Hazel Phi: 11-type-constructors

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SYNTAX

Kind	κ	$::=$	$\texttt{Type} \mid \texttt{KHole} \mid \mathsf{S}_{\kappa}(\tau) \mid \Pi_{t::\kappa_1}.\kappa_2$
User Types	$\hat{\tau}$	$::=$	$t \mid \texttt{bse} \mid \hat{\tau_1} \oplus \hat{\tau_2} \mid \llparenthesis\rrparenthesis^{\mathsf{u}} \mid \llparenthesis\hat{\tau}\rrparenthesis^{\mathsf{u}} \mid \lambda t{::}\texttt{Type}.\hat{\tau} \mid \hat{\tau_1}\ \hat{\tau_2}$
Internal Types	τ	$::=$	$t \mid \texttt{bse} \mid \tau_1 \oplus \tau_2 \mid \llparenthesis\rrparenthesis^{\mathsf{u}} \mid \llparenthesis\tau\rrparenthesis^{\mathsf{u}} \mid \llparenthesis t\rrparenthesis^{\mathsf{u}} \mid \lambda t{::}\kappa.\tau \mid \tau_1\ \tau_2$
Base Types	$\texttt{bse}$	$::=$	$\texttt{Int} \mid \texttt{Float} \mid \texttt{Bool}$
BinOp	$\oplus$	$::=$	$\times \mid + \mid \rightarrow$
Type Pattern			
User Expression			
Internal Expression			

DECLARATIVES

$\boxed{\Delta;\Phi \vdash \tau ::> \kappa}$ τ has principal (well formed) kind κ

$$\frac{\Delta;\Phi \vdash \mathsf{OK}}{\Delta;\Phi \vdash \texttt{bse} ::> \mathsf{S}_{\texttt{Type}}(\texttt{bse})}\ \texttt{PK-Base} \qquad \frac{\Delta;\Phi_1, t{::}\kappa, \Phi_2 \vdash \mathsf{OK}}{\Delta;\Phi \vdash t ::> \mathsf{S}_{\kappa}(t)}\ \texttt{PK-Var} \qquad \frac{\Delta;\Phi \vdash \tau_1{::}\texttt{Type} \quad \Delta;\Phi \vdash \tau_2{::}\texttt{Type}}{\Delta;\Phi \vdash \tau_1 \oplus \tau_2 ::> \mathsf{S}_{\texttt{Type}}(\tau_1 \oplus \tau_2)}\ \texttt{PK-}\oplus$$

$$\frac{\Delta_1, \mathrm{u}{::}\kappa, \Delta_2;\Phi \vdash \mathsf{OK}}{\Delta;\Phi \vdash \llparenthesis\rrparenthesis^{\mathsf{u}} ::> \mathsf{S}_{\kappa}(\llparenthesis\rrparenthesis^{\mathsf{u}})}\ \texttt{PK-EHole} \qquad \frac{\Delta_1, \mathrm{u}{::}\kappa, \Delta_2;\Phi \vdash \mathsf{OK} \quad \Delta;\Phi \vdash \tau{::}\kappa_1}{\Delta;\Phi \vdash \llparenthesis\tau\rrparenthesis^{\mathsf{u}} ::> \mathsf{S}_{\kappa}(\llparenthesis\tau\rrparenthesis^{\mathsf{u}})}\ \texttt{PK-NEHole}$$

$$\frac{\Delta_1, \mathrm{u}{::}\kappa, \Delta_2;\Phi \vdash \mathsf{OK} \quad t \notin \Phi}{\Delta;\Phi \vdash \llparenthesis t\rrparenthesis^{\mathsf{u}} ::> \mathsf{S}_{\kappa}(\llparenthesis t\rrparenthesis^{\mathsf{u}})}\ \texttt{PK-Unbound} \qquad \frac{\Delta;\underline{\Phi, t{::}\kappa_1} \vdash \tau ::> \kappa_2}{\Delta;\Phi \vdash \lambda t{::}\kappa_1.\tau ::> \mathsf{S}_{\Pi_{t::\kappa_1}.\kappa_2}(\lambda t{::}\kappa_1.\tau)}\ \texttt{PK-}\lambda$$

$$\frac{\Delta;\Phi \vdash \tau_1 ::> \kappa \quad \Delta;\Phi \vdash \kappa \blacktriangleright_{\Pi} \Pi_{t::\kappa_1}.\kappa_2 \quad \Delta;\Phi \vdash \tau_2{::}\kappa_1}{\Delta;\Phi \vdash \tau_1\ \tau_2 ::> [\tau_2/t]\kappa_2}\ \texttt{PK-Ap}$$

$\boxed{\Delta;\Phi \vdash \tau{::}\kappa}$ τ is well formed at kind κ

$$\frac{\Delta;\Phi \vdash \tau ::> \mathsf{S}_{\kappa}(\tau)}{\Delta;\Phi \vdash \tau{::}\kappa}\ \texttt{WFaK-1} \qquad \frac{\Delta;\Phi \vdash \tau ::> \kappa_1 \quad \Delta;\Phi \vdash \kappa_1 \lesssim \kappa}{\Delta;\Phi \vdash \tau{::}\kappa}\ \texttt{WFaK-Subsump}$$

$$\frac{\Delta;\Phi \vdash \tau ::> \kappa}{\Delta;\Phi \vdash \tau{::}\kappa}\ \texttt{WFaK-Reit} \qquad \frac{\Delta;\Phi \vdash \tau{::}\kappa}{\Delta;\Phi \vdash \tau{::}\mathsf{S}_{\kappa}(\tau)}\ \texttt{WFaK-Self}$$

$$\frac{\Delta;\Phi \vdash \tau{::}\Pi_{t::\kappa_3}.\kappa_4 \quad \Delta;\Phi \vdash \Pi_{t::\kappa_3}.\kappa_4 \lesssim \Pi_{t::\kappa_1}.\kappa_2}{\Delta;\Phi \vdash \tau{::}\Pi_{t::\kappa_1}.\kappa_2}\ \texttt{WFaK-}\Pi\texttt{CSKTrans} \qquad \frac{\Delta;\Phi \vdash \tau{::}\mathsf{S}_{\kappa}(\tau_1) \quad \Delta;\Phi \vdash \tau_1{::}\kappa}{\Delta;\Phi \vdash \tau{::}\kappa}\ \texttt{WFaK-Flatten}$$

$\boxed{\Delta;\Phi \vdash \kappa \blacktriangleright_{\Pi} \Pi_{t::\kappa_1}.\kappa_2}$ κ has matched Π-kind $\Pi_{t::\kappa_1}.\kappa_2$

$$\frac{\Delta;\Phi \vdash \mathsf{OK}}{\Delta;\Phi \vdash \texttt{KHole} \blacktriangleright_{\Pi} \Pi_{t::\texttt{KHole}}.\texttt{KHole}}\ \blacktriangleright_{\Pi}\texttt{-KHole} \qquad \frac{\Delta;\Phi \vdash \kappa \equiv \mathsf{S}_{\texttt{KHole}}(\tau)}{\Delta;\Phi \vdash \kappa \blacktriangleright_{\Pi} \Pi_{t::\mathsf{S}_{\texttt{KHole}}(\tau)}.\mathsf{S}_{\texttt{KHole}}(\tau\ t)}\ \blacktriangleright_{\Pi}\texttt{-SKHole} \qquad \frac{\Delta;\Phi \vdash \kappa \equiv \Pi_{t::\kappa_1}.\kappa_2}{\Delta;\Phi \vdash \kappa \blacktriangleright_{\Pi} \Pi_{t::\kappa_1}.\kappa_2}\ \blacktriangleright_{\Pi}\texttt{-}\Pi$$

$\boxed{\Delta;\Phi \vdash \kappa_1 \equiv \kappa_2}$ κ_1 is equivalent to κ_2

$$\frac{\Delta;\Phi \vdash \kappa\ \mathsf{OK}}{\Delta;\Phi \vdash \kappa \equiv \kappa}\ \texttt{KEquiv-Refl} \qquad \frac{\Delta;\Phi \vdash \kappa_2 \equiv \kappa_1}{\Delta;\Phi \vdash \kappa_1 \equiv \kappa_2}\ \texttt{KEquiv-Symm} \qquad \frac{\Delta;\Phi \vdash \kappa_1 \equiv \kappa_3 \quad \Delta;\Phi \vdash \kappa_3 \equiv \kappa_2}{\Delta;\Phi \vdash \kappa_1 \equiv \kappa_2}\ \texttt{KEquiv-Trans}$$

$$\frac{\Delta;\Phi \vdash \tau{::}\mathsf{S}_{\kappa}(\tau_1)}{\Delta;\Phi \vdash \mathsf{S}_{\mathsf{S}_{\kappa}(\tau_1)}(\tau) \equiv \mathsf{S}_{\kappa}(\tau_1)}\ \texttt{KEquiv-SKind}_{\texttt{SKind}} \qquad \frac{\Delta;\Phi \vdash \tau{::}\Pi_{t::\kappa_1}.\kappa_2}{\Delta;\Phi \vdash \mathsf{S}_{\Pi_{t::\kappa_1}.\kappa_2}(\tau) \equiv \Pi_{t_1::\kappa_1}.\mathsf{S}_{[t_1/t]\kappa_2}(\tau\ t_1)}\ \texttt{KEquiv-SKind}_{\Pi}$$

$$\frac{\Delta;\Phi \vdash \kappa_1 \equiv \kappa_2 \quad \Delta;\underline{\Phi, t{::}\kappa_1} \vdash \kappa_3 \equiv \kappa_4}{\Delta;\Phi \vdash \Pi_{t::\kappa_1}.\kappa_2 \equiv \Pi_{t::\kappa_3}.\kappa_4}\ \texttt{KEquiv-}\Pi \qquad \frac{\Delta;\Phi \vdash \tau_1 \overset{\kappa_1}{\equiv} \tau_2 \quad \Delta;\Phi \vdash \kappa_1 \equiv \kappa_2}{\Delta;\Phi \vdash \mathsf{S}_{\kappa_1}(\tau_1) \equiv \mathsf{S}_{\kappa_2}(\tau_2)}\ \texttt{KEquiv-SKind}$$

$\boxed{\Delta;\Phi \vdash \kappa_1 \lesssim \kappa_2}$ κ_1 is a consistent subkind of κ_2

$$\frac{\Delta;\Phi \vdash \kappa\ \mathsf{OK}}{\Delta;\Phi \vdash \texttt{KHole} \lesssim \kappa}\ \texttt{CSK-KHoleL} \qquad \frac{\Delta;\Phi \vdash \kappa\ \mathsf{OK}}{\Delta;\Phi \vdash \kappa \lesssim \texttt{KHole}}\ \texttt{CSK-KHoleR}$$

$$\frac{\Delta;\Phi \vdash \mathsf{S}_{\texttt{KHole}}(\tau)\ \mathsf{OK} \quad \Delta;\Phi \vdash \kappa\ \mathsf{OK}}{\Delta;\Phi \vdash \mathsf{S}_{\texttt{KHole}}(\tau) \lesssim \kappa}\ \texttt{CSK-SKind}_{\texttt{KHole}}\texttt{L} \qquad \frac{\Delta;\Phi \vdash \kappa\ \mathsf{OK} \quad \Delta;\Phi \vdash \mathsf{S}_{\texttt{KHole}}(\tau)\ \mathsf{OK}}{\Delta;\Phi \vdash \kappa \lesssim \mathsf{S}_{\texttt{KHole}}(\tau)}\ \texttt{CSK-SKind}_{\texttt{KHole}}\texttt{R}$$

$$\frac{\Delta;\Phi \vdash \kappa_1 \equiv \kappa_2}{\Delta;\Phi \vdash \kappa_1 \lesssim \kappa_2}\ \texttt{CSK-KEquiv} \qquad \frac{\Delta;\Phi \vdash \kappa_1 \equiv \kappa_3 \quad \Delta;\Phi \vdash \kappa_3 \lesssim \kappa_4 \quad \Delta;\Phi \vdash \kappa_4 \equiv \kappa_2}{\Delta;\Phi \vdash \kappa_1 \lesssim \kappa_2}\ \texttt{CSK-Normal}$$

$$\frac{\Delta;\Phi \vdash \mathsf{S}_{\kappa}(\tau)\ \mathsf{OK}}{\Delta;\Phi \vdash \mathsf{S}_{\kappa}(\tau) \lesssim \kappa}\ \texttt{CSK-SKind} \qquad \frac{\Delta;\Phi \vdash \kappa_3 \lesssim \kappa_1 \quad \Delta;\underline{\Phi, t{::}\kappa_3} \vdash \kappa_2 \lesssim \kappa_4}{\Delta;\Phi \vdash \Pi_{t::\kappa_1}.\kappa_2 \lesssim \Pi_{t::\kappa_3}.\kappa_4}\ \texttt{CSK-}\Pi$$

$$\frac{\Delta;\Phi \vdash \kappa_1 \lesssim \kappa_2 \quad \Delta;\Phi \vdash \tau_1 \overset{\kappa_1}{\equiv} \tau_2}{\Delta;\Phi \vdash \mathsf{S}_{\kappa_1}(\tau_1) \lesssim \mathsf{S}_{\kappa_2}(\tau_2)}\ \texttt{CSK}-?$$

$\boxed{\Delta;\Phi \vdash \tau_1 \overset{\kappa}{\equiv} \tau_2}$ τ_1 is provably equivalent to τ_2 at kind κ

$$\frac{\Delta;\Phi \vdash \tau{::}\kappa}{\Delta;\Phi \vdash \tau \overset{\kappa}{\equiv} \tau}\ \texttt{EquivAK-Refl} \qquad \frac{\Delta;\Phi \vdash \tau_2 \overset{\kappa}{\equiv} \tau_1}{\Delta;\Phi \vdash \tau_1 \overset{\kappa}{\equiv} \tau_2}\ \texttt{EquivAK-Symm} \qquad \frac{\Delta;\Phi \vdash \tau_1 \overset{\kappa}{\equiv} \tau_3 \quad \Delta;\Phi \vdash \tau_3 \overset{\kappa}{\equiv} \tau_1}{\Delta;\Phi \vdash \tau_1 \overset{\kappa}{\equiv} \tau_2}\ \texttt{EquivAK-Trans}$$

$$\frac{\Delta;\Phi \vdash \tau_1 ::> \kappa_1 \quad \Delta;\Phi \vdash \kappa_1 \equiv \mathsf{S}_{\kappa}(\tau_2)}{\Delta;\Phi \vdash \tau_1 \overset{\kappa}{\equiv} \tau_2}\ \texttt{EquivAK-SKind} \qquad \frac{\Delta;\Phi \vdash \tau_1{::}\Pi_{t::\kappa_1}.\kappa_3 \quad \Delta;\Phi \vdash \tau_2{::}\Pi_{t::\kappa_1}.\kappa_4 \quad \Delta;\underline{\Phi, t{::}\kappa_1} \vdash \tau_1\ t \overset{\kappa_2}{\equiv} \tau_2\ t}{\Delta;\Phi \vdash \tau_1 \overset{\Pi_{t::\kappa_1}.\kappa_2}{\equiv} \tau_2}\ \texttt{EquivAK-}\Pi$$

$$\frac{\Delta;\Phi \vdash \tau_1 \overset{\Pi_{t::\kappa_1}.\kappa_2}{\equiv} \tau_3 \quad \Delta;\Phi \vdash \tau_2 \overset{\kappa_1}{\equiv} \tau_4}{\Delta;\Phi \vdash \tau_1\ \tau_2 \overset{[\tau_2/t]\kappa_2}{\equiv} \tau_3\ \tau_4}\ \texttt{EquivAK-Ap}$$

$$\frac{\Delta;\Phi \vdash \tau_1 \overset{\mathsf{S}_{\kappa}(\tau)}{\equiv} \tau_2}{\Delta;\Phi \vdash \tau_1 \overset{\kappa}{\equiv} \tau_2}\ (1)$$

$$\frac{\Delta;\Phi \vdash \tau_1 \overset{\texttt{Type}}{\equiv} \tau_3 \quad \Delta;\Phi \vdash \tau_2 \overset{\texttt{Type}}{\equiv} \tau_4}{\Delta;\Phi \vdash \tau_1 \oplus \tau_2 \overset{\texttt{Type}}{\equiv} \tau_3 \oplus \tau_4}\ (2) \qquad \frac{\Delta;\Phi \vdash \kappa_1 \equiv \kappa_2 \quad \Delta;\underline{\Phi, t{::}\kappa_1} \vdash \tau_1 \overset{\kappa}{\equiv} \tau_2}{\Delta;\Phi \vdash \lambda t{::}\kappa_1.\tau_1 \overset{\Pi_{t::\kappa_1}.\kappa}{\equiv} \lambda t{::}\kappa_2.\tau_2}\ (3) \qquad \frac{\Delta;\Phi \vdash \tau_1 \overset{\kappa_1}{\equiv} \tau_2 \quad \Delta;\Phi \vdash \kappa_1 \equiv \kappa}{\Delta;\Phi \vdash \tau_1 \overset{\kappa}{\equiv} \tau_2}\ (4)$$

$\boxed{\Delta;\Phi \vdash \kappa\ \mathsf{OK}}$ κ is well formed

$$\frac{\Delta;\Phi \vdash \mathsf{OK}}{\Delta;\Phi \vdash \texttt{Type}\ \mathsf{OK}}\ \texttt{KWF-Type} \qquad \frac{\Delta;\Phi \vdash \mathsf{OK}}{\Delta;\Phi \vdash \texttt{KHole}\ \mathsf{OK}}\ \texttt{KWF-KHole} \qquad \frac{\Delta;\Phi \vdash \tau{::}\kappa}{\Delta;\Phi \vdash \mathsf{S}_{\kappa}(\tau)\ \mathsf{OK}}\ \texttt{KWF-SKind} \qquad \frac{\Delta;\underline{\Phi, t{::}\kappa_1} \vdash \kappa_2\ \mathsf{OK}}{\Delta;\Phi \vdash \Pi_{t::\kappa_1}.\kappa_2\ \mathsf{OK}}\ \texttt{KWF-}\Pi$$

$\boxed{\Delta;\Phi \vdash \mathsf{OK}}$ Context is well formed

$$\frac{}{\cdot;\cdot \vdash \mathsf{OK}}\ \texttt{CWF-Nil} \qquad \frac{t \notin \Phi \quad \Delta;\Phi \vdash \kappa\ \mathsf{OK}}{\Delta;\underline{\Phi, t{::}\kappa} \vdash \mathsf{OK}}\ \texttt{CWF-TypVar} \qquad \frac{\mathrm{u} \notin \Delta \quad \Delta;\Phi \vdash \kappa\ \mathsf{OK}}{\underline{\Delta, \mathrm{u}{::}\kappa};\Phi \vdash \mathsf{OK}}\ \texttt{CWF-Hole}$$

METATHEORY

Lemma 1 (COK). *If $\Delta;\Phi \vdash \mathcal{J}$, then $\Delta;\Phi \vdash \mathsf{OK}$*

Proof. By simultaneous induction on derivations.
No interesting cases. ☐

Lemma 2 (Exchange).
If $\Delta;\Phi_1, t_{L1}{::}\kappa_{L1}, t_{L2}{::}\kappa_{L2}, \Phi_2 \vdash \mathcal{J}$ and $\Delta;\Phi_1, t_{L2}{::}\kappa_{L2}, t_{L1}{::}\kappa_{L1}, \Phi_2 \vdash \mathsf{OK}$, then $\Delta;\Phi_1, t_{L2}{::}\kappa_{L2}, t_{L1}{::}\kappa_{L1}, \Phi_2 \vdash \mathcal{J}$

Proof. By induction on derivations.
No interesting cases.
(Only rules with Φ extended in the consequent are interesting, which is only CWF-TypVar, but when $\mathcal{J}$ is CWF, Exchange is identity) ☐

Corollary 3 (Marked-Exchange).
If $\Delta;\underline{\underline{\Phi, t_{L1}{::}\kappa_{L1}}, t_{L2}{::}\kappa_{L2}} \vdash \mathcal{J}$ and $\Delta;\underline{\underline{\Phi, t_{L2}{::}\kappa_{L2}}, t_{L1}{::}\kappa_{L1}} \vdash \mathsf{OK}$, then $\Delta;\underline{\underline{\Phi, t_{L2}{::}\kappa_{L2}}, t_{L1}{::}\kappa_{L1}} \vdash \mathcal{J}$

Lemma 4 (Weakening).
If $\Delta;\Phi \vdash \mathcal{J}$ and $\Delta;\underline{\Phi, t_L{::}\kappa_L} \vdash \mathsf{OK}$, then $\Delta;\underline{\Phi, t_L{::}\kappa_L} \vdash \mathcal{J}$

Lemma 5 (OK-PK). *If $\Delta;\Phi \vdash \tau ::> \kappa$, then $\Delta;\Phi \vdash \kappa\ \mathsf{OK}$*

Lemma 6 (OK-WFaK). *If $\Delta;\Phi \vdash \tau{::}\kappa$, then $\Delta;\Phi \vdash \kappa\ \mathsf{OK}$*

Lemma 7 (OK-MatchPi)**.** *If* $\Delta;\Phi \vdash \kappa \overset{\blacktriangleright}{\Pi} \Pi_{t::\kappa_1}.\kappa_2$*, then* $\Delta;\Phi \vdash \kappa$ *OK and* $\Delta;\Phi \vdash \Pi_{t::\kappa_1}.\kappa_2$ *OK*

Lemma 8 (OK-KEquiv)**.** *If* $\Delta;\Phi \vdash \kappa_1 \equiv \kappa_2$*, then* $\Delta;\Phi \vdash \kappa_1$ *OK and* $\Delta;\Phi \vdash \kappa_2$ *OK*

Lemma 9 (OK-CSK)**.** *If* $\Delta;\Phi \vdash \kappa_1 \lesssim \kappa_2$*, then* $\Delta;\Phi \vdash \kappa_1$ *OK and* $\Delta;\Phi \vdash \kappa_2$ *OK*

Lemma 10 (OK-EquivAK)**.** *If* $\Delta;\Phi \vdash \tau_1 \overset{\kappa}{\equiv} \tau_2$*, then* $\Delta;\Phi \vdash \tau_1::\kappa$ *and* $\Delta;\Phi \vdash \tau_2::\kappa$ *and* $\Delta;\Phi \vdash \kappa$ *OK*

Lemma 11 (OK-Substitution)**.**
If $\Delta;\Phi \vdash \tau_L::\kappa_{L1}$ *and* $\Delta;\Phi, t_L::\kappa_{L1} \vdash \kappa_{L2}$ *OK, then* $\Delta;\Phi \vdash [\tau_L/t_L]\kappa_{L2}$ *OK*
(induction on $\Delta;\Phi, t_L::\kappa_{L1} \vdash \kappa_{L2}$ *OK)*

Lemma 12 (K-Substitution)**.**
If $\Delta;\Phi \vdash \tau_{L1}::\kappa_{L1}$ *and* $\Delta;\Phi, t_L::\kappa_{L1} \vdash \tau_{L2}::\kappa_{L2}$*, then* $\Delta;\Phi \vdash [\tau_{L1}/t_L]\tau_{L2}::[\tau_{L1}/t_L]\kappa_{L2}$
(induction on $\Delta;\Phi, t_L::\kappa_{L1} \vdash \tau_{L2}::\kappa_{L2}$*)*

Proof. By simultaneous induction on derivations.
The interesting cases per lemma:

Weakening

$$
\dfrac{
  \dfrac{
    \dfrac{}{\Delta; \underline{\Phi, t{::}\kappa_1} \vdash \tau ::> \kappa_2}\;\texttt{premiss}
    \qquad
    \dfrac{
      \dfrac{
        \dfrac{
          \dfrac{}{\Delta; \underline{\Phi, t_L{::}\kappa_L} \vdash \mathsf{OK}}\;\texttt{IH}
        }{\Delta; \Phi \vdash \kappa_L\ \mathsf{OK}}\;\texttt{premiss of subderivation}
        \qquad
        \dfrac{
          \dfrac{}{\Delta; \underline{\Phi, t{::}\kappa_1} \vdash \tau ::> \kappa_2}\;\texttt{premiss}
        }{\Delta; \underline{\Phi, t{::}\kappa_1} \vdash \mathsf{OK}}\;\texttt{COK}
      }{\Delta; \underline{\Phi, t{::}\kappa_1} \vdash \kappa_L\ \mathsf{OK}}\;\texttt{Weakening}
      \qquad
      \dfrac{}{t_L \notin \underline{\Phi, t{::}\kappa_1}}
    }{\Delta; \underline{\underline{\Phi, t{::}\kappa_1}, t_L{::}\kappa_L} \vdash \mathsf{OK}}\;\texttt{CWF-TypVar}
  }{\Delta; \underline{\underline{\Phi, t{::}\kappa_1}, t_L{::}\kappa_L} \vdash \tau ::> \kappa_2}\;\texttt{Weakening}
  \qquad
  \dfrac{}{\Delta; \underline{\underline{\Phi, t_L{::}\kappa_L}, t{::}\kappa_1} \vdash \mathsf{OK}}\;\texttt{CWF-TypVar}
}{
  \dfrac{\Delta; \underline{\underline{\Phi, t_L{::}\kappa_L}, t{::}\kappa_1} \vdash \tau ::> \kappa_2}{\Delta; \underline{\Phi, t_L{::}\kappa_L} \vdash \lambda t{::}\kappa_1.\tau ::> \mathtt{S}_{\Pi_{t::\kappa_1}.\kappa_2}(\lambda t{::}\kappa_1.\tau)}\;\texttt{PK-}\lambda
}\;\texttt{Marked-Exchange}
$$

Weakening.		$\Delta; \Phi \vdash \kappa_1$ OK	by subderivation premiss
		$\Delta; \underline{\Phi, t_L::\kappa_L} \vdash$ OK	by IH
		$\Delta; \underline{\Phi, t_L::\kappa_L} \vdash \kappa_1$ OK	by Weakening on subderivation premiss
		$\Delta; \underline{\underline{\Phi, t_L::\kappa_L}, t::\kappa_1} \vdash$ OK	by CWF-TypVar
		$\Delta; \underline{\underline{\Phi, t::\kappa_1}, t_L::\kappa_L} \vdash$ OK	by ?
		$\Delta; \underline{\underline{\Phi, t::\kappa_1}, t_L::\kappa_L} \vdash \tau ::> \kappa_2$	by Weakening on premiss
		$\Delta; \underline{\underline{\Phi, t_L::\kappa_L}, t::\kappa_1} \vdash \tau ::> \kappa_2$	by Marked-Exchange
		$\Delta; \underline{\Phi, t_L::\kappa_L} \vdash \lambda t::\kappa_1.\tau ::> \mathsf{S}_{\Pi_{t::\kappa_1}.\kappa_2}(\lambda t::\kappa_1.\tau)$	by PK-λ
OK-PK.	PK-Base	$\Delta; \Phi \vdash \mathtt{bse}::\mathsf{S}_{\mathtt{Type}}(\mathtt{bse})$	by (9)
		$\Delta; \Phi \vdash \mathtt{bse}::\mathtt{Type}$	by (10)
	*	$\Delta; \Phi \vdash \mathsf{S}_{\mathtt{Type}}(\mathtt{bse})$ OK	by (43)
	*	$\Delta; \Phi \vdash$ OK	by premiss
	PK-Ap		bad
OK-WFaK.	(12)	$\Delta; \Phi \vdash \tau_2::\kappa$	by (10)
	*	$\Delta; \Phi \vdash \mathsf{S}_\kappa(\tau_2)$ OK	by (43)
OK-KEquiv.	(22)	$\Delta; \Phi \vdash \tau\ t ::> \kappa$	
OK-Substitution.	(41)	$\Delta; \Phi, t_L::\kappa_{L1} \vdash$ OK	premiss (41)
		$\Delta; \Phi \vdash \kappa_{L1}$ OK	by subderivation premiss (46)
	*	$\Delta; \Phi \vdash$ OK	by OK-KWF
	*	$\Delta; \Phi \vdash [\tau_L/t_L]\mathtt{Type}$ OK	by (41) and degenerate subst
	(43)	$\Delta; \Phi, t_L::\kappa_{L1} \vdash \tau::\kappa$	premiss (43)
		$\Delta; \Phi, t_L::\kappa_{L1} \vdash$ OK	by OK-WFaK
		$\Delta; \Phi \vdash \kappa_{L1}$ OK	by subderivation premiss (46)
	*	$\Delta; \Phi \vdash$ OK	by OK-KWF
		$\Delta; \Phi \vdash [\tau_{L1}/t_L]\tau::[\tau_{L1}/t_L]\kappa$	by K-Substitution on premiss
	*	$\Delta; \Phi \vdash [\tau_L/t_L]\mathsf{S}_\kappa(\tau)$ OK	by (43)

□

Lemma 13 (PK-Unicity). *If $\Delta; \Phi \vdash \tau_L ::> \kappa_{L1}$ and $\Delta; \Phi \vdash \tau_L ::> \kappa_{L2}$ then κ_{L1} is κ_{L2}*

Lemma 14. *If $\Delta; \Phi \vdash \tau ::> \kappa_1$ and $\Delta; \Phi \vdash \tau::\kappa_2$, then $\Delta; \Phi \vdash \kappa_1 \lesssim \kappa_2$*

Lemma 15. *If $\Delta; \Phi \vdash \kappa_1 \lesssim \mathsf{S}_{\kappa_2}(\tau)$, then $\Delta; \Phi \vdash \kappa_1 \lesssim \kappa_2$*