidene)(4-methoxyphenyl)amine (10a): The general procedure with 1 mol% of $[Pd_2(dba)_3]$, 3 mol% of (±)-BINAP, and a reaction temperature of 90°C gave **10a** in 90% yield as an orange oil. ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 1.89 (s, 3H), 3.80 (s, 3H), 4.23 (s, 2H), 4.67 (s, 2H), 6.75–6.70 (m, 2H), 6.91–6.88 (m, 2H), 7.43–7.40 (m, 5H) ppm; ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 16.5 (CH_3), 55.1 (CH_3), 72.8 (CH_2), 75.4 (CH_2), 113.9 (2CH), 120.5 (2CH), 127.6 (CH), 127.7 (2CH), 128.2 (2CH), 137.5 (C), 143.4 (C), 155.8 (C), 169.3 (C) ppm; HRMS: *m*/*z* calcd for $C_{17}H_{19}NO_2$: 269.14103; found: 269.14074.

(2-But-2-ynyloxy-1-methylethylidene)(4-methoxyphenyl)amine (10b): The general procedure with 1 mol% of $[Pd_2(dba)_3]$, 3 mol% of (±)-BINAP, and a reaction temperature of 90°C gave **10b** in 94% yield as an orange oil. ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 1.72 (s, 6H), 3.62 (s, 3H), 4.10 (s, 4H), 6.58–6.54 (m, 2H), 6.74–6.71 (m, 2H) ppm; ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 3.0 (CH_3), 16.2 (CH_3), 54.7 (CH_3), 58.2 (CH_2), 74.1 (CH_2), 74.3 (C), 82.6 (C), 113.6 (2CH), 120.6 (2CH), 143.1 (C), 155.5 (C), 169.4 (C) ppm; HRMS: *m*/*z* calcd for $C_{14}H_{17}NO_2$: 231.12538; found: 231.12493.

(4-Methoxyphenyl)(1-methylnonylidene)amine (10c): The general procedure with 1 mol% of $[Pd_2(dba)_3]$, 3 mol% of (±)-BINAP, and a reaction temperature of 90°C gave **10c** in 95% yield as an orange oil. ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 0.91–0.87 (t, ^3J = 6.1 Hz, 3H), 1.35–1.20 (m, 10H), 1.73–1.69 (m, 2H), 1.78 (s, 3H), 2.42–2.36 (t, ^3J = 7.9 Hz, 2H), 3.78 (s, 3H), 6.66–6.62 (m, 2H), 6.89–6.82 (m, 2H) ppm; ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 13.9 (CH_3), 19.1 (CH_3), 22.5 (CH_2), 26.3 (CH_2), 29.1 (CH_2), 29.2 (CH_2), 29.3 (CH_2), 31.7 (CH_2), 41.7 (CH_2), 55.2 (CH_3), 113.9 (2CH), 120.5 (2CH), 144.7 (C), 155.5 (C), 172.4 (C) ppm; HRMS: *m*/*z* calcd for $C_{17}H_{27}NO$: 261.20871; found: 261.20993.

(4-Methoxyphenyl)[1-methyl-2-(methylphenylamino)ethylidene]amine (10d): The general procedure with 1 mol% of $[Pd_2(dba)_3]$, 3 mol% of (±)-BINAP, and a reaction temperature of 90°C gave **10d** in 92% yield as an orange oil. ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 1.81 (s, 3H), 3.13 (s, 3H), 3.81 (s, 3H), 4.19 (s, 2H), 6.81–6.71 (m, 3H), 6.92–6.86 (m, 4H), 7.34–7.29 (m, 2H) ppm; ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 16.7 (CH_3), 39.2 (CH_3), 55.1 (CH_3), 62.0 (CH_2), 112.1 (2CH), 113.9 (2CH), 116.6 (CH), 120.4 (2CH), 128.9 (2CH), 143.6 (C), 149.1 (C), 155.7 (C), 170.9 (C) ppm; HRMS: *m*/*z* calcd for $C_{17}H_{20}N_2O$: 268.15701; found: 268.15743.

(2-Benzyloxy-1-methylethylidene)(4-methoxybenzyl)amine (10e): The general procedure with 1 mol% of $[Pd_2(dba)_3]$, 3 mol% of (±)-BINAP, and a reaction temperature of 90°C gave **10e** in 94% yield as an orange oil. ^{1}H NMR ($CDCl_3$, 200 MHz): δ = 2.02 (s, 3H), 3.82 (s, 3H), 4.16 (s, 2H), 4.52 (s, 2H), 4.59 (s, 2H), 6.95–6.91 (m, 2H), 7.40–7.28 (m, 7H) ppm; ^{13}C NMR ($CDCl_3$, 50.3 MHz): δ = 14.8 (CH_3), 54.3 (CH_2), 54.9 (CH_3), 72.5 (CH_2), 76.4 (CH_2), 113.6 (2CH), 127.5 (CH), 127.6 (2CH), 128.1 (2CH), 128.7 (2CH), 131.8 (C), 137.7 (C), 158.2 (C), 168.1 (C) ppm; HRMS: *m*/*z* calcd for $C_{18}H_{21}NO_2$: 283.15668; found: 283.15680.

[2-(4-Methoxybenzylimino)propyl]methylphenylamine (10f): The general procedure with 1 mol% of $[Pd_2(dba)_3]$, 3 mol% of (±)-BINAP, and a reaction temperature of 90°C gave **10f** in 93% yield as an orange oil. ^{1}H NMR ($CDCl_3$, 200 MHz): δ = 1.92 (s, 3H), 3.09 (s, 3H), 3.85 (s, 3H), 4.12 (s, 2H), 4.56 (s, 2H), 6.88–6.82 (d, ^3J = 8.7 Hz, 2H), 6.97–6.94 (d, ^3J = 8.7 Hz, 2H), 7.32–7.30 (m, 5H) ppm; ^{13}C NMR ($CDCl_3$, 50.3 MHz): δ = 14.8 (CH_3), 38.9 (CH_3), 54.3 (CH_2), 54.9 (CH_3), 62.4 (CH_2), 112.2 (2CH), 113.6 (2CH), 116.4 (CH), 128.6 (2CH), 128.8 (2CH), 131.9 (C), 149.3 (C), 158.1 (C), 169.3 (C) ppm; HRMS: *m*/*z* calcd for $C_{18}H_{22}N_2O$: 282.17266; found: 282.17303.

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