Online Appendix to "Selecting the Relevant Variables for Factor Estimation in FAVAR Models"

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Abstract

This Online Appendix contains additional supporting lemmas whose results are used in the proofs of Theorems 1 and 2 of the main paper as well as Lemmas A1-A2 of that paper.

Additional Supporting Lemmas and Their Proofs

In this Online Appendix, we state and prove a number of additional supporting lemmas. The results given by these lemmas are used to prove Theorems 1 and 2 as well as Lemmas A1-A2 of the main paper and, thus, help to deliver the main results of the paper.

Lemma OA-1: Let a and θ be real numbers such that $a > 0$ and $\theta \geq 1$. Also, let G be a finite non-negative integer. Then,

$$\sum_{m=1}^{\infty} m^G \exp\left\{-am^\theta\right\} < \infty$$

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Proof of Lemma OA-1: By the integral test,

$$\sum_{m=1}^{\infty} m^G \exp\left\{-am^\theta\right\} < \infty \text{ for finite non-negative integer } G$$

if

$$\int_1^{\infty} x^G \exp\left\{-ax^\theta\right\} dx < \infty \text{ for finite non-negative integer } G$$

In addition, note that since, by assumption, $a > 0$ and $\theta \geq 1$, we have

$$\int_1^{\infty} x^G \exp\left\{-ax^\theta\right\} dx \leq \int_1^{\infty} x^G \exp\left\{-ax\right\} dx$$

We will first consider the case where $G = 0$. In this case, note that

$$\int_1^{\infty} x^0 \exp\left\{-ax\right\} dx = \int_1^{\infty} \exp\left\{-ax\right\} dx$$

Let $u = -ax$, so that $-\frac{du}{a} = dx$; and we have

$$\begin{aligned} \int_1^{\infty} \exp\left\{-ax\right\} dx &= -\frac{1}{a}\int_{-a}^{-\infty} \exp\left\{u\right\} du \\ &= \frac{1}{a}\int_{-\infty}^{-a} \exp\left\{u\right\} du \\ &= \frac{\exp\left\{-a\right\}}{a} \\ &< \infty \text{ for any } a > 0. \end{aligned} \tag{1}$$

Next, consider the case where G is an integer such that $G \geq 1$. Here, we will show that

$$\int_1^{\infty} x^G \exp\left\{-ax\right\} dx = \left[\frac{1}{a} + \sum_{k=1}^{G} \frac{1}{a}\left(\prod_{j=0}^{k-1} \frac{G-j}{a}\right)\right] \exp\left\{-a\right\} < \infty$$

using mathematical induction. To proceed, first consider the case where $G = 1$. Let

$$\begin{aligned} u &= x,\ du = dx \\ dv &= \exp\left\{-ax\right\} dx,\ v = -\frac{1}{a}\exp\left\{-ax\right\}; \end{aligned}$$

and making use of integration-by-parts, we have

$$\begin{aligned}
\int_1^\infty x \exp\{-ax\}\, dx &= -\frac{x}{a}\exp\{-ax\}\Big|_1^\infty + \int_1^\infty \frac{1}{a}\exp\{-ax\}\, dx \\
&= \frac{1}{a}\exp\{-a\} - \frac{1}{a^2}\exp\{-ax\}\Big|_1^\infty \\
&= \frac{1}{a}\exp\{-a\} + \frac{1}{a^2}\exp\{-a\} \\
&= \left(\frac{1}{a} + \frac{1}{a^2}\right)\exp\{-a\} \\
&= \left\{\frac{1}{a} + \sum_{k=1}^{1}\frac{1}{a}\left(\prod_{j=0}^{k-1}\frac{1-j}{a}\right)\right\}\exp\{-a\} < \infty
\end{aligned}$$

Next, for $G = 2$, let

$$\begin{aligned}
u &= x^2,\ du = 2xdx \\
dv &= \exp\{-ax\}\, dx,\ v = -\frac{1}{a}\exp\{-ax\};
\end{aligned}$$

and we again make use of integration-by-parts to obtain

$$\begin{aligned}
\int_1^\infty x^2 \exp\{-ax\}\, dx &= -\frac{x^2}{a}\exp\{-ax\}\Big|_1^\infty + \frac{2}{a}\int_1^\infty x\exp\{-ax\}\, dx \\
&= \frac{1}{a}\exp\{-a\} + \frac{2}{a}\left(\frac{1}{a} + \frac{1}{a^2}\right)\exp\{-a\} \\
&= \frac{1}{a}\exp\{-a\} + 2\left(\frac{1}{a^2} + \frac{1}{a^3}\right)\exp\{-a\} \\
&= \left(\frac{1}{a} + \frac{2}{a^2} + \frac{2}{a^3}\right)\exp\{-a\} \\
&= \left[\frac{1}{a} + \sum_{k=1}^{2}\frac{1}{a}\left(\prod_{j=0}^{k-1}\frac{2-j}{a}\right)\right]\exp\{-a\} \\
&< \infty
\end{aligned}$$

Now, suppose that, for some $G \geq 2$,

$$\int_1^\infty x^{G-1}\exp\{-ax\}\, dx = \left[\frac{1}{a} + \sum_{k=1}^{G-1}\frac{1}{a}\left(\prod_{j=0}^{k-1}\frac{G-1-j}{a}\right)\right]\exp\{-a\};$$

then, let

$$\begin{aligned} u &= x^{G},\ du = Gx^{G-1}dx \\ dv &= \exp\{-ax\}\,dx,\ v = -\frac{1}{a}\exp\{-ax\}\,; \end{aligned}$$

and, using integration-by-parts, we have

$$\begin{aligned} \int_1^\infty x^G \exp\{-ax\}\,dx &= -\frac{x^G}{a}\exp\{-ax\}\Big|_1^\infty + \frac{G}{a}\int_1^\infty x^{G-1}\exp\{-ax\}\,dx \\ &= \frac{1}{a}\exp\{-a\} + \frac{G}{a}\left[\frac{1}{a} + \sum_{k=1}^{G-1}\frac{1}{a}\left(\prod_{j=0}^{k-1}\frac{G-1-j}{a}\right)\right]\exp\{-a\} \\ &= \frac{1}{a}\exp\{-a\} + \left[\frac{G}{a^2} + \sum_{k=1}^{G-1}\frac{1}{a}\frac{G}{a}\left(\prod_{j=0}^{k-1}\frac{G-(j+1)}{a}\right)\right]\exp\{-a\} \\ &= \left\{\frac{1}{a} + \frac{G}{a^2} + \frac{1}{a}\frac{G}{a}\left(\frac{G-1}{a}\right) + \frac{1}{a}\frac{G}{a}\left(\frac{G-1}{a}\right)\left(\frac{G-2}{a}\right)\right. \\ &\quad \left. + \cdots + \frac{1}{a}\frac{G}{a}\left(\frac{G-1}{a}\right)\left(\frac{G-2}{a}\right)\times\cdots\times\left(\frac{1}{a}\right)\right\}\exp\{-a\} \\ &= \left\{\frac{1}{a} + \sum_{k=1}^{G}\frac{1}{a}\left(\prod_{j=0}^{k-1}\frac{G-j}{a}\right)\right\}\exp\{-a\} \\ &< \infty. \end{aligned} \tag{2}$$

In view of expressions (1) and (2), it then follows by the integral test for series convergence that

$$\sum_{m=1}^{\infty} m^G \exp\left\{-am^\theta\right\} < \infty$$

for any finite non-negative integer G and for any constants a and θ such that $a > 0$ and $\theta \geq 1$. $\square$

Lemma OA-2: Let $\{V_t\}$ be a sequence of random variables (or random vectors) defined on some probability space $(\Omega, \mathcal{F}, P)$, and let

$$X_t = g\left(V_t, V_{t-1}, ..., V_{t-\varkappa}\right)$$

be a measurable function for some finite positive integer $\varkappa$. In addition, defne $\mathcal{G}_{-\infty}^{t} = \sigma\left(...., X_{t-1}, X_t\right)$, $\mathcal{G}_{t+m}^{\infty} = \sigma\left(X_{t+m}, X_{t+m+1}, ...\right)$, $\mathcal{F}_{-\infty}^{t} = \sigma\left(...., V_{t-1}, V_t\right)$, and $\mathcal{F}_{t+m-\varkappa}^{\infty} = \sigma\left(V_{t+m-\varkappa}, V_{t+m+1-\varkappa}, ...\right)$. Under this setting, the following results hold.

(a) Let

$$\begin{aligned}\beta_{V,m-\varkappa} &= \sup_t \beta\left(\mathcal{F}_{-\infty}^t, \mathcal{F}_{t+m-\varkappa}^{\infty}\right) = \sup_t E\left[\sup\left\{\left|P\left(B|\mathcal{F}_{-\infty}^t\right) - P\left(B\right)\right| : B \in \mathcal{F}_{t+m-\varkappa}^{\infty}\right\}\right],\\ \beta_{X,m} &= \sup_t \beta\left(\mathcal{G}_{-\infty}^t, \mathcal{G}_{t+m}^{\infty}\right) = \sup_t E\left[\sup\left\{\left|P\left(H|\mathcal{G}_{-\infty}^t\right) - P\left(H\right)\right| : H \in \mathcal{G}_{t+m}^{\infty}\right\}\right].\end{aligned}$$

If $\{V_t\}$ is β-mixing with

$$\beta_{V,m-\varkappa} \leq \overline{C}_1 \exp\left\{-C_2\left(m-\varkappa\right)\right\}$$

for all $m \geq \varkappa$ and for some positive constants $\overline{C}_1$ and C_2; then X_t is also β-mixing with β-mixing coefficient satisfying

$$\beta_{X,m} \leq C_1 \exp\left\{-C_2 m\right\} \text{ for all } m \geq \varkappa,$$

where C_1 is a positive constant such that $C_1 \geq \overline{C}_1 \exp\left\{C_2 \varkappa\right\}$.

(b) Let

$$\begin{aligned}\alpha_{V,m-\varkappa} &= \sup_t \alpha\left(\mathcal{F}_{-\infty}^t, \mathcal{F}_{t+m-\varkappa}^{\infty}\right) = \sup_t \sup_{G\in\mathcal{F}_{-\infty}^t, H\in\mathcal{F}_{t+m-\varkappa}^{\infty}} \left|P\left(G\cap H\right) - P\left(G\right)P\left(H\right)\right|,\\ \alpha_{X,m} &= \sup_t \alpha\left(\mathcal{G}_{-\infty}^t, \mathcal{G}_{t+m}^{\infty}\right) = \sup_t \sup_{G\in\mathcal{G}_{-\infty}^t, H\in\mathcal{G}_{t+m}^{\infty}} \left|P\left(G\cap H\right) - P\left(G\right)P\left(H\right)\right|\end{aligned}$$

If $\{V_t\}$ is α-mixing with

$$\alpha_{V,m-\varkappa} \leq \overline{C}_1 \exp\left\{-C_2\left(m-\varkappa\right)\right\}$$

for all $m \geq \varkappa$ and for some positive constants $\overline{C}_1$ and C_2; then X_t is also α-mixing with α-mixing coefficient satisfying

$$\alpha_{X,m} \leq C_1 \exp\left\{-C_2 m\right\} \text{ for all } m \geq \varkappa,$$

where C_1 is a positive constant such that $C_1 \geq \overline{C}_1 \exp\left\{C_2 \varkappa\right\}$.

Proof of Lemma OA-2:

To show part (a), note first that it is well known that

$$\begin{aligned}\beta_{X,m} &= \sup_t E\left[\sup\left\{\left|P\left(H|\mathcal{G}_{-\infty}^t\right) - P\left(H\right)\right| : H \in \mathcal{G}_{t+m}^{\infty}\right\}\right]\\ &= \sup_t \left\{\frac{1}{2}\sup \sum_{i=1}^{I}\sum_{j=1}^{J}\left|P\left(G_i\cap H_j\right) - P\left(G_i\right)P\left(H_j\right)\right|\right\}\end{aligned}$$

where the second supremum on the last line above is taken over all pairs of finite partitions $\{G_1, ..., G_I\}$ and $\{H_1, ..., H_J\}$ of Ω such that $G_i \in \mathcal{G}_{-\infty}^t$ for $i = 1, ..., I$ and $H_j \in \mathcal{G}_{t+m}^{\infty}$ for

$j = 1, ..., J$. See, for example, Borovkova, Burton, and Dehling (2001). Similarly,

$$\begin{aligned}
\beta_{V,m-\varkappa} &= \sup_t E\left[\sup\left\{\left|P\left(B|\mathcal{F}_{-\infty}^{t}\right) - P\left(B\right)\right| : B \in \mathcal{F}_{t+m-\varkappa}^{\infty}\right\}\right] \\
&= \sup_t \left\{\frac{1}{2}\sup\sum_{i=1}^{L}\sum_{j=1}^{M}\left|P\left(A_i \cap B_j\right) - P\left(A_i\right)P\left(B_j\right)\right|\right\}
\end{aligned}$$

where, similar to the definition of $\beta_{X,m}$, the second supremum on the last line above is taken over all pairs of finite partitions $\{A_1, ..., A_L\}$ and $\{B_1, ..., B_M\}$ of Ω such that $A_i \in \mathcal{F}_{-\infty}^{t}$ for $i = 1, ..., I$ and $B_j \in \mathcal{F}_{t+m-\varkappa}^{\infty}$ for $j = 1, ..., M$. Moreover, since X_t is measurable on any σ-field on which $V_t, V_{t-1}, ..., V_{t-\varkappa}$ are measurable, we also have

$$\mathcal{G}_{-\infty}^{t} = \sigma\left(...., X_{t-1}, X_t\right) \subseteq \sigma\left(...., V_{t-1}, V_t\right) = \mathcal{F}_{-\infty}^{t}$$

and

$$\mathcal{G}_{t+m}^{\infty} = \sigma\left(X_{t+m}, X_{t+m+1}, ...\right) \subseteq \sigma\left(V_{t+m-\varkappa}, V_{t+m+1-\varkappa}, ...\right) = \mathcal{F}_{t+m-\varkappa}^{\infty}.$$

It, thus, follows that, for all $m \geq \varkappa$,

$$\begin{aligned}
\beta_{X,m} &= \sup_t \left\{\frac{1}{2}\sup\sum_{i=1}^{I}\sum_{j=1}^{J}\left|P\left(G_i \cap H_j\right) - P\left(G_i\right)P\left(H_j\right)\right|\right\} \\
&\leq \sup_t \left\{\frac{1}{2}\sup\sum_{i=1}^{L}\sum_{j=1}^{M}\left|P\left(A_i \cap B_j\right) - P\left(A_i\right)P\left(B_j\right)\right|\right\} \\
&= \beta_{V,m-\varkappa} \\
&\leq \overline{C}_1 \exp\left\{-C_2\left(m - \varkappa\right)\right\} \\
&= \overline{C}_1 \exp\left\{C_2\varkappa\right\}\exp\left\{-C_2 m\right\} \\
&\leq C_1 \exp\left\{-C_2 m\right\}
\end{aligned}$$

for some positive constant $C_1 \geq \overline{C}_1 \exp\{C_2\varkappa\}$ which exists given that $\varkappa$ is fixed. Moreover, we have

$$\beta_{X,m} \leq C_1 \exp\left\{-C_2 m\right\} \to 0 \text{ as } m \to \infty,$$

which establishes the required result for part (a).

Part (b) can be shown in a manner similar to part (a), so to avoid redundancy, we do not include an explicit proof here. □

Remark: Note that part (b) of Lemma OA-2 is similar to a result given in Theorem 14.1 of Davidson (1994) but adapted to suit our situation and our notatons here. Indeed, parts (a) and (b) of this lemma are both well-known results in the probability literature. We have chosen to state these results explicitly here only so that we can more easily refer to them in the proofs of some of our other results.

Lemma OA-3: Let $\{X_t\}$ be a sequence of random variables that is α-mixing. Let $p > 1$

and $r \geq p/(p-1)$, and let $q = \max\{p, r\}$. Suppose that, for all t,

$$\|X_t\|_q = \left(E|X_t|^q\right)^{\frac{1}{q}} < \infty$$

Then,

$$|Cov(X_t, X_{t+m})| \leq 2\left(2^{1-1/p}+1\right)\alpha_m^{1-1/p-1/r}\|X_t\|_p\|X_{t+m}\|_r$$

where

$$\alpha_m = \sup_t \alpha\left(\mathcal{F}_{-\infty}^t, \mathcal{F}_{t+m}^\infty\right) = \sup_{G \in \mathcal{F}_{-\infty}^t, H \in \mathcal{F}_{t+m}^\infty} |P(G \cap H) - P(G)P(H)|.$$

Remark: This is Corollary 14.3 of Davidson (1994). For a proof, see pages 212-213 of Davidson (1994).

Lemma OA-4: Suppose that Assumption 2-3 hold. Let $\tau_1 = \lfloor T_0^{\alpha_1} \rfloor$, where $1 > \alpha_1 > 0$ and $T_0 = T - p + 1$. Then,

(a)

$$\frac{1}{\tau_1^2}\sum_{\substack{g,h=(r-1)\tau+p \\ g \leq h}}^{(r-1)\tau+\tau_1+p-1} |E[u_{ig}u_{ih}]| = O\left(\frac{1}{\tau_1}\right)$$

(b)

$$\frac{1}{\tau_1^3}\sum_{\substack{h,v,w=(r-1)\tau+p \\ h \leq v \leq w}}^{(r-1)\tau+\tau_1+p-1} |E(u_{ih}u_{iv}u_{iw})| = O\left(\frac{1}{\tau_1^2}\right)$$

(c)

$$\frac{1}{\tau_1^4}\sum_{\substack{g,h,v,w=(r-1)\tau+p \\ g \leq h \leq v \leq w}}^{(r-1)\tau+\tau_1+p-1} |E[u_{ig}u_{ih}u_{iv}u_{iw}]| = O\left(\frac{1}{\tau_1^2}\right)$$

Proof of Lemma OA-4:

To show part (a), first write

$$\frac{1}{\tau_1^2}\sum_{\substack{g,h=(r-1)\tau+p \\ g \leq h}}^{(r-1)\tau+\tau_1+p-1} |E[u_{ig}u_{ih}]| = \frac{1}{\tau_1^2}\sum_{g=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1} E\left[u_{ig}^2\right] + \frac{1}{\tau_1^2}\sum_{\substack{g,h=(r-1)\tau+p \\ g < h}}^{(r-1)\tau+\tau_1+p-1} |E[u_{ig}u_{ih}]| \quad (3)$$

Consider now the first term on the right-hand side of expression (3). Note that, trivially, by Assumption 2-3(b), there exists a positive constant C such that

$$\frac{1}{\tau_1^2}\sum_{g=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1} E\left[u_{ig}^2\right] \leq \frac{C}{\tau_1} = O\left(\frac{1}{\tau_1}\right) \quad (4)$$

For the second term on the right-hand side of expression (3), note that by Assumption 2-3(c), $\{u_{it}\}_{t=-\infty}^{\infty}$ is β-mixing with β mixing coefficient satisfying

$$\beta_i\left(m\right) \leq a_1 \exp\left\{-a_2 m\right\}.$$

for every i. Since $\alpha_{i,m} \leq \beta_i\left(m\right)$, it follows that $\{u_{it}\}_{t=-\infty}^{\infty}$ is α-mixing as well, with α mixing coefficient satisfying

$$\alpha_{i,m} \leq a_1 \exp\left\{-a_2 m\right\} \text{ for every } i.$$

Hence, in this case, we can apply Lemma OA-3 with $p = 6$ and $r = 5/4$ to obtain

$$\begin{aligned}
& \frac{1}{\tau_1^2} \sum_{\substack{g,h=(r-1)\tau+p \\ g<h}}^{(r-1)\tau+\tau_1+p-1} \left|E\left[u_{ig}u_{ih}\right]\right| \\
\leq\; & \frac{1}{\tau_1^2} \sum_{\substack{g,h=(r-1)\tau+p \\ g<h}}^{(r-1)\tau+\tau_1+p-1} 2\left(2^{1-\frac{1}{6}}+1\right)\left[a_1 \exp\left\{-a_2\left(h-g\right)\right\}\right]^{1-\frac{1}{6}-\frac{4}{5}} \left(E\left|u_{ig}\right|^6\right)^{\frac{1}{6}} \left(E\left|u_{ih}\right|^{\frac{5}{4}}\right)^{\frac{4}{5}}
\end{aligned}$$

Next, by application of Liapunov's inequality, we have that there exists some positive constant $\overline{C}$ such that

$$\begin{aligned}
\left(E\left|u_{ig}\right|^6\right)^{\frac{1}{6}} \left(E\left|u_{ih}\right|^{\frac{5}{4}}\right)^{\frac{4}{5}} &\leq \left(E\left|u_{ig}\right|^6\right)^{\frac{1}{6}} \left(E\left|u_{ih}\right|^6\right)^{\frac{1}{6}} \\
&\leq \left(\sup_t E\left|u_{it}\right|^6\right)^{\frac{1}{3}} \\
&= \overline{C}^{\frac{1}{3}} < \infty \quad \text{(by Assumption 2-3(b))}
\end{aligned}$$

Moreover, let $\varrho = h - g$, so that $h = g + \varrho$. Using these notations and the boundedness of

$\left(E\left|u_{ig}\right|^{6}\right)^{\frac{1}{6}}\left(E\left|u_{ih}\right|^{\frac{5}{4}}\right)^{\frac{4}{5}}$ as shown above, we can further write

$$\begin{aligned}
& \frac{1}{\tau_1^2}\sum_{\substack{g,h=(r-1)\tau+p\\ g<h}}^{(r-1)\tau+\tau_1+p-1}\left|E\left[u_{ig}u_{ih}\right]\right| \\
& \frac{1}{\tau_1^2}\sum_{\substack{g,h=(r-1)\tau+p\\ g<h}}^{(r-1)\tau+\tau_1+p-1} 2\left(2^{1-\frac{1}{6}}+1\right)\left[a_1\exp\left\{-a_2\left(h-g\right)\right\}\right]^{1-\frac{1}{6}-\frac{4}{5}}\left(E\left|u_{ig}\right|^{6}\right)^{\frac{1}{6}}\left(E\left|u_{ih}\right|^{\frac{5}{4}}\right)^{\frac{4}{5}} \\
\leq\ & \frac{\overline{C}^{\frac{1}{3}}}{\tau_1^2}\sum_{\substack{g,h=(r-1)\tau+p\\ g<h}}^{(r-1)\tau+\tau_1+p-1} 2\left(2^{\frac{5}{6}}+1\right)\left[a_1\exp\left\{-a_2\left(h-g\right)\right\}\right]^{\frac{1}{30}} \\
\leq\ & \frac{C^*}{\tau_1^2}\sum_{\substack{g,h=(r-1)\tau+p\\ g<h}}^{(r-1)\tau+\tau_1+p-1}\exp\left\{-\frac{a_2}{30}\varrho\right\} \\
& \left(\text{for some constant } C^* \text{ such that } 2\left(2^{\frac{5}{6}}+1\right)\overline{C}^{\frac{1}{3}}a_1^{\frac{1}{30}}\leq C^*<\infty\right) \\
\leq\ & \frac{C^*}{\tau_1^2}\sum_{g=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\ \sum_{\varrho=1}^{\infty}\exp\left\{-\frac{a_2}{30}\varrho\right\} \\
=\ & \frac{C^*}{\tau_1}\sum_{\varrho=1}^{\infty}\exp\left\{-\frac{a_2}{30}\varrho\right\} \\
=\ & O\left(\frac{1}{\tau_1}\right)\quad\text{(given Lemma OA-1)}
\end{aligned}\tag{5}$$

It follows from expressions (3), (4), and (5) that

$$\begin{aligned}
\frac{1}{\tau_1^2}\sum_{\substack{g,h=(r-1)\tau+p\\ g\leq h}}^{(r-1)\tau+\tau_1+p-1}\left|E\left[u_{ig}u_{ih}\right]\right| &= \frac{1}{\tau_1^2}\sum_{g=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}E\left[u_{ig}^2\right]+\frac{1}{\tau_1^2}\sum_{\substack{g,h=(r-1)\tau+p\\ g<h}}^{(r-1)\tau+\tau_1+p-1}\left|E\left[u_{ig}u_{ih}\right]\right| \\
&= O\left(\frac{1}{\tau_1}\right)+O\left(\frac{1}{\tau_1}\right) \\
&= O\left(\frac{1}{\tau_1}\right).
\end{aligned}$$

To show part (b), first write

$$\begin{aligned}\frac{1}{\tau_1^3}\sum_{\substack{h,v,w=(r-1)\tau+p\\ h\leq v\leq w}}^{(r-1)\tau+\tau_1+p-1}\left|E\left(u_{ih}u_{iv}u_{iw}\right)\right| &= \frac{1}{\tau_1^3}\sum_{h=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}E\left|u_{ih}\right|^3+\frac{1}{\tau_1^3}\sum_{\substack{h,v,w=(r-1)\tau+p\\ h\leq v\leq w\\ v-h>w-v,\ v-h>0}}^{(r-1)\tau+\tau_1+p-1}\left|E\left(u_{ih}u_{iv}u_{iw}\right)\right| \\ &\quad +\frac{1}{\tau_1^3}\sum_{\substack{h,v,w=(r-1)\tau+p\\ h\leq v\leq w\\ w-v\geq v-h,\ w-v>0}}^{(r-1)\tau+\tau_1+p-1}\left|E\left(u_{ih}u_{iv}u_{iw}\right)\right| \qquad (6)\end{aligned}$$

For the first term on the right-hand side of expression (6) above, note that, trivially, we can apply Assumption 2-3(b) to obtain

$$\frac{1}{\tau_1^3}\sum_{h=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}E\left|u_{ih}\right|^3\leq\frac{C}{\tau_1^2}=O\left(\frac{1}{\tau_1^2}\right). \qquad (7)$$

Next, for the second term on the right-hand side of expression (6) above, we can apply Lemma OA-3 with $p=6$ and $r=5/4$ to obtain

$$\begin{aligned}&\frac{1}{\tau_1^3}\sum_{\substack{h,v,w=(r-1)\tau+p\\ h\leq v\leq w\\ v-h>w-v,\ v-h>0}}^{(r-1)\tau+\tau_1+p-1}\left|E\left(u_{ih}u_{iv}u_{iw}\right)\right| \\ \leq\ &\frac{1}{\tau_1^3}\sum_{\substack{h,v,w=(r-1)\tau+p\\ h\leq v\leq w\\ v-h>w-v,\ v-h>0}}^{(r-1)\tau+\tau_1+p-1}2\left(2^{1-\frac{1}{6}}+1\right)\left[a_1\exp\left\{-a_2\left(v-h\right)\right\}\right]^{1-\frac{1}{6}-\frac{4}{5}}\left(E\left|u_{ih}\right|^6\right)^{\frac{1}{6}}\left(E\left|u_{iv}u_{iw}\right|^{\frac{5}{4}}\right)^{\frac{4}{5}}\end{aligned}$$

Next, by application of Hölder's inequality, we have

$$\begin{aligned}\left(E\left|u_{ih}\right|^6\right)^{\frac{1}{6}}\left(E\left|u_{iv}u_{iw}\right|^{\frac{5}{4}}\right)^{\frac{4}{5}} &\leq \left(E\left|u_{ih}\right|^6\right)^{\frac{1}{6}}\left(\left(E\left|u_{iv}\right|^{\frac{5}{2}}\right)^{\frac{1}{2}}\left(E\left|u_{iw}\right|^{\frac{5}{2}}\right)^{\frac{1}{2}}\right)^{\frac{4}{5}} \\ &= \left(E\left|u_{ih}\right|^6\right)^{\frac{1}{6}}\left(E\left|u_{iv}\right|^{\frac{5}{2}}\right)^{\frac{2}{5}}\left(E\left|u_{iw}\right|^{\frac{5}{2}}\right)^{\frac{2}{5}} \\ &\leq \left(E\left|u_{ih}\right|^6\right)^{\frac{1}{6}}\left(E\left|u_{iv}\right|^6\right)^{\frac{1}{6}}\left(E\left|u_{iw}\right|^6\right)^{\frac{1}{6}} \\ &\quad \text{(by Liapunov's inequality)} \\ &= \overline{C}^{\frac{1}{2}}<\infty\ \text{ (by Assumption 2-3(b))}\end{aligned}$$

Moreover, let $\varrho_1=v-h$ and $\varrho_2=w-v$, so that $v=h+\varrho_1$ and $w=v+\ \varrho_2=h+\varrho_1+\ \varrho_2$.

Using these notations and the boundedness of $\left(E\left|u_{ih}\right|^{6}\right)^{\frac{1}{6}}\left(E\left|u_{iv}u_{iw}\right|^{\frac{5}{4}}\right)^{\frac{4}{5}}$ as shown above, we can further write

$$
\begin{aligned}
& \frac{1}{\tau_1^3}\sum_{\substack{h,v,w=(r-1)\tau+p\\ h\leq v\leq w\\ v-h>w-v,\ v-h>0}}^{(r-1)\tau+\tau_1+p-1}\left|E\left(u_{ih}u_{iv}u_{iw}\right)\right| \\
\leq\ & \frac{1}{\tau_1^3}\sum_{\substack{h,v,w=(r-1)\tau+p\\ h\leq v\leq w\\ v-h>w-v,\ v-h>0}}^{(r-1)\tau+\tau_1+p-1} 2\left(2^{1-\frac{1}{6}}+1\right)\left[a_1\exp\left\{-a_2\left(v-h\right)\right\}\right]^{1-\frac{1}{6}-\frac{4}{5}}\left(E\left|u_{ih}\right|^{6}\right)^{\frac{1}{6}}\left(E\left|u_{iv}u_{iw}\right|^{\frac{5}{4}}\right)^{\frac{4}{5}} \\
\leq\ & \frac{\overline{C}^{\frac{1}{2}}}{\tau_1^3}\sum_{\substack{h,v,w=(r-1)\tau+p\\ h\leq v\leq w\\ v-h>w-v,\ v-h>0}}^{(r-1)\tau+\tau_1+p-1} 2\left(2^{\frac{5}{6}}+1\right)\left[a_1\exp\left\{-a_2\left(v-h\right)\right\}\right]^{\frac{1}{30}} \\
\leq\ & \frac{C^*}{\tau_1^3}\sum_{\substack{h,v,w=(r-1)\tau+p\\ h\leq v\leq w\\ v-h>w-v,\ v-h>0}}^{(r-1)\tau+\tau_1+p-1}\exp\left\{-\frac{a_2}{30}\varrho_1\right\} \\
& \left(\text{for some constant } C^* \text{ such that } 2\left(2^{\frac{5}{6}}+1\right)\overline{C}^{\frac{1}{2}}a_1^{\frac{1}{30}}\leq C^*<\infty\right) \\
\leq\ & \frac{C^*}{\tau_1^3}\sum_{h=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\sum_{\varrho_1=1}^{\infty}\sum_{\varrho_2=0}^{\varrho_1-1}\exp\left\{-\frac{a_2}{30}\varrho_1\right\} \\
\leq\ & \frac{C^*}{\tau_1^3}\sum_{h=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\sum_{\varrho_1=1}^{\infty}\varrho_1\exp\left\{-\frac{a_2}{30}\varrho_1\right\} \\
=\ & \frac{C^*}{\tau_1^2}\sum_{\varrho_1=1}^{\infty}\varrho_1\exp\left\{-\frac{a_2}{30}\varrho_1\right\} \\
=\ & O\left(\frac{1}{\tau_1^2}\right)\quad \text{(given Lemma OA-1)} \qquad (8)
\end{aligned}
$$

Similarly, for the third term on the right-hand side of expression (6), we can apply Lemma

OA-3 with $p = 6$ and $r = 5/4$ to obtain

$$\begin{aligned} & \frac{1}{\tau_1^3} \sum_{\substack{h,v,w=(r-1)\tau+p \\ h \leq v \leq w \\ w-v \geq v-h,\ w-v>0}}^{(r-1)\tau+\tau_1+p-1} \left| E\left(u_{ih} u_{iv} u_{iw}\right) \right| \\ \leq \ & \frac{1}{\tau_1^3} \sum_{\substack{h,v,w=(r-1)\tau+p \\ h \leq v \leq w \\ w-v \geq v-h,\ w-v>0}}^{(r-1)\tau+\tau_1+p-1} 2\left(2^{1-\frac{1}{6}}+1\right)\left[a_1 \exp\left\{-a_2\left(w-v\right)\right\}\right]^{1-\frac{4}{5}-\frac{1}{6}} \left(E\left|u_{ih} u_{iv}\right|^{\frac{5}{4}}\right)^{\frac{4}{5}} \left(E\left|u_{iw}\right|^{6}\right)^{\frac{1}{6}} \end{aligned}$$

Next, by applying Hölder's inequality, we have

$$\begin{aligned} \left(E\left|u_{ih} u_{iv}\right|^{\frac{5}{4}}\right)^{\frac{4}{5}} \left(E\left|u_{iw}\right|^{6}\right)^{\frac{1}{6}} & \leq \left(\left(E\left|u_{ih}\right|^{\frac{5}{2}}\right)^{\frac{1}{2}} \left(E\left|u_{iv}\right|^{\frac{5}{2}}\right)^{\frac{1}{2}}\right)^{\frac{4}{5}} \left(E\left|u_{iw}\right|^{6}\right)^{\frac{1}{6}} \\ & = \left(E\left|u_{ih}\right|^{\frac{5}{2}}\right)^{\frac{2}{5}} \left(E\left|u_{iv}\right|^{\frac{5}{2}}\right)^{\frac{2}{5}} \left(E\left|u_{iw}\right|^{6}\right)^{\frac{1}{6}} \\ & \leq \left(E\left|u_{ih}\right|^{6}\right)^{\frac{1}{6}} \left(E\left|u_{iv}\right|^{6}\right)^{\frac{1}{6}} \left(E\left|u_{iw}\right|^{6}\right)^{\frac{1}{6}} \\ & \quad \text{(by Liapunov's inequality)} \\ & = \overline{C}^{\frac{1}{2}} < \infty \ \text{ (by Assumption 2-3(b))} \end{aligned}$$

Moreover, let $\varrho_1 = v - h$ and $\varrho_2 = w - v$, so that $v = h + \varrho_1$ and $w = v + \varrho_2 = h + \varrho_1 + \varrho_2$. Using these notations and the boundedness of $\left(E\left|u_{ih} u_{iv}\right|^{\frac{5}{4}}\right)^{\frac{4}{5}} \left(E\left|u_{iw}\right|^{6}\right)^{\frac{1}{6}}$ as shown above, we can further write

$$
\begin{aligned}
& \frac{1}{\tau_1^3} \sum_{\substack{h,v,w=(r-1)\tau+p \\ h\leq v\leq w \\ w-v\geq v-h,\ w-v>0}}^{(r-1)\tau+\tau_1+p-1} \left|E\left(u_{ih}u_{iv}u_{iw}\right)\right| \\
\leq\ & \frac{1}{\tau_1^3} \sum_{\substack{h,v,w=(r-1)\tau+p \\ h\leq v\leq w \\ w-v\geq v-h,\ w-v>0}}^{(r-1)\tau+\tau_1+p-1} 2\left(2^{1-\frac{1}{6}}+1\right)\left[a_1\exp\left\{-a_2\left(w-v\right)\right\}\right]^{1-\frac{4}{5}-\frac{1}{6}}\left(E\left|u_{ih}u_{iv}\right|^{\frac{5}{4}}\right)^{\frac{4}{5}}\left(E\left|u_{iw}\right|^{6}\right)^{\frac{1}{6}} \\
\leq\ & \frac{\overline{C}^{\frac{1}{2}}}{\tau_1^3} \sum_{\substack{h,v,w=(r-1)\tau+p \\ h\leq v\leq w \\ w-v\geq v-h,\ w-v>0}}^{(r-1)\tau+\tau_1+p-1} 2\left(2^{\frac{5}{6}}+1\right)\left[a_1\exp\left\{-a_2\left(w-v\right)\right\}\right]^{\frac{1}{30}} \\
\leq\ & \frac{C^*}{\tau_1^3} \sum_{\substack{h,v,w=(r-1)\tau+p \\ h\leq v\leq w \\ w-v\geq v-h,\ w-v>0}}^{(r-1)\tau+\tau_1+p-1} \exp\left\{-\frac{a_2}{30}\varrho_2\right\} \\
& \left(\text{for some constant } C^* \text{ such that } 2\left(2^{\frac{5}{6}}+1\right)\overline{C}^{\frac{1}{2}}a_1^{\frac{1}{30}} \leq C^* < \infty\right) \\
\leq\ & \frac{C^*}{\tau_1^3} \sum_{h=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1} \sum_{\varrho_2=1}^{\infty} \sum_{\varrho_1=0}^{\varrho_2} \exp\left\{-\frac{a_2}{30}\varrho_2\right\} \\
=\ & \frac{C^*}{\tau_1^3} \sum_{h=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1} \sum_{\varrho_2=1}^{\infty} \left(\varrho_2+1\right)\exp\left\{-\frac{a_2}{30}\varrho_2\right\} \\
=\ & \frac{C^*}{\tau_1^2}\left[\sum_{\varrho_2=1}^{\infty}\varrho_2\exp\left\{-\frac{a_2}{30}\varrho_2\right\}+\sum_{\varrho_2=1}^{\infty}\exp\left\{-\frac{a_2}{30}\varrho_2\right\}\right] \\
=\ & O\left(\frac{1}{\tau_1^2}\right) \quad \text{(given Lemma OA-1)} \qquad (9)
\end{aligned}
$$

It follows from expressions (6), (7), (8), and (9) that

$$\begin{aligned}
\frac{1}{\tau_1^3}\sum_{\substack{h,v,w=(r-1)\tau+p\\ h\leq v\leq w}}^{(r-1)\tau+\tau_1+p-1}\left|E\left(u_{ih}u_{iv}u_{iw}\right)\right| &= \frac{1}{\tau_1^3}\sum_{h=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}E\left|u_{ih}\right|^3+\frac{1}{\tau_1^3}\sum_{\substack{h,v,w=(r-1)\tau+p\\ h\leq v\leq w\\ v-h>w-v,\ v-h>0}}^{(r-1)\tau+\tau_1+p-1}\left|E\left(u_{ih}u_{iv}u_{iw}\right)\right| \\
&\quad +\frac{1}{\tau_1^3}\sum_{\substack{h,v,w=(r-1)\tau+p\\ h\leq v\leq w\\ w-v\geq v-h,\ w-v>0}}^{(r-1)\tau+\tau_1+p-1}\left|E\left(u_{ih}u_{iv}u_{iw}\right)\right| \\
&= O\left(\frac{1}{\tau_1^2}\right)+O\left(\frac{1}{\tau_1^2}\right)+O\left(\frac{1}{\tau_1^2}\right) \\
&= O\left(\frac{1}{\tau_1^2}\right).
\end{aligned}$$

Finally, to show part (c), we first write

$$\begin{aligned}
&\frac{1}{\tau_1^4}\sum_{\substack{g,h,v,w=(r-1)\tau+p\\ g\leq h\leq v\leq w}}^{(r-1)\tau+\tau_1+p-1}\left|E\left[u_{ig}u_{ih}u_{iv}u_{iw}\right]\right| \\
=\;& \frac{1}{\tau_1^4}\sum_{\substack{g,h=(r-1)\tau+p\\ g\leq h}}^{(r-1)\tau+\tau_1+p-1}\left|E\left[u_{ig}u_{ih}^3\right]\right| + \frac{1}{\tau_1^4}\sum_{\substack{g,h,v,w=(r-1)\tau+p\\ g\leq h\leq v\leq w\\ w-v>v-h,\ w-v>0}}^{(r-1)\tau+\tau_1+p-1}\left|E\left[u_{ig}u_{ih}u_{iv}u_{iw}\right]\right| \\
&+\frac{1}{\tau_1^4}\sum_{\substack{g,h,v,w=(r-1)\tau+p\\ g\leq h\leq v\leq w\\ w-v\leq v-h,\ v-h>0}}^{(r-1)\tau+\tau_1+p-1}\left|E\left[u_{ig}u_{ih}u_{iv}u_{iw}\right]\right| \\
=\;& \frac{1}{\tau_1^4}\sum_{\substack{g,h=(r-1)\tau+p\\ g\leq h}}^{(r-1)\tau+\tau_1+p-1}\left|E\left[u_{ig}u_{ih}^3\right]\right| + \frac{1}{\tau_1^4}\sum_{\substack{g,h,v,w=(r-1)\tau+p\\ g\leq h\leq v\leq w\\ w-v>v-h,\ w-v>0}}^{(r-1)\tau+\tau_1+p-1}\left|E\left[\left\{u_{ig}u_{ih}-E\left(u_{ig}u_{ih}\right)+E\left(u_{ig}u_{ih}\right)\right\}u_{iv}u_{iw}\right]\right| \\
&+\frac{1}{\tau_1^4}\sum_{\substack{g,h,v,w=(r-1)\tau+p\\ g\leq h\leq v\leq w\\ w-v\leq v-h,\ v-h>0}}^{(r-1)\tau+\tau_1+p-1}\left|E\left[\left\{u_{ig}u_{ih}-E\left(u_{ig}u_{ih}\right)+E\left(u_{ig}u_{ih}\right)\right\}u_{iv}u_{iw}\right]\right| \\
\leq\;& \frac{1}{\tau_1^4}\sum_{\substack{g,h=(r-1)\tau+p\\ g\leq h}}^{(r-1)\tau+\tau_1+p-1}\left|E\left[u_{ig}u_{ih}^3\right]\right| + \frac{1}{\tau_1^4}\sum_{\substack{g,h,v,w=(r-1)\tau+p\\ g\leq h\leq v\leq w\\ w-v>v-h,\ w-v>0}}^{(r-1)\tau+\tau_1+p-1}\left|E\left[\left\{u_{ig}u_{ih}-E\left(u_{ig}u_{ih}\right)\right\}u_{iv}u_{iw}\right]\right| \\
&+\frac{1}{\tau_1^4}\sum_{\substack{g,h,v,w=(r-1)\tau+p\\ g\leq h\leq v\leq w\\ w-v\leq v-h,\ v-h>0}}^{(r-1)\tau+\tau_1+p-1}\left|E\left[\left\{u_{ig}u_{ih}-E\left(u_{ig}u_{ih}\right)\right\}u_{iv}u_{iw}\right]\right| \\
&+\frac{1}{\tau_1^4}\sum_{\substack{g,h,v,w=(r-1)\tau+p\\ g\leq h\leq v\leq w\\ w-h>0}}^{(r-1)\tau+\tau_1+p-1}\left|E\left(u_{ig}u_{ih}\right)\right|\left|E\left(u_{iv}u_{iw}\right)\right| \qquad (10)
\end{aligned}$$

For the first term on the right-hand side of expression (10) above, note that, trivially, by

Jensen's inequality and Hölder's inequality, we have

$$\begin{aligned}
\frac{1}{\tau_1^4}\sum_{\substack{g,h=(r-1)\tau+p\\ g\leq h}}^{(r-1)\tau+\tau_1+p-1}\left|E\left[u_{ig}u_{ih}^3\right]\right| &\leq \frac{1}{\tau_1^4}\sum_{\substack{g,h=(r-1)\tau+p\\ g\leq h}}^{(r-1)\tau+\tau_1+p-1}E\left[\left|u_{ig}u_{ih}^3\right|\right] \\
&\leq \frac{1}{\tau_1^4}\sum_{\substack{g,h=(r-1)\tau+p\\ g\leq h}}^{(r-1)\tau+\tau_1+p-1}\sqrt{E\left|u_{ig}\right|^2}\sqrt{E\left|u_{ih}\right|^6} \\
&\leq \frac{1}{\tau_1^4}\sum_{\substack{g,h=(r-1)\tau+p\\ g\leq h}}^{(r-1)\tau+\tau_1+p-1}\left(E\left|u_{ih}\right|^6\right)^{\frac{1}{6}}\sqrt{E\left|u_{ih}\right|^6} \\
&\quad \text{(by Liapunov's inequality)} \\
&\leq \frac{\overline{C}^{\frac{2}{3}}\tau_1^2}{\tau_1^4}\quad\text{(by Assumption 2-3(b))} \\
&= O\left(\frac{1}{\tau_1^2}\right) \qquad (11)
\end{aligned}$$

Next, for the second term on the right-hand side of expression (10), we can apply Lemma OA-3 with $p = 4/3$ and $r = 6$ to obtain

$$\begin{aligned}
&\frac{1}{\tau_1^4}\sum_{\substack{g,h,v,w=(r-1)\tau+p\\ g\leq h\leq v\leq w\\ w-v>v-h,\ w-v>0}}^{(r-1)\tau+\tau_1+p-1}\left|E\left[\left\{u_{ig}u_{ih}-E\left(u_{ig}u_{ih}\right)\right\}u_{iv}u_{iw}\right]\right| \\
\leq\ &\frac{1}{\tau_1^4}\sum_{\substack{g,h,v,w=(r-1)\tau+p\\ g\leq h\leq v\leq w\\ w-v>v-h,\ w-v>0}}^{(r-1)\tau+\tau_1+p-1}\Big\{2\left(2^{1-\frac{3}{4}}+1\right)\left[a_1\exp\left\{-a_2\left(w-v\right)\right\}\right]^{1-\frac{3}{4}-\frac{1}{6}} \\
&\qquad\times\left(E\left|\left\{u_{ig}u_{ih}-E\left(u_{ig}u_{ih}\right)\right\}u_{iv}\right|^{\frac{4}{3}}\right)^{\frac{3}{4}}\left(E\left|u_{iw}\right|^6\right)^{\frac{1}{6}}\Big\}
\end{aligned}$$

Next, by repeated application of Hölder's inequality, we have

$$
\begin{aligned}
E\left|\left\{u_{ig}u_{ih}-E\left(u_{ig}u_{ih}\right)\right\}u_{iv}\right|^{\frac{4}{3}} &\leq \left[E\left|u_{ig}u_{ih}-E\left(u_{ig}u_{ih}\right)\right|^{\frac{12}{7}}\right]^{\frac{7}{9}}\left[E\left|u_{iv}\right|^{6}\right]^{\frac{2}{9}} \\
&\leq \left[2^{\frac{5}{7}}\left(E\left|u_{ig}u_{ih}\right|^{\frac{12}{7}}+\left|E\left[u_{ig}u_{ih}\right]\right|^{\frac{12}{7}}\right)\right]^{\frac{7}{9}}\left[E\left|u_{iv}\right|^{6}\right]^{\frac{2}{9}} \\
&\quad \text{(by Loève's } c_r \text{ inequality)} \\
&\leq \left[2^{\frac{5}{7}}\left(E\left|u_{ig}u_{ih}\right|^{\frac{12}{7}}+E\left|u_{ig}u_{ih}\right|^{\frac{12}{7}}\right)\right]^{\frac{7}{9}}\left[E\left|u_{iv}\right|^{6}\right]^{\frac{2}{9}} \\
&\quad \text{(by Jensen's inequality)} \\
&= \left[2^{\frac{12}{7}}E\left|u_{ig}u_{ih}\right|^{\frac{12}{7}}\right]^{\frac{7}{9}}\left[E\left|u_{iv}\right|^{6}\right]^{\frac{2}{9}} \\
&\leq 2^{\frac{4}{3}}\left[\left(E\left|u_{ig}\right|^{\frac{24}{7}}\right)^{\frac{1}{2}}\left(E\left|u_{ih}\right|^{\frac{24}{7}}\right)^{\frac{1}{2}}\right]^{\frac{7}{9}}\left[E\left|u_{iv}\right|^{6}\right]^{\frac{2}{9}} \\
&= 2^{\frac{4}{3}}\left[\left(E\left|u_{ig}\right|^{\frac{24}{7}}\right)^{\frac{7}{24}}\left(E\left|u_{ih}\right|^{\frac{24}{7}}\right)^{\frac{7}{24}}\right]^{\frac{4}{3}}\left[E\left|u_{iv}\right|^{6}\right]^{\frac{2}{9}} \\
&\leq 2^{\frac{4}{3}}\left[\left(E\left|u_{ig}\right|^{6}\right)^{\frac{1}{6}}\left(E\left|u_{ih}\right|^{6}\right)^{\frac{1}{6}}\right]^{\frac{4}{3}}\left[E\left|u_{iv}\right|^{6}\right]^{\frac{2}{9}} \\
&\leq 2^{\frac{4}{3}}\left(\overline{C}\right)^{\frac{2}{9}}\left(\overline{C}\right)^{\frac{2}{9}}\left(\overline{C}\right)^{\frac{2}{9}} \quad \text{(by Assumption 2-3(b))} \\
&= 2^{\frac{4}{3}}\overline{C}^{\frac{2}{3}}
\end{aligned}
$$

Moreover, let $\varrho_1 = v - h$ and $\varrho_2 = w - v$ so that $v = h + \varrho_1$ and $w = v + \varrho_2 = h + \varrho_1 + \varrho_2$. Using these notations and the boundedness of $E\left|\left\{u_{ig}u_{ih}-E\left(u_{ig}u_{ih}\right)\right\}u_{iv}\right|^{\frac{4}{3}}$ as shown above, we can further write

$$
\begin{aligned}
& \frac{1}{\tau_1^4} \sum_{\substack{g,h,v,w=(r-1)\tau+p \\ g \leq h \leq v \leq w \\ w-v>v-h,\ w-v>0}}^{(r-1)\tau+\tau_1+p-1} \left| E\left[\left\{ u_{ig} u_{ih} - E\left(u_{ig} u_{ih} \right) \right\} u_{iv} u_{iw} \right] \right| \\
\leq & \frac{1}{\tau_1^4} \sum_{\substack{g,h,v,w=(r-1)\tau+p \\ g \leq h \leq v \leq w \\ w-v>v-h,\ w-v>0}}^{(r-1)\tau+\tau_1+p-1} \left\{ 2\left(2^{1-\frac{3}{4}} + 1 \right) \left[a_1 \exp\left\{ -a_2 \left(w - v \right) \right\} \right]^{1-\frac{3}{4}-\frac{1}{6}} \right. \\
& \qquad \left. \times \left(E\left| \left\{ u_{ig} u_{ih} - E\left(u_{ig} u_{ih} \right) \right\} u_{iv} \right|^{\frac{4}{3}} \right)^{\frac{3}{4}} \left(E\left| u_{iw} \right|^{6} \right)^{\frac{1}{6}} \right\} \\
\leq & \frac{1}{\tau_1^4} \sum_{\substack{g,h,v,w=(r-1)\tau+p \\ g \leq h \leq v \leq w \\ w-v>v-h,\ w-v>0}}^{(r-1)\tau+\tau_1+p-1} 2\left(2^{\frac{1}{4}} + 1 \right) \left[a_1 \exp\left\{ -a_2 \left(w - v \right) \right\} \right]^{\frac{1}{12}} \left(2^{\frac{4}{3}} \overline{C}^{\frac{2}{3}} \right)^{\frac{3}{4}} \left(\overline{C} \right)^{\frac{1}{6}} \\
\leq & \frac{C^*}{\tau_1^4} \sum_{\substack{g,h,v,w=(r-1)\tau+p \\ g \leq h \leq v \leq w \\ w-v>v-h,\ w-v>0}}^{(r-1)\tau+\tau_1+p-1} \exp\left\{ -\frac{a_2}{12} \varrho_2 \right\} \\
& \left(\text{for some constant } C^* \text{ such that } 4\left(2^{\frac{1}{4}} + 1 \right) \overline{C}^{\frac{2}{3}} a_1^{\frac{1}{12}} \leq C^* < \infty \right) \\
\leq & \frac{C^*}{\tau_1^4} \sum_{g=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1} \sum_{h=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1} \sum_{\varrho_2=1}^{\infty} \sum_{\varrho_1=0}^{\varrho_2-1} \exp\left\{ -\frac{a_2}{12} \varrho_2 \right\} \\
\leq & \frac{C^*}{\tau_1^2} \sum_{\rho_2=1}^{\infty} \varrho_2 \exp\left\{ -\frac{a_2}{12} \varrho_2 \right\} \\
= & O\left(\frac{1}{\tau_1^2} \right) \quad \text{(given Lemma OA-1)} \qquad (12)
\end{aligned}
$$

Similarly, for the third term on the right-hand side of expression (10) above, we can apply

Lemma OA-3 with $p = 2$ and $r = 3$ to obtain

$$\begin{aligned}
&\frac{1}{\tau_1^4} \sum_{\substack{g,h,v,w=(r-1)\tau+p \\ g\leq h\leq v\leq w \\ w-v\leq v-h,\ v-h>0}}^{(r-1)\tau+\tau_1+p-1} \left| E\left[\left\{u_{ig}u_{ih} - E\left(u_{ig}u_{ih}\right)\right\} u_{iv}u_{iw}\right]\right| \\
\leq\ &\frac{1}{\tau_1^4} \sum_{\substack{g,h,v,w=(r-1)\tau+p \\ g\leq h\leq v\leq w \\ w-v\leq v-h,\ v-h>0}}^{(r-1)\tau+\tau_1+p-1} \Big\{2\left(2^{1-\frac{1}{2}}+1\right)\left[a_1 \exp\left\{-a_2\left(v-h\right)\right\}\right]^{1-\frac{1}{2}-\frac{1}{3}} \\
&\qquad\qquad \times \left(E\left|\left\{u_{ig}u_{ih} - E\left(u_{ig}u_{ih}\right)\right\}\right|^2\right)^{\frac{1}{2}} \left(E\left|u_{iv}u_{iw}\right|^3\right)^{\frac{1}{3}}\Big\}
\end{aligned}$$

Next, applications of Hölder's inequality yield

$$\begin{aligned}
E\left|u_{iv}u_{iw}\right|^3 &\leq \left(E\left|u_{iv}\right|^6\right)^{\frac{1}{2}}\left(E\left|u_{iw}\right|^6\right)^{\frac{1}{2}} \\
&\leq \left(\overline{C}\right)^{\frac{1}{2}}\left(\overline{C}\right)^{\frac{1}{2}} \quad \text{(by Assumption 2-3(b))} \\
&= \overline{C} < \infty
\end{aligned}$$

and

$$\begin{aligned}
E\left|\left\{u_{ig}u_{ih} - E\left(u_{ig}u_{ih}\right)\right\}\right|^2 &\leq 2\left(E\left|u_{ig}u_{ih}\right|^2 + E\left|u_{ig}u_{ih}\right|^2\right) \\
&\quad \text{(by Loève's } c_r \text{ inequality and Jensen's inequality)} \\
&= 4E\left|u_{ig}u_{ih}\right|^2 \\
&\leq 4\left[\left(E\left|u_{ig}\right|^4\right)^{\frac{1}{4}}\left(E\left|u_{ih}\right|^4\right)^{\frac{1}{4}}\right]^2 \\
&\leq 4\left[\left(E\left|u_{ig}\right|^6\right)^{\frac{1}{6}}\left(E\left|u_{ih}\right|^6\right)^{\frac{1}{6}}\right]^2 \quad \text{(by Liapunov's inequality)} \\
&\leq 4\left(\sup_{i,t} E\left|u_{it}\right|^6\right)^{\frac{2}{3}} \\
&\leq 4\left(\overline{C}\right)^{\frac{2}{3}} < \infty \quad \text{(by Assumption 2-3(b))}
\end{aligned}$$

Moreover, let $\varrho_1 = v - h$ and $\varrho_2 = w - v$ so that $v = h + \varrho_1$ and $w = v + \varrho_2 = h + \varrho_1 + \varrho_2$. Using these notations and the boundedness of $E\left|u_{iv}u_{iw}\right|^3$ and $E\left|\left\{u_{ig}u_{ih} - E\left(u_{ig}u_{ih}\right)\right\}\right|^2$ as shown above, we can further write

$$
\begin{aligned}
& \frac{1}{\tau_1^4} \sum_{\substack{g,h,v,w=(r-1)\tau+p \\ g\leq h\leq v\leq w \\ w-v\leq v-h,\ v-h>0}}^{(r-1)\tau+\tau_1+p-1} \left| E\left[\left\{u_{ig}u_{ih} - E\left(u_{ig}u_{ih}\right)\right\} u_{iv}u_{iw}\right]\right| \\
\leq \ & \frac{1}{\tau_1^4} \sum_{\substack{g,h,v,w=(r-1)\tau+p \\ g\leq h\leq v\leq w \\ w-v\leq v-h,\ v-h>0}}^{(r-1)\tau+\tau_1+p-1} \Big\{ 2\left(2^{1-\frac{1}{2}}+1\right)\left[a_1 \exp\left\{-a_2\left(v-h\right)\right\}\right]^{1-\frac{1}{2}-\frac{1}{3}} \\
& \qquad\qquad\qquad\qquad \times \left(E\left|\left\{u_{ig}u_{ih} - E\left(u_{ig}u_{ih}\right)\right\}\right|^2\right)^{\frac{1}{2}} \left(E\left|u_{iv}u_{iw}\right|^3\right)^{\frac{1}{3}} \Big\} \\
\leq \ & \frac{1}{\tau_1^4} \sum_{\substack{g,h,v,w=(r-1)\tau+p \\ g\leq h\leq v\leq w \\ w-v\leq v-h,\ v-h>0}}^{(r-1)\tau+\tau_1+p-1} 2\left(2^{\frac{1}{2}}+1\right)\left[a_1 \exp\left\{-a_2\left(v-h\right)\right\}\right]^{\frac{1}{6}} \left(4\overline{C}^{\frac{2}{3}}\right)^{\frac{1}{2}} \left(\overline{C}\right)^{\frac{1}{3}} \\
\leq \ & \frac{C^*}{\tau_1^4} \sum_{\substack{g,h,v,w=(r-1)\tau+p \\ g\leq h\leq v\leq w \\ w-v\leq v-h,\ v-h>0}}^{(r-1)\tau+\tau_1+p-1} \exp\left\{-\frac{a_2}{6}\varrho_1\right\} \\
& \left(\text{for some constant } C^* \text{ such that } 4\left(2^{\frac{1}{2}}+1\right)\overline{C}^{\frac{2}{3}} a_1^{\frac{1}{6}} \leq C^* < \infty\right) \\
\leq \ & \frac{C^*}{\tau_1^4} \sum_{g=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1} \ \sum_{h=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1} \ \sum_{\varrho_1=1}^{\infty} \sum_{\varrho_2=0}^{\varrho_1} \exp\left\{-\frac{a_2}{6}\varrho_1\right\} \\
= \ & \frac{C^*}{\tau_1^2} \sum_{\rho_1=1}^{\infty} \left(\varrho_1+1\right) \exp\left\{-\frac{a_2}{6}\varrho_1\right\} \\
= \ & O\left(\frac{1}{\tau_1^2}\right) \quad \text{(given Lemma OA-1)} \qquad\qquad (13)
\end{aligned}
$$

Finally, consider the fourth term on the right-hand side of expression (10) above. For this term, we apply the result given in part (a) to obtain

$$\begin{aligned}
&\frac{1}{\tau_1^4}\sum_{\substack{g,h,v,w=(r-1)\tau+p\\ g\le h\le v\le w\\ w-h>0}}^{(r-1)\tau+\tau_1+p-1} \left|E\left(u_{ig}u_{ih}\right)\right|\left|E\left(u_{iv}u_{iw}\right)\right| \\
\le\; & \left(\frac{1}{\tau_1^2}\sum_{\substack{g,h=(r-1)\tau+p\\ g\le h}}^{(r-1)\tau+\tau_1+p-1}\left|E\left(u_{ig}u_{ih}\right)\right|\right)\left(\frac{1}{\tau_1^2}\sum_{\substack{v,w=(r-1)\tau+p\\ v\le w}}^{(r-1)\tau+\tau_1+p-1}\left|E\left(u_{iv}u_{iw}\right)\right|\right) \\
=\; & O\left(\frac{1}{\tau_1^2}\right).
\end{aligned}\tag{14}$$

It follows from expressions (10)-(14) that

$$\begin{aligned}
&\frac{1}{\tau_1^4}\sum_{\substack{g,h,v,w=(r-1)\tau+p\\ g\le h\le v\le w}}^{(r-1)\tau+\tau_1+p-1}\left|E\left[u_{ig}u_{ih}u_{iv}u_{iw}\right]\right| \\
\le\; & \frac{1}{\tau_1^4}\sum_{\substack{g,h=(r-1)\tau+p\\ g\le h}}^{(r-1)\tau+\tau_1+p-1}\left|E\left[u_{ig}u_{ih}^3\right]\right| + \frac{1}{\tau_1^4}\sum_{\substack{g,h,v,w=(r-1)\tau+p\\ g\le h\le v\le w\\ w-v>v-h,\ w-v>0}}^{(r-1)\tau+\tau_1+p-1}\left|E\left[\left\{u_{ig}u_{ih}-E\left(u_{ig}u_{ih}\right)\right\}u_{iv}u_{iw}\right]\right| \\
& +\frac{1}{\tau_1^4}\sum_{\substack{g,h,v,w=(r-1)\tau+p\\ g\le h\le v\le w\\ w-v\le v-h,\ v-h>0}}^{(r-1)\tau+\tau_1+p-1}\left|E\left[\left\{u_{ig}u_{ih}-E\left(u_{ig}u_{ih}\right)\right\}u_{iv}u_{iw}\right]\right| \\
& +\frac{1}{\tau_1^4}\sum_{\substack{g,h,v,w=(r-1)\tau+p\\ g\le h\le v\le w\\ w-h>0}}^{(r-1)\tau+\tau_1+p-1}\left|E\left(u_{ig}u_{ih}\right)\right|\left|E\left(u_{iv}u_{iw}\right)\right| \\
=\; & O\left(\frac{1}{\tau_1^2}\right).\ \square
\end{aligned}$$

Lemma OA-5: Suppose that Assumptions 2-1, 2-2(a)-(b), 2-5, and 2-6 hold. Then, there exists a positve constant $\overline{C}$ such that

$$E\left\|\underline{W}_t\right\|_2^6\le\overline{C}<\infty \text{ for all } t$$

and, thus,

$$E\left\|\underline{Y}_t\right\|_2^6\le\overline{C}<\infty \text{ and } E\left\|\underline{F}_t\right\|_2^6\le\overline{C}<\infty \text{ for all } t,$$

where

$$\underset{dp\times 1}{\underline{Y}_t} = \begin{pmatrix} Y_t \\ Y_{t-1} \\ \vdots \\ Y_{t-p+1} \end{pmatrix}, \text{ and } \underset{Kp\times 1}{\underline{F}_t} = \begin{pmatrix} F_t \\ F_{t-1} \\ \vdots \\ F_{t-p+1} \end{pmatrix}.$$

Proof of Lemma OA-5:

To proceed, note that, given Assumption 2-1, we can write the vector moving-average (VMA) representation of the companion form of the FAVAR model as

$$\begin{aligned} \underline{W}_t &= \left(I_{(d+K)p} - A\right)^{-1} \alpha + \sum_{j=0}^{\infty} A^j E_{t-j} \\ &= \left(I_{(d+K)p} - A\right)^{-1} J'_{d+K} J_{d+K} \alpha + \sum_{j=0}^{\infty} A^j J'_{d+K} J_{d+K} E_{t-j} \\ &= \left(I_{(d+K)p} - A\right)^{-1} J'_{d+K} \mu + \sum_{j=0}^{\infty} A^j J'_{d+K} \varepsilon_{t-j}, \end{aligned} \tag{15}$$

where

$$\begin{aligned} \underline{W}_t &= \begin{pmatrix} W_t \\ W_{t-1} \\ \vdots \\ W_{t-p+2} \\ W_{t-p+1} \end{pmatrix}, \ E_t = \begin{pmatrix} \varepsilon_t \\ 0 \\ \vdots \\ 0 \\ 0 \end{pmatrix}, \alpha = \begin{pmatrix} \mu \\ 0 \\ \vdots \\ 0 \\ 0 \end{pmatrix}, \\ \underset{(d+K)\times(d+K)p}{J_{d+K}} &= \begin{bmatrix} I_{d+K} & 0 & \cdots & 0 & 0 \end{bmatrix}, \text{ and } A = \begin{pmatrix} A_1 & A_2 & \cdots & A_{p-1} & A_p \\ I_{d+K} & 0 & \cdots & \cdots & 0 \\ 0 & \ddots & \ddots & & \vdots \\ \vdots & \ddots & \ddots & \ddots & \vdots \\ 0 & \cdots & 0 & I_{d+K} & 0 \end{pmatrix}. \end{aligned}$$

By the triangle inequality,

$$\left\|\underline{W}_t\right\|_2 \le \left\|\left(I_{(d+K)p} - A\right)^{-1} J'_{d+K}\mu\right\|_2 + \left\|\sum_{j=0}^{\infty} A^j J'_{d+K}\varepsilon_{t-j}\right\|_2$$

Moreover, using the inequality $\left|\sum_{i=1}^{m} a_i\right|^r \leq m^{r-1}\sum_{i=1}^{m} |a_i|^r$ for $r \geq 1$, we get

$$\|\underline{W}_t\|_2^6 \leq 2^5 \left(\left\|\left(I_{(d+K)p} - A\right)^{-1} J'_{d+K}\mu\right\|_2^6 + \left\|\sum_{j=0}^{\infty} A^j J'_{d+K}\varepsilon_{t-j}\right\|_2^6\right)$$

so that

$$E\|\underline{W}_t\|_2^6 \leq 32\left\|\left(I_{(d+K)p} - A\right)^{-1} J'_{d+K}\mu\right\|_2^6 + 32E\left\|\sum_{j=0}^{\infty} A^j J'_{d+K}\varepsilon_{t-j}\right\|_2^6 \tag{16}$$

Focusing first on the first term on the right-hand side of the inequality (16), we note that

$$\begin{aligned}
\left\|\left(I_{(d+K)p} - A\right)^{-1} J'_{d+K}\mu\right\|_2^6 &= \left(\mu' J_{d+K}\left(I_{(d+K)p} - A\right)^{-1\prime}\left(I_{(d+K)p} - A\right)^{-1} J'_{d+K}\mu\right)^3 \\
&= \left(\mu' J_{d+K}\left[\left(I_{(d+K)p} - A\right)\left(I_{(d+K)p} - A\right)'\right]^{-1} J'_{d+K}\mu\right)^3 \\
&\leq \left(\frac{1}{\lambda_{\min}\left\{\left(I_{(d+K)p} - A\right)\left(I_{(d+K)p} - A\right)'\right\}}\right)^3 \left(\mu' J_{d+K} J'_{d+K}\mu\right)^3 \\
&= \left(\frac{1}{\lambda_{\min}\left\{\left(I_{(d+K)p} - A\right)\left(I_{(d+K)p} - A\right)'\right\}}\right)^3 \left(\mu'\mu\right)^3
\end{aligned}$$

Now, by Assumption 2-6, there exists a constant $\underline{C} > 0$ such that

$$\begin{aligned}
\lambda_{\min}\left\{\left(I_{(d+K)p} - A\right)\left(I_{(d+K)p} - A\right)'\right\} &= \lambda_{\min}\left\{\left(I_{(d+K)p} - A\right)'\left(I_{(d+K)p} - A\right)\right\} \\
&= \sigma^2_{\min}\left(I_{(d+K)p} - A\right) \\
&\geq \underline{C}\lambda^2_{\min}\left(I_{(d+K)p} - A\right) \\
&\geq \underline{C}\left[1 - \phi_{\max}\right]^2 \\
&> 0
\end{aligned}$$

where $\phi_{\max} = \max\left\{\left|\lambda_{\max}(A)\right|, \left|\lambda_{\min}(A)\right|\right\}$ and where $0 < \phi_{\max} < 1$ since, by Assumption 2-1, all eigenvalues of A have modulus less than 1. It follows by Assumption 2-5 that, there exists a positive constant $\overline{C}_1$ such that

$$\begin{aligned}
\left\|\left(I_{(d+K)p} - A\right)^{-1} J'_{d+K}\mu\right\|_2^6 &\leq \left(\frac{1}{\lambda_{\min}\left\{\left(I_{(d+K)p} - A\right)\left(I_{(d+K)p} - A\right)'\right\}}\right)^3 \left(\mu'\mu\right)^3 \\
&\leq \frac{\|\mu\|_2^6}{\underline{C}^3\left[1 - \phi_{\max}\right]^6} \leq \overline{C}_1 < \infty.
\end{aligned}$$

To show the boundedness of the second term on the right-hand side of the inequality (16), let $e_{g,(d+K)p}$ be a $(d+K)\,p \times 1$ elementary vector whose g^{th} component is 1 and all other components are 0 for $g \in \{1, 2, ..., (d+K)\,p\}$, and note that

$$\begin{aligned}
\left\| \sum_{j=0}^{\infty} A^j J'_{d+K} \varepsilon_{t-j} \right\|_2^2 &= \sum_{g=1}^{(d+K)p} \left(\sum_{j=0}^{\infty} e'_{g,(d+K)p} A^j J'_{d+K} \varepsilon_{t-j} \right)^2 \\
&= \sum_{g=1}^{(d+K)p} \sum_{j=0}^{\infty} \sum_{k=0}^{\infty} e'_{g,(d+K)p} A^j J'_{d+K} \varepsilon_{t-j} \varepsilon'_{t-k} J_{d+K} \left(A'\right)^k e_{g,(d+K)p}
\end{aligned}$$

from which we obtain, by applying the inequality $\left| \sum_{i=1}^{m} a_i \right|^r \leq m^{r-1} \sum_{i=1}^{m} |a_i|^r$ for $r \geq 1$

$$\begin{aligned}
& \left\| \sum_{j=0}^{\infty} A^j J'_{d+K} \varepsilon_{t-j} \right\|_2^6 \\
= \ & \left[\sum_{g=1}^{(d+K)p} \left(\sum_{j=0}^{\infty} e'_{g,(d+K)p} A^j J'_{d+K} \varepsilon_{t-j} \right)^2 \right]^3 \\
\leq \ & \left[(d+K)\,p\right]^2 \sum_{g=1}^{(d+K)p} \left(\sum_{j=0}^{\infty} e'_{g,(d+K)p} A^j J'_{d+K} \varepsilon_{t-j} \right)^6 \\
= \ & \left[(d+K)\,p\right]^2 \sum_{g=1}^{(d+K)p} \left\{ \sum_{j=0}^{\infty} \sum_{k=0}^{\infty} \sum_{i=0}^{\infty} \sum_{\ell=0}^{\infty} \sum_{r=0}^{\infty} \sum_{s=0}^{\infty} e'_{g,(d+K)p} A^j J'_{d+K} \varepsilon_{t-j} \varepsilon'_{t-k} J_{d+K} \left(A'\right)^k e_{g,(d+K)p} \right. \\
& \left. \times e'_{g,(d+K)p} A^i J'_d \varepsilon_{t-i} \varepsilon'_{t-\ell} J_{d+K} \left(A'\right)^\ell e_{g,(d+K)p} e'_{g,(d+K)p} A^r J'_{d+K} \varepsilon_{t-r} \varepsilon'_{t-s} J_d \left(A'\right)^s e_{g,(d+K)p} \right\}
\end{aligned}$$

Hence,

$$\begin{aligned}
&E\left\|\sum_{j=0}^{\infty}A^{j}J_{d+K}'\varepsilon_{t-j}\right\|_{2}^{6}\\
\leq\ & \left[\left(d+K\right)p\right]^{2}\sum_{g=1}^{(d+K)p}\sum_{j=0}^{\infty}E\left|e_{g,(d+K)p}'A^{j}J_{d+K}'\varepsilon_{t-j}\right|^{6}\\
&+\left[\left(d+K\right)p\right]^{2}\sum_{g=1}^{(d+K)p}\binom{6}{3}\left(\sum_{j=0}^{\infty}E\left|e_{g,(d+K)p}'A^{j}J_{d+K}'\varepsilon_{t-j}\right|^{3}\right)^{2}\\
&+\left[\left(d+K\right)p\right]^{2}\sum_{g=1}^{(d+K)p}\binom{6}{2}\binom{4}{2}\left(\sum_{j=0}^{\infty}E\left|e_{g,(d+K)p}'A^{j}J_{d+K}'\varepsilon_{t-j}\right|^{2}\right)^{3}\\
&+\left[\left(d+K\right)p\right]^{2}\sum_{g=1}^{(d+K)p}\binom{6}{4}\sum_{j=0}^{\infty}E\left|e_{g,(d+K)p}'A^{j}J_{d+K}'\varepsilon_{t-j}\right|^{4}\sum_{k=0}^{\infty}E\left|e_{g,(d+K)p}'A^{k}J_{d+K}'\varepsilon_{t-k}\right|^{2}\\
=\ & \left[\left(d+K\right)p\right]^{2}\sum_{g=1}^{(d+K)p}\sum_{j=0}^{\infty}E\left|e_{g,(d+K)p}'A^{j}J_{d+K}'\varepsilon_{t-j}\right|^{6}\\
&+20\left[\left(d+K\right)p\right]^{2}\sum_{g=1}^{(d+K)p}\left(\sum_{j=0}^{\infty}E\left|e_{g,(d+K)p}'A^{j}J_{d+K}'\varepsilon_{t-j}\right|^{3}\right)^{2}\\
&+90\left[\left(d+K\right)p\right]^{2}\sum_{g=1}^{(d+K)p}\left(\sum_{j=0}^{\infty}E\left|e_{g,(d+K)p}'A^{j}J_{d+K}'\varepsilon_{t-j}\right|^{2}\right)^{3}\\
&+15\left[\left(d+K\right)p\right]^{2}\sum_{g=1}^{(d+K)p}\sum_{j=0}^{\infty}E\left|e_{g,(d+K)p}'A^{j}J_{d+K}'\varepsilon_{t-j}\right|^{4}\sum_{k=0}^{\infty}E\left|e_{g,(d+K)p}'A^{k}J_{d+K}'\varepsilon_{t-k}\right|^{2}
\end{aligned}$$

Next, applying the Cauchy-Schwarz inequality, we further obtain

$$\begin{aligned}
& E\left\Vert \sum_{j=0}^{\infty} A^{j} J_{d+K}^{\prime} \varepsilon_{t-j} \right\Vert_{2}^{6} \\
\leq \;& \left[\left(d+K\right)p\right]^{2} \sum_{g=1}^{(d+K)p} \sum_{j=0}^{\infty} \left[e_{g,(d+K)p}^{\prime} A^{j} J_{d+K}^{\prime} J_{d+K} \left(A^{j}\right)^{\prime} e_{g,(d+K)p} \right]^{3} E \left\Vert \varepsilon_{t-j} \right\Vert_{2}^{6} \\
& +20 \left[\left(d+K\right)p\right]^{2} \sum_{g=1}^{(d+K)p} \left(\sum_{j=0}^{\infty} \left[e_{g,(d+K)p}^{\prime} A^{j} J_{d+K}^{\prime} J_{d+K} \left(A^{j}\right)^{\prime} e_{g,(d+K)p} \right]^{\frac{3}{2}} E \left\Vert \varepsilon_{t-j} \right\Vert_{2}^{3} \right)^{2} \\
& +90 \left[\left(d+K\right)p\right]^{2} \sum_{g=1}^{(d+K)p} \left(\sum_{j=0}^{\infty} \left[e_{g,(d+K)p}^{\prime} A^{j} J_{d+K}^{\prime} J_{d+K} \left(A^{j}\right)^{\prime} e_{g,(d+K)p} \right] E \left\Vert \varepsilon_{t-j} \right\Vert_{2}^{2} \right)^{3} \\
& +15 \left[\left(d+K\right)p\right]^{2} \sum_{g=1}^{(d+K)p} \left\{ \sum_{j=0}^{\infty} \left[e_{g,(d+K)p}^{\prime} A^{j} J_{d+K}^{\prime} J_{d+K} \left(A^{j}\right)^{\prime} e_{g,(d+K)p} \right]^{2} E \left\Vert \varepsilon_{t-j} \right\Vert_{2}^{4} \right. \\
& \qquad\qquad \left. \times \sum_{k=0}^{\infty} \left[e_{g,(d+K)p}^{\prime} A^{k} J_{d+K}^{\prime} J_{d+K} \left(A^{k}\right)^{\prime} e_{g,(d+K)p} \right] E \left\Vert \varepsilon_{t-k} \right\Vert_{2}^{2} \right\} \\
\leq \;& \left[\left(d+K\right)p\right]^{2} \sum_{g=1}^{(d+K)p} \sum_{j=0}^{\infty} \left[e_{g,(d+K)p}^{\prime} A^{j} \left(A^{j}\right)^{\prime} e_{g,(d+K)p} \right]^{3} E \left\Vert \varepsilon_{t-j} \right\Vert_{2}^{6} \\
& +20 \left[\left(d+K\right)p\right]^{2} \sum_{g=1}^{(d+K)p} \left(\sum_{j=0}^{\infty} \left[e_{g,(d+K)p}^{\prime} A^{j} \left(A^{j}\right)^{\prime} e_{g,(d+K)p} \right]^{\frac{3}{2}} E \left\Vert \varepsilon_{t-j} \right\Vert_{2}^{3} \right)^{2} \\
& +90 \left[\left(d+K\right)p\right]^{2} \sum_{g=1}^{(d+K)p} \left(\sum_{j=0}^{\infty} \left[e_{g,(d+K)p}^{\prime} A^{j} \left(A^{j}\right)^{\prime} e_{g,(d+K)p} \right] E \left\Vert \varepsilon_{t-j} \right\Vert_{2}^{2} \right)^{3} \\
& +15 \left[\left(d+K\right)p\right]^{2} \sum_{g=1}^{(d+K)p} \left\{ \sum_{j=0}^{\infty} \left[e_{g,(d+K)p}^{\prime} A^{j} \left(A^{j}\right)^{\prime} e_{g,(d+K)p} \right]^{2} E \left\Vert \varepsilon_{t-j} \right\Vert_{2}^{4} \right. \\
& \qquad\qquad \left. \times \sum_{k=0}^{\infty} \left[e_{g,(d+K)p}^{\prime} A^{k} \left(A^{k}\right)^{\prime} e_{g,(d+K)p} \right] E \left\Vert \varepsilon_{t-k} \right\Vert_{2}^{2} \right\}
\end{aligned}$$

In addition, observe that, for every $g \in \{1, 2, ..., (d+K)\,p\}$

$$\begin{aligned}
& e'_{g,(d+K)p} A^j \left(A^j\right)' e_{g,(d+K)p} \\
\leq \; & \lambda_{\max}\left\{A^j \left(A^j\right)'\right\} \\
= \; & \lambda_{\max}\left\{\left(A^j\right)' A^j\right\} \\
= \; & \sigma^2_{\max}\left(A^j\right) \\
\leq \; & C \max\left\{\left|\lambda_{\max}\left(A^j\right)\right|^2, \left|\lambda_{\min}\left(A^j\right)\right|^2\right\} \text{ (by Assumption 2-6)} \\
= \; & C \max\left\{\left|\lambda_{\max}(A)\right|^{2j}, \left|\lambda_{\min}(A)\right|^{2j}\right\} \\
= \; & C\phi^{2j}_{\max}
\end{aligned}$$

where $\phi_{\max} = \max\{|\lambda_{\max}(A)|, |\lambda_{\min}(A)|\}$ and where $0 < \phi_{\max} < 1$ given that Assumption 2-1 implies that all eigenvalues of A have modulus less than 1. Now, in light of Assumption 2-2(b), we can set $C \geq 1$ to be a constant such that $E\left\|\varepsilon_{t-j}\right\|_2^6 \leq C < \infty$, so that, by Liapunov's inequality,

$$\begin{aligned}
E\left\|\varepsilon_{t-j}\right\|_2^2 & \leq \left(E\left\|\varepsilon_{t-j}\right\|_2^6\right)^{\frac{1}{3}} \leq C^{\frac{1}{3}}, \; E\left\|\varepsilon_{t-j}\right\|_2^3 \leq \left(E\left\|\varepsilon_{t-j}\right\|_2^6\right)^{\frac{1}{2}} \leq C^{\frac{1}{2}}, \\
E\left\|\varepsilon_{t-j}\right\|_2^4 & \leq \left(E\left\|\varepsilon_{t-j}\right\|_2^6\right)^{\frac{2}{3}} \leq C^{\frac{2}{3}},
\end{aligned}$$

and, thus,

$$
\begin{aligned}
& E\left\|\sum_{j=0}^{\infty} A^j J_{d+K}' \varepsilon_{t-j}\right\|_2^6 \\
\leq\ & \left[(d+K)\,p\right]^2 \sum_{g=1}^{(d+K)p} \sum_{j=0}^{\infty} \left[e_{g,(d+K)p}' A^j \left(A^j\right)' e_{g,(d+K)p}\right]^3 E\left\|\varepsilon_{t-j}\right\|_2^6 \\
& +20\left[(d+K)\,p\right]^2 \sum_{g=1}^{(d+K)p} \left(\sum_{j=0}^{\infty} \left[e_{g,(d+K)p}' A^j \left(A^j\right)' e_{g,(d+K)p}\right]^{\frac{3}{2}} E\left\|\varepsilon_{t-j}\right\|_2^3\right)^2 \\
& +90\left[(d+K)\,p\right]^2 \sum_{g=1}^{(d+K)p} \left(\sum_{j=0}^{\infty} \left[e_{g,(d+K)p}' A^j \left(A^j\right)' e_{g,(d+K)p}\right] E\left\|\varepsilon_{t-j}\right\|_2^2\right)^3 \\
& +15\left[(d+K)\,p\right]^2 \sum_{g=1}^{(d+K)p} \left\{\sum_{j=0}^{\infty} \left[e_{g,(d+K)p}' A^j \left(A^j\right)' e_{g,(d+K)p}\right]^2 E\left\|\varepsilon_{t-j}\right\|_2^4\right. \\
& \qquad\qquad \left.\times \sum_{k=0}^{\infty} \left[e_{g,(d+K)p}' A^k \left(A^k\right)' e_{g,(d+K)p}\right] E\left\|\varepsilon_{t-k}\right\|_2^2\right\} \\
\leq\ & C\left[(d+K)\,p\right]^2 \left\{\sum_{g=1}^{(d+K)p} \sum_{j=0}^{\infty} \phi_{\max}^{6j} + 20 \sum_{g=1}^{(d+K)p} \left(\sum_{j=0}^{\infty} \phi_{\max}^{3j}\right)^2 + 90 \sum_{g=1}^{(d+K)p} \left(\sum_{j=0}^{\infty} \phi_{\max}^{2j}\right)^3\right. \\
& \qquad\qquad \left. +15 \sum_{g=1}^{(d+K)p} \left(\sum_{j=0}^{\infty} \phi_{\max}^{4j}\right)\left(\sum_{k=0}^{\infty} \phi_{\max}^{2k}\right)\right\} \\
\leq\ & C\left[(d+K)\,p\right]^3 \\
& \times\left\{\frac{1}{1-\phi_{\max}^6} + 20\left(\frac{1}{1-\phi_{\max}^3}\right)^2 + 90\left(\frac{1}{1-\phi_{\max}^2}\right)^3 + 15\left(\frac{1}{1-\phi_{\max}^4}\right)\left(\frac{1}{1-\phi_{\max}^2}\right)\right\} \\
\leq\ & \overline{C}_2 < \infty
\end{aligned}
$$

for some constant such that

$$
\begin{aligned}
& \overline{C}_2 \\
\geq\ & C\left[(d+K)\,p\right]^3 \\
& \times\left\{\frac{1}{1-\phi_{\max}^6} + 20\left(\frac{1}{1-\phi_{\max}^3}\right)^2 + 90\left(\frac{1}{1-\phi_{\max}^2}\right)^3 + 15\left(\frac{1}{1-\phi_{\max}^4}\right)\left(\frac{1}{1-\phi_{\max}^2}\right)\right\}.
\end{aligned}
$$

Putting everything together, we see that

$$\begin{aligned} E\left\|\underline{W}_t\right\|_2^6 &\leq 32\left\|\left(I_{(d+K)p}-A\right)^{-1} J_{d+K}'\mu\right\|_2^6 + 32E\left\|\sum_{j=0}^{\infty} A^j J_{d+K}'\varepsilon_{t-j}\right\|_2^6 \\ &\leq 32\left(\overline{C}_1+\overline{C}_2\right) \\ &\leq \overline{C} < \infty \end{aligned}$$

for a constant $\overline{C}$ such that $0 < 32\left(\overline{C}_1+\overline{C}_2\right) \leq \overline{C} < \infty$.

In addition, define$\mathcal{P}_{(d+K)p}$ to be the $(d+K)\,p \times (d+K)\,p$ permutation matrix such that

$$\mathcal{P}_{(d+K)p}\underline{W}_t = \begin{pmatrix} \underset{dp\times 1}{\underline{Y}_t} \\ \underset{Kp\times 1}{\underline{F}_t} \end{pmatrix}; \tag{17}$$

and let $S_d' = \begin{pmatrix} I_{dp} & \underset{dp\times Kp}{0} \end{pmatrix}$ and $S_K' = \begin{pmatrix} \underset{Kp\times dp}{0} & I_{Kp} \end{pmatrix}$. Note that

$$\begin{aligned} S_d'\mathcal{P}_{(d+K)p}\underline{W}_t &= \begin{pmatrix} I_{dp} & \underset{dp\times Kp}{0} \end{pmatrix}\begin{pmatrix} \underset{dp\times 1}{\underline{Y}_t} \\ \underset{Kp\times 1}{\underline{F}_t} \end{pmatrix} = \underline{Y}_t, \\ S_K'\mathcal{P}_{(d+K)p}\underline{W}_t &= \begin{pmatrix} \underset{Kp\times dp}{0} & I_{Kp} \end{pmatrix}\begin{pmatrix} \underset{dp\times 1}{\underline{Y}_t} \\ \underset{Kp\times 1}{\underline{F}_t} \end{pmatrix} = \underline{F}_t. \end{aligned}$$

so that

$$\begin{aligned} \left\|\underline{Y}_t\right\|_2 &\leq \left\|S_d'\right\|_2 \left\|\mathcal{P}_{(d+K)p}\right\|_2 \left\|\underline{W}_t\right\|_2 \\ &= \sqrt{\lambda_{\max}\left(S_d S_d'\right)}\sqrt{\lambda_{\max}\left(\mathcal{P}_{(d+K)p}'\mathcal{P}_{(d+K)p}\right)}\left\|\underline{W}_t\right\|_2 \\ &= \sqrt{\lambda_{\max}\left(S_d' S_d\right)}\sqrt{\lambda_{\max}\left(I_{(d+K)p}\right)}\left\|\underline{W}_t\right\|_2 \\ &= \sqrt{\lambda_{\max}\left(I_{dp}\right)}\sqrt{\lambda_{\max}\left(I_{(d+K)p}\right)}\left\|\underline{W}_t\right\|_2 \\ &= \left\|\underline{W}_t\right\|_2 \end{aligned}$$

and

$$
\begin{aligned}
\left\|\underline{F}_t\right\|_2 &\leq \left\|S_K'\right\|_2 \left\|\mathcal{P}_{(d+K)p}\right\|_2 \left\|\underline{W}_t\right\|_2 \\
&= \sqrt{\lambda_{\max}\left(S_K S_K'\right)} \sqrt{\lambda_{\max}\left(\mathcal{P}_{(d+K)p}' \mathcal{P}_{(d+K)p}\right)} \left\|\underline{W}_t\right\|_2 \\
&= \sqrt{\lambda_{\max}\left(S_K' S_K\right)} \sqrt{\lambda_{\max}\left(I_{(d+K)p}\right)} \left\|\underline{W}_t\right\|_2 \\
&= \sqrt{\lambda_{\max}\left(I_{Kp}\right)} \sqrt{\lambda_{\max}\left(I_{(d+K)p}\right)} \left\|\underline{W}_t\right\|_2 \\
&= \left\|\underline{W}_t\right\|_2
\end{aligned}
$$

It further follows that

$$
E\left\|\underline{Y}_t\right\|_2^6 \leq E\left\|\underline{W}_t\right\|_2^6 \leq \overline{C} < \infty \text{ and } E\left\|\underline{F}_t\right\|_2^6 \leq E\left\|\underline{W}_t\right\|_2^6 \leq \overline{C} < \infty. \ \square
$$

Lemma OA-6: Suppose that Assumptions 2-1, 2-2(a)-(b), 2-3, 2-5, 2-6, and 2-9(b) hold. Then, the following statements are true as $N_1, T \to \infty$

(a)

$$
\max_{1\leq \ell \leq d} \max_{i \in H^c} \left| \frac{1}{q} \sum_{r=1}^{q} \frac{1}{\tau_1} \sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1} \gamma_i' \underline{F}_t \varepsilon_{\ell,t+1} \right| \xrightarrow{p} 0.
$$

(b)

$$
\max_{1\leq \ell \leq d} \max_{i \in H^c} \frac{1}{q} \sum_{r=1}^{q} \left(\frac{1}{\tau_1} \sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1} \gamma_i' \underline{F}_t \varepsilon_{\ell,t+1} \right)^2 \xrightarrow{p} 0
$$

(c)

$$
\max_{1\leq \ell \leq d} \max_{i \in H^c} \left| \frac{1}{q} \sum_{r=1}^{q} \frac{1}{\tau_1} \sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1} y_{\ell,t+1} u_{it} \right| \xrightarrow{p} 0.
$$

(d)

$$
\max_{1\leq \ell \leq d} \max_{i \in H^c} \frac{1}{q} \sum_{r=1}^{q} \left(\frac{1}{\tau_1} \sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1} y_{\ell,t+1} u_{it} \right)^2 \xrightarrow{p} 0
$$

(e)

$$
\max_{1\leq \ell \leq d} \max_{i \in H^c} \left| \frac{1}{q} \sum_{r=1}^{q} \left(\frac{1}{\tau_1} \sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1} \gamma_i' \underline{F}_t \varepsilon_{\ell,t+1} \right) \left(\frac{1}{\tau_1} \sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1} y_{\ell,t+1} u_{it} \right) \right| \xrightarrow{p} 0
$$

Proof of Lemma OA-6.

To show part (a), first write

$$
\begin{aligned}
& P\left\{\max_{1\leq\ell\leq d}\max_{i\in H^c}\left|\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\underline{F}_t\varepsilon_{\ell,t+1}\right|\geq\epsilon\right\} \\
= \;& P\left\{\max_{1\leq\ell\leq d}\max_{i\in H^c}\left(\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\underline{F}_t\varepsilon_{\ell,t+1}\right)^6\geq\epsilon^6\right\} \\
\leq \;& P\left\{\max_{1\leq\ell\leq d}\max_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\underline{F}_t\varepsilon_{\ell,t+1}\right)^6\geq\epsilon^6\right\} \\
& \text{(by Jensen's inequality)} \\
\leq \;& P\left\{\sum_{\ell=1}^{d}\sum_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\underline{F}_t\varepsilon_{\ell,t+1}\right)^6\geq\epsilon^6\right\} \\
\leq \;& \frac{1}{\epsilon^6}\frac{1}{q}\sum_{r=1}^{q}\sum_{\ell=1}^{d}\sum_{i\in H^c}E\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\underline{F}_t\varepsilon_{\ell,t+1}\right)^6
\end{aligned}
$$

Next, note that

$$
\begin{aligned}
& \frac{1}{q}\sum_{r=1}^{q}\sum_{\ell=1}^{d}\sum_{i\in H^c} E\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\underline{F}_t\varepsilon_{\ell,t+1}\right)^6 \\
\leq\ & \frac{1}{q\tau_1^6}\sum_{r=1}^{q}\sum_{\ell=1}^{d}\sum_{i\in H^c}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1} E\left[\gamma_i'\underline{F}_t\varepsilon_{\ell,t+1}\right]^6 \\
& +\frac{20}{q\tau_1^6}\sum_{r=1}^{q}\sum_{\ell=1}^{d}\sum_{i\in H^c}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\sum_{\substack{s=(r-1)\tau+p\\ s\neq t}}^{(r-1)\tau+\tau_1+p-1} E\left[\left|\gamma_i'\underline{F}_t\varepsilon_{\ell,t+1}\right|\right]^3 E\left[\left|\gamma_i'\underline{F}_s\varepsilon_{\ell,s+1}\right|\right]^3 \\
& +\frac{15}{q\tau_1^6}\sum_{r=1}^{q}\sum_{\ell=1}^{d}\sum_{i\in H^c}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\sum_{\substack{s=(r-1)\tau+p\\ s\neq t}}^{(r-1)\tau+\tau_1+p-1} E\left[\gamma_i'\underline{F}_t\varepsilon_{\ell,t+1}\right]^4 E\left[\gamma_i'\underline{F}_s\varepsilon_{\ell,s+1}\right]^2 \\
& +\frac{90}{q\tau_1^6}\sum_{r=1}^{q}\sum_{\ell=1}^{d}\sum_{i\in H^c}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\sum_{\substack{s=(r-1)\tau+p\\ s\neq t}}^{(r-1)\tau+\tau_1+p-1}\sum_{\substack{r=(r-1)\tau+p\\ r\neq t,\ r\neq s}}^{(r-1)\tau+\tau_1+p-1}\Big\{E\left[\gamma_i'\underline{F}_t\varepsilon_{\ell,t+1}\right]^2 E\left[\gamma_i'\underline{F}_s\varepsilon_{\ell,s+1}\right]^2 \\
& \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad \times E\left[\gamma_i'\underline{F}_s\varepsilon_{\ell,r+1}\right]^2\Big\} \\
\leq\ & \frac{1}{q\tau_1^6}\sum_{r=1}^{q}\sum_{\ell=1}^{d}\sum_{i\in H^c}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1} E\left[\left(\gamma_i'\underline{F}_t\right)^6\right] E\left[\varepsilon_{\ell,t+1}^6\right] \\
& +\frac{20}{q\tau_1^6}\sum_{r=1}^{q}\sum_{\ell=1}^{d}\sum_{i\in H^c}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\sum_{\substack{s=(r-1)\tau+p\\ s\neq t}}^{(r-1)\tau+\tau_1+p-1}\frac{1}{64}E\left[\gamma_i'\underline{F}_t\underline{F}_t'\gamma_i+\varepsilon_{\ell,t+1}^2\right]^3 E\left[\gamma_i'\underline{F}_s\underline{F}_s'\gamma_i+\varepsilon_{\ell,s+1}^2\right]^3 \\
& +\frac{15}{q\tau_1^6}\sum_{r=1}^{q}\sum_{\ell=1}^{d}\sum_{i\in H^c}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\sum_{\substack{s=(r-1)\tau+p\\ s\neq t}}^{(r-1)\tau+\tau_1+p-1} E\left[\gamma_i'\underline{F}_t\underline{F}_t'\gamma_i\right]^2 E\left[\varepsilon_{\ell,t+1}^4\right] E\left[\gamma_i'\underline{F}_s\underline{F}_s'\gamma_i\right] E\left[\varepsilon_{\ell,s+1}^2\right] \\
& +\frac{90}{q\tau_1^6}\sum_{r=1}^{q}\sum_{\ell=1}^{d}\sum_{i\in H^c}\left\{\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\sum_{\substack{s=(r-1)\tau+p\\ s\neq t}}^{(r-1)\tau+\tau_1+p-1} E\left[\gamma_i'\underline{F}_t\underline{F}_t'\gamma_i\right] E\left[\varepsilon_{\ell,t+1}^2\right] E\left[\gamma_i'\underline{F}_s\underline{F}_s'\gamma_i\right] E\left[\varepsilon_{\ell,s+1}^2\right]\right. \\
& \qquad\qquad\qquad\qquad \left.\times\sum_{\substack{r=(r-1)\tau+p\\ r\neq t,\ r\neq s}}^{(r-1)\tau+\tau_1+p-1} E\left[\gamma_i'\underline{F}_r\underline{F}_r'\gamma_i\right] E\left[\varepsilon_{\ell,r+1}^2\right]\right\}
\end{aligned}
$$

$$
\begin{aligned}
&\leq \frac{1}{q\tau_1^6}\sum_{r=1}^{q}\sum_{\ell=1}^{d}\sum_{i\in H^c}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\left\|\gamma_i\right\|_2^6 E\left[\left\|\underline{F}_t\right\|_2^6\right] E\left[\varepsilon_{\ell,t+1}^6\right] \\
&\quad +\frac{(20\cdot 16)}{64q\tau_1^6}\sum_{r=1}^{q}\sum_{\ell=1}^{d}\sum_{i\in H^c}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\sum_{\substack{s=(r-1)\tau+p\\ s\neq t}}^{(r-1)\tau+\tau_1+p-1}\Big\{\left(E\left[\left(\gamma_i'\underline{F}_t\right)^6\right]+E\left[\varepsilon_{\ell,t+1}^6\right]\right) \\
&\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad \times\left(E\left[\left(\gamma_i'\underline{F}_s\right)^6\right]+E\left[\varepsilon_{\ell,s+1}^6\right]\right)\Big\} \\
&\quad +\frac{15}{q\tau_1^6}\sum_{r=1}^{q}\sum_{\ell=1}^{d}\sum_{i\in H^c}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\sum_{\substack{s=(r-1)\tau+p\\ s\neq t}}^{(r-1)\tau+\tau_1+p-1}\Big\{\left\|\gamma_i\right\|_2^4 E\left[\left\|\underline{F}_t\right\|_2^4\right] E\left[\varepsilon_{\ell,t+1}^4\right] \\
&\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad \times\left\|\gamma_i\right\|_2^2 E\left[\left\|\underline{F}_s\right\|_2^2\right] E\left[\varepsilon_{\ell,s+1}^2\right]\Big\} \\
&\quad +\frac{90}{q\tau_1^6}\sum_{r=1}^{q}\sum_{\ell=1}^{d}\sum_{i\in H^c}\left\{\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\left\|\gamma_i\right\|_2^2 E\left[\left\|\underline{F}_t\right\|_2^2\right] E\left[\varepsilon_{\ell,t+1}^2\right]\right. \\
&\qquad \left.\times\sum_{\substack{s=(r-1)\tau+p\\ s\neq t}}^{(r-1)\tau+\tau_1+p-1}\left\|\gamma_i\right\|_2^2 E\left[\left\|\underline{F}_s\right\|_2^2\right] E\left[\varepsilon_{\ell,s+1}^2\right]\sum_{\substack{r=(r-1)\tau+p\\ r\neq t,\ r\neq s}}^{(r-1)\tau+\tau_1+p-1}\left\|\gamma_i\right\|_2^2 E\left[\left\|\underline{F}_r\right\|_2^2\right] E\left[\varepsilon_{\ell,r+1}^2\right]\right\} \\
&\leq C\left(\frac{N_1}{\tau_1^5}+5\frac{N_1}{\tau_1^4}+15\frac{N_1}{\tau_1^4}+90\frac{N_1}{\tau_1^3}\right) \\
&\quad \text{(applying Assumptions 2-2(b), Assumption 2-5, and Lemma OA-5)} \\
&= O\left(\frac{N_1}{\tau_1^3}\right).
\end{aligned}
$$

It follows that

$$
P\left\{\max_{1\leq\ell\leq d}\max_{i\in H^c}\left|\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\underline{F}_t\varepsilon_{\ell,t+1}\right|\geq\epsilon\right\}=O\left(\frac{N_1}{\tau_1^3}\right)=o\left(1\right).
$$

To show part (b), note that, for any $\epsilon > 0$

$$
\begin{aligned}
& P\left\{\max_{1\leq \ell\leq d}\max_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\underline{F}_t\varepsilon_{\ell,t+1}\right)^2 \geq \epsilon\right\} \\
= \; & P\left\{\max_{1\leq \ell\leq d}\max_{i\in H^c}\left|\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\underline{F}_t\varepsilon_{\ell,t+1}\right)^2\right|^3 \geq \epsilon^3\right\} \\
\leq \; & P\left\{\max_{1\leq \ell\leq d}\max_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\underline{F}_t\varepsilon_{\ell,t+1}\right)^6 \geq \epsilon^3\right\} \\
& \text{(by Jensen't inequality)} \\
\leq \; & P\left\{\sum_{\ell=1}^{d}\sum_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\underline{F}_t\varepsilon_{\ell,t+1}\right)^6 \geq \epsilon^3\right\} \\
\leq \; & \frac{1}{\epsilon^3}\frac{1}{q}\sum_{r=1}^{q}\sum_{\ell=1}^{d}\sum_{i\in H^c}E\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\underline{F}_t\varepsilon_{\ell,t+1}\right)^6
\end{aligned}
$$

The rest of the proof for part (b) then follows in a manner similar to the argument given for part (a) above.

To show part (c), first note that, for any $\epsilon > 0$,

$$
\begin{aligned}
& P\left\{\max_{1\leq \ell\leq d}\max_{i\in H^c}\left|\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}y_{\ell,t+1}u_{it}\right| \geq \epsilon\right\} \\
= \; & P\left\{\max_{1\leq \ell\leq d}\max_{i\in H^c}\left(\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}y_{\ell,t+1}u_{it}\right)^6 \geq \epsilon^6\right\} \\
\leq \; & P\left\{\max_{1\leq \ell\leq d}\max_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}y_{\ell,t+1}u_{it}\right)^6 \geq \epsilon^6\right\} \\
& \text{(by convexity or Jensen's inequality)} \\
\leq \; & P\left\{\sum_{\ell=1}^{d}\sum_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}y_{\ell,t+1}u_{it}\right)^6 \geq \epsilon^6\right\} \\
\leq \; & \frac{1}{\epsilon^6}\frac{1}{q}\sum_{r=1}^{q}\sum_{\ell=1}^{d}\sum_{i\in H^c}E\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}y_{\ell,t+1}u_{it}\right)^6 \qquad (18)
\end{aligned}
$$

Now, there exists a constant $C_1 > 1$ such that

$$\begin{aligned}
&\frac{1}{q}\sum_{r=1}^{q}\sum_{\ell=1}^{d}\sum_{i\in H^c} E\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1} y_{\ell,t+1}u_{it}\right)^6 \\
\leq\ & \frac{C_1}{q\tau_1^6}\sum_{r=1}^{q}\sum_{i\in H^c}\left\{\sum_{\substack{t,s,g,h,v,w=(r-1)\tau+p \\ t\leq s\leq g\leq h\leq v\leq w}}^{(r-1)\tau+\tau_1+p-1} \left|E\left[u_{it}u_{is}u_{ig}u_{ih}u_{iv}u_{iw}\right]\right|\right. \\
&\left.\times\sum_{\ell=1}^{d}\left|E\left[y_{\ell,t+1}y_{\ell,s+1}y_{\ell,g+1}y_{\ell,h+1}y_{\ell,v+1}y_{\ell,w+1}\right]\right|\right\}
\end{aligned}$$

Next, note that, by repeated application of Hölder's inequality, we have by Lemma OA-5 that there exists a positive constant $\overline{C}$ such that

$$\begin{aligned}
&\sum_{\ell=1}^{d}\left|E\left[y_{\ell,t+1}y_{\ell,s+1}y_{\ell,g+1}y_{\ell,h+1}y_{\ell,v+1}y_{\ell,w+1}\right]\right| \\
\leq\ & \sum_{\ell=1}^{d}\left(E\left[y_{\ell,t+1}^2y_{\ell,s+1}^2y_{\ell,g+1}^2\right]\right)^{\frac{1}{2}}\left(E\left[y_{\ell,h+1}^2y_{\ell,v+1}^2y_{\ell,w+1}^2\right]\right)^{\frac{1}{2}} \\
\leq\ & \sum_{\ell=1}^{d}\left(\left\{E\left[y_{\ell,t+1}^6\right]\right\}^{\frac{1}{3}}\left(E\left[\left|y_{\ell,s+1}y_{\ell,g+1}\right|^3\right]\right)^{\frac{2}{3}}\right)^{\frac{1}{2}}\left(\left\{E\left[y_{\ell,h+1}^6\right]\right\}^{\frac{1}{3}}\left(E\left[\left|y_{\ell,v+1}y_{\ell,w+1}\right|^3\right]\right)^{\frac{2}{3}}\right)^{\frac{1}{2}} \\
\leq\ & \sum_{\ell=1}^{d}\left[\left(\left\{E\left[y_{\ell,t+1}^6\right]\right\}^{\frac{1}{3}}\left\{E\left[y_{\ell,s+1}^6\right]\right\}^{\frac{1}{3}}\left\{E\left[y_{\ell,g+1}^6\right]\right\}^{\frac{1}{3}}\right)^{\frac{1}{2}}\right. \\
&\left.\times\left(\left\{E\left[y_{\ell,h+1}^6\right]\right\}^{\frac{1}{3}}\left\{E\left[y_{\ell,v+1}^6\right]\right\}^{\frac{1}{3}}\left\{E\left[y_{\ell,w+1}^6\right]\right\}^{\frac{1}{3}}\right)^{\frac{1}{2}}\right] \\
\leq\ & \sum_{\ell=1}^{d}\left\{E\left[y_{\ell,t+1}^6\right]\right\}^{\frac{1}{6}}\left\{E\left[y_{\ell,s+1}^6\right]\right\}^{\frac{1}{6}}\left\{E\left[y_{\ell,g+1}^6\right]\right\}^{\frac{1}{6}}\left\{E\left[y_{\ell,h+1}^6\right]\right\}^{\frac{1}{6}}\left\{E\left[y_{\ell,v+1}^6\right]\right\}^{\frac{1}{6}}\left\{E\left[y_{\ell,w+1}^6\right]\right\}^{\frac{1}{6}} \\
\leq\ & d\max_{1\leq\ell\leq d}\sup_t E\left[y_{\ell,t}^6\right] \\
\leq\ & \overline{C} < \infty \\
&\Big(\text{since, given that } y_{\ell,t} = \mathbf{e}_{\ell,dp}'\underline{Y}_t;\ E\left[y_{\ell,t}^6\right] \leq E\left\|\underline{Y}_t\right\|_2^6 \leq \overline{C} \text{ by Lemma OA-5} \\
&\text{where } \overline{C} \text{ is a constant not depending on } \ell \text{ or } t\ \Big)
\end{aligned}$$

Hence, we can write

$$
\begin{aligned}
& \frac{1}{q}\sum_{r=1}^{q}\sum_{\ell=1}^{d}\sum_{i\in H^c} E\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1} y_{\ell,t+1}u_{it}\right)^6 \\
\leq \quad & \frac{C_1\overline{C}}{q\tau_1^6}\sum_{r=1}^{q}\sum_{i\in H^c}\sum_{\substack{t,s,g,h,v,w=(r-1)\tau+p \\ t\leq s\leq g\leq h\leq v\leq w}}^{(r-1)\tau+\tau_1+p-1} \left|E\left[u_{it}u_{is}u_{ig}u_{ih}u_{iv}u_{iw}\right]\right| \\
\leq \quad & \frac{C_1\overline{C}}{q\tau_1^6}\sum_{r=1}^{q}\sum_{i\in H^c}\sum_{\substack{t,s,g=(r-1)\tau+p \\ t\leq s\leq g}}^{(r-1)\tau+\tau_1+p-1} \left|E\left[u_{it}u_{is}u_{ig}^4\right]\right| \\
& +\frac{C_1\overline{C}}{q\tau_1^6}\sum_{r=1}^{q}\sum_{i\in H}\sum_{\substack{t,s,g,h,v,w=(r-1)\tau+p \\ t\leq s\leq g\leq h\leq v\leq w \\ w-v\geq\max\{v-h,h-g\},w-v>0}}^{(r-1)\tau+\tau_1+p-1} \left|E\left[u_{it}u_{is}u_{ig}u_{ih}u_{iv}u_{iw}\right]\right| \\
& +\frac{C_1\overline{C}}{q\tau_1^6}\sum_{r=1}^{q}\sum_{i\in H^c}\sum_{\substack{t,s,g,h,v,w=(r-1)\tau+p \\ t\leq s\leq g\leq h\leq v\leq w \\ v-h\geq\max\{w-v,h-g\},v-h>0}}^{(r-1)\tau+\tau_1+p-1} \left|E\left[u_{it}u_{is}u_{ig}u_{ih}u_{iv}u_{iw}\right]\right| \\
& +\frac{C_1\overline{C}}{q\tau_1^6}\sum_{r=1}^{q}\sum_{i\in H}\sum_{\substack{t,s,g,h,v,w=(r-1)\tau+p \\ t\leq s\leq g\leq h\leq v\leq w \\ h-g\geq\max\{w-v,v-h\},h-g>0}}^{(r-1)\tau+\tau_1+p-1} \left|E\left[u_{it}u_{is}u_{ig}u_{ih}u_{iv}u_{iw}\right]\right|
\end{aligned}
$$

$$
\begin{aligned}
&\le \frac{C_1\overline{C}}{q\tau_1^6}\sum_{r=1}^{q}\sum_{i\in H^c}\sum_{\substack{t,s,g=(r-1)\tau+p\\ t\le s\le g}}^{(r-1)\tau+\tau_1+p-1}\left|E\left[u_{it}u_{is}u_{ig}^4\right]\right| \\
&\quad+\frac{C_1\overline{C}}{q\tau_1^6}\sum_{r=1}^{q}\sum_{i\in H}\sum_{\substack{t,s,g,h,v,w=(r-1)\tau+p\\ t\le s\le g\le h\le v\le w\\ w-v\ge\max\{v-h,h-g\},w-v>0}}^{(r-1)\tau+\tau_1+p-1}\left|E\left[u_{it}u_{is}u_{ig}u_{ih}u_{iv}u_{iw}\right]\right| \\
&\quad+\frac{C_1\overline{C}}{q\tau_1^6}\sum_{r=1}^{q}\sum_{i\in H^c}\sum_{\substack{t,s,g,h,v,w=(r-1)\tau+p\\ t\le s\le g\le h\le v\le w\\ v-h\ge\max\{w-v,h-g\},v-h>0}}^{(r-1)\tau+\tau_1+p-1}\left|E\left[\left\{u_{it}u_{is}u_{ig}u_{ih}-E\left(u_{it}u_{is}u_{ig}u_{ih}\right)\right\}u_{iv}u_{iw}\right]\right| \\
&\quad+\frac{C_1\overline{C}}{q\tau_1^6}\sum_{r=1}^{q}\sum_{i\in H^c}\sum_{\substack{t,s,g,h,v,w=(r-1)\tau+p\\ t\le s\le g\le h\le v\le w\\ v-h\ge\max\{w-v,h-g\},v-h>0}}^{(r-1)\tau+\tau_1+p-1}\left|E\left(u_{it}u_{is}u_{ig}u_{ih}\right)\right|\left|E\left(u_{iv}u_{iw}\right)\right| \\
&\quad+\frac{C_1\overline{C}}{q\tau_1^6}\sum_{r=1}^{q}\sum_{i\in H^c}\sum_{\substack{t,s,g,h,v,w=(r-1)\tau+p\\ t\le s\le g\le h\le v\le w\\ h-g\ge\max\{w-v,v-h\},h-g>0}}^{(r-1)\tau+\tau_1+p-1}\left|E\left[\left\{u_{it}u_{is}u_{ig}-E\left(u_{it}u_{is}u_{ig}\right)\right\}u_{ih}u_{iv}u_{iw}\right]\right| \\
&\quad+\frac{C_1\overline{C}}{q\tau_1^6}\sum_{r=1}^{q}\sum_{i\in H^c}\sum_{\substack{t,s,g,h,v,w=(r-1)\tau+p\\ t\le s\le g\le h\le v\le w\\ h-g\ge\max\{w-v,v-h\},h-g>0}}^{(r-1)\tau+\tau_1+p-1}\left|E\left(u_{it}u_{is}u_{ig}\right)\right|\left|E\left(u_{ih}u_{iv}u_{iw}\right)\right| \\
&= \mathcal{T}_1+\mathcal{T}_2+\mathcal{T}_3+\mathcal{T}_4+\mathcal{T}_5+\mathcal{T}_6,\ \ (say)\,. \qquad (19)
\end{aligned}
$$

Consider first $\mathcal{T}_1$. Note that

$$
\begin{aligned}
\mathcal{T}_1 &= \frac{C_1\overline{C}}{q\tau_1^6}\sum_{r=1}^{q}\sum_{i\in H^c}\sum_{\substack{t,s,g=(r-1)\tau+p\\ t\leq s\leq g}}^{(r-1)\tau+\tau_1+p-1}\left|E\left[u_{it}u_{is}u_{ig}^4\right]\right| \\
&\leq \frac{C_1\overline{C}}{q\tau_1^6}\sum_{r=1}^{q}\sum_{i\in H^c}\sum_{\substack{t,s,g=(r-1)\tau+p\\ t\leq s\leq g}}^{(r-1)\tau+\tau_1+p-1} E\left[\left|u_{it}u_{is}u_{ig}^4\right|\right] \\
&\leq \frac{C_1\overline{C}}{q\tau_1^6}\sum_{r=1}^{q}\sum_{i\in H^c}\sum_{\substack{t,s,g=(r-1)\tau+p\\ t\leq s\leq g}}^{(r-1)\tau+\tau_1+p-1} \left(E\left[\left|u_{it}u_{is}\right|^3\right]\right)^{\frac{1}{3}}\left(E\left[\left|u_{ig}\right|^6\right]\right)^{\frac{2}{3}} \quad \text{(by Hölder's inequality)} \\
&\leq \frac{C_1\overline{C}}{q\tau_1^6}\sum_{r=1}^{q}\sum_{i\in H^c}\sum_{\substack{t,s,g=(r-1)\tau+p\\ t\leq s\leq g}}^{(r-1)\tau+\tau_1+p-1} \left(\left[E\left\{\left|u_{it}\right|^6\right\}\right]^{\frac{1}{2}}\left[E\left\{\left|u_{is}\right|^6\right\}\right]^{\frac{1}{2}}\right)^{\frac{1}{3}}\left(E\left[\left|u_{ig}\right|^6\right]\right)^{\frac{2}{3}} \\
&\quad\ \text{(by further application of Hölder's inequality)} \\
&= \frac{C_1\overline{C}}{q\tau_1^6}\sum_{r=1}^{q}\sum_{i\in H^c}\sum_{\substack{t,s,g=(r-1)\tau+p\\ t\leq s\leq g}}^{(r-1)\tau+\tau_1+p-1} \left(E\left\{\left|u_{it}\right|^6\right\}\right)^{\frac{1}{6}}\left(E\left\{\left|u_{it}\right|^6\right\}\right)^{\frac{1}{6}}\left(E\left[\left|u_{ig}\right|^6\right]\right)^{\frac{2}{3}} \\
&\leq \frac{C_1\overline{C}}{q\tau_1^6}\sum_{r=1}^{q}\sum_{i\in H^c}\sum_{\substack{t,s,g=(r-1)\tau+p\\ t\leq s\leq g}}^{(r-1)\tau+\tau_1+p-1} \overline{C} \quad \text{(by Assumption 2-3(b))} \\
&\leq C_1\overline{C}^2\frac{N_1}{\tau_1^5} \\
&= O\left(\frac{N_1}{\tau_1^5}\right).
\end{aligned}
\tag{20}
$$

Next, consider $\mathcal{T}_2$. For this term, note first that by Assumption 2-3(c), $\{u_{it}\}_{t=-\infty}^{\infty}$ is β-mixing with β mixing coefficient satisfying

$$\beta_i\left(m\right) \leq a_1\exp\left\{-a_2 m\right\}$$

for every i. Since $\alpha_{i,m} \leq \beta_i\left(m\right)$, it follows that $\{u_{it}\}_{t=-\infty}^{\infty}$ is α-mixing as well, with α mixing coefficient satisfying

$$\alpha_{i,m} \leq a_1\exp\left\{-a_2 m\right\} \text{ for every } i.$$

Hence, we apply Lemma OA-3 with $p = 5/4$ and $r = 6$ to obtain

$$\begin{aligned}
& \mathcal{T}_2 \\
= \; & \frac{C_1 \overline{C}}{q \tau_1^6} \sum_{r=1}^{q} \sum_{i \in H^c} \sum_{\substack{t,s,g,h,v,w=(r-1)\tau+p \\ t \leq s \leq g \leq h \leq v \leq w \\ w-v \geq \max\{v-h,h-g\}, w-v>0}}^{(r-1)\tau+\tau_1+p-1} \left| E \left[u_{it} u_{is} u_{ig} u_{ih} u_{iv} u_{iw} \right] \right| \\
\leq \; & \frac{C_1 \overline{C}}{q \tau_1^6} \sum_{r=1}^{q} \sum_{i \in H^c} \sum_{\substack{t,s,g,h,v,w=(r-1)\tau+p \\ t \leq s \leq g \leq h \leq v \leq w \\ w-v \geq \max\{v-h,h-g\}, w-v>0}}^{(r-1)\tau+\tau_1+p-1} \Big\{ 2 \left(2^{1-\frac{4}{5}} + 1 \right) \left[a_1 \exp\left\{ -a_2 (w-v) \right\} \right]^{1-\frac{4}{5}-\frac{1}{6}} \\
& \times \left(E \left| u_{it} u_{is} u_{ig} u_{ih} u_{iv} \right|^{\frac{5}{4}} \right)^{\frac{4}{5}} \left(E \left| u_{iw} \right|^6 \right)^{\frac{1}{6}} \Big\}
\end{aligned}$$

Next, by Liapunov's inequality and Assumption 2-3(b), we obtain

$$\left(E \left| u_{iw} \right|^6 \right)^{\frac{1}{6}} \leq \left(E \left| u_{iw} \right|^7 \right)^{\frac{1}{7}} \leq \overline{C}^{\frac{1}{7}}$$

Making use of this bound and by repeated application of Hölder's inequality, we have

$$\begin{aligned}
& E \left| u_{it} u_{is} u_{ig} u_{ih} u_{iv} \right|^{\frac{5}{4}} \\
\leq \; & \left[E \left| u_{it} u_{is} u_{ig} \right|^{\frac{25}{12}} \right]^{\frac{3}{5}} \left[E \left| u_{ih} u_{iv} \right|^{\frac{25}{8}} \right]^{\frac{2}{5}} \\
\leq \; & \left[\left(E \left| u_{it} u_{is} \right|^{\frac{150}{47}} \right)^{\frac{47}{72}} \left(E \left| u_{ig} \right|^6 \right)^{\frac{25}{72}} \right]^{\frac{3}{5}} \left[\left(E \left| u_{ih} \right|^{\frac{25}{4}} \right)^{\frac{1}{2}} \left(E \left| u_{iv} \right|^{\frac{25}{4}} \right)^{\frac{1}{2}} \right]^{\frac{2}{5}} \\
\leq \; & \left[\left(\sqrt{E \left| u_{it} \right|^{\frac{300}{47}}} \sqrt{E \left| u_{is} \right|^{\frac{300}{47}}} \right)^{\frac{47}{72}} \left(E \left| u_{ig} \right|^6 \right)^{\frac{25}{72}} \right]^{\frac{3}{5}} \left[\left(E \left| u_{ih} \right|^{\frac{25}{4}} \right)^{\frac{1}{2}} \left(E \left| u_{iv} \right|^{\frac{25}{4}} \right)^{\frac{1}{2}} \right]^{\frac{2}{5}} \\
= \; & \left(E \left| u_{it} \right|^{\frac{300}{47}} \right)^{\frac{141}{720}} \left(E \left| u_{is} \right|^{\frac{300}{47}} \right)^{\frac{141}{720}} \left(E \left| u_{ih} \right|^6 \right)^{\frac{15}{72}} \left(E \left| u_{iv} \right|^{\frac{25}{4}} \right)^{\frac{1}{5}} \left(E \left| u_{iw} \right|^{\frac{25}{4}} \right)^{\frac{1}{5}} \\
= \; & \left[\left(E \left| u_{it} \right|^{\frac{300}{47}} \right)^{\frac{47}{300}} \left(E \left| u_{is} \right|^{\frac{300}{47}} \right)^{\frac{47}{300}} \right]^{\frac{5}{4}} \left[\left(E \left| u_{ih} \right|^6 \right)^{\frac{1}{6}} \right]^{\frac{5}{4}} \left[\left(E \left| u_{iv} \right|^{\frac{25}{4}} \right)^{\frac{4}{25}} \right]^{\frac{5}{4}} \left[\left(E \left| u_{iw} \right|^{\frac{25}{4}} \right)^{\frac{4}{25}} \right]^{\frac{5}{4}} \\
\leq \; & \left[\left(E \left| u_{it} \right|^7 \right)^{\frac{1}{7}} \left(E \left| u_{is} \right|^7 \right)^{\frac{1}{7}} \right]^{\frac{5}{4}} \left[\left(E \left| u_{ih} \right|^7 \right)^{\frac{1}{7}} \right]^{\frac{5}{4}} \left[\left(E \left| u_{iv} \right|^7 \right)^{\frac{1}{7}} \right]^{\frac{5}{4}} \left[\left(E \left| u_{iw} \right|^7 \right)^{\frac{1}{7}} \right]^{\frac{5}{4}} \\
\leq \; & \left(\overline{C} \right)^{\frac{5}{28}} \left(\overline{C} \right)^{\frac{5}{28}} \left(\overline{C} \right)^{\frac{5}{28}} \left(\overline{C} \right)^{\frac{5}{28}} \left(\overline{C} \right)^{\frac{5}{28}} \quad \text{(by Assumption 2-3(b))} \\
= \; & \overline{C}^{\frac{25}{28}}
\end{aligned}$$

Moreover, let $\rho_1 = h - g$, $\rho_2 = v - h$, and $\rho_3 = w - v$, so that $h = g + \rho_1$, $v = h + \rho_2 = g + \rho_1 + \rho_2$, $w = v + \rho_3 = g + \rho_1 + \rho_2 + \rho_3$. Using these notations and the boundedness of $E\left|u_{it}u_{is}u_{ig}u_{ih}u_{iv}\right|^{\frac{5}{4}}$ as shown above, we can further write

$$\begin{aligned}
& \mathcal{T}_2 \\
\leq\ & \frac{C_1\overline{C}}{q\tau_1^6}\sum_{r=1}^{q}\sum_{i\in H^c}\sum_{\substack{t,s,g,h,v,w=(r-1)\tau+p \\ t\leq s\leq g\leq h\leq v\leq w \\ w-v\geq\max\{v-h,h-g\},w-v>0}}^{(r-1)\tau+\tau_1+p-1}\left\{2\left(2^{1-\frac{4}{5}}+1\right)\left[a_1\exp\left\{-a_2\left(w-v\right)\right\}\right]^{1-\frac{4}{5}-\frac{1}{6}}\right. \\
& \left.\times\left(E\left|u_{it}u_{is}u_{ig}u_{ih}u_{iv}\right|^{\frac{5}{4}}\right)^{\frac{4}{5}}\left(E\left|u_{iw}\right|^{6}\right)^{\frac{1}{6}}\right\} \\
\leq\ & \frac{C_1\overline{C}}{q\tau_1^6}\sum_{r=1}^{q}\sum_{i\in H^c}\sum_{\substack{t,s,g,h,v,w=(r-1)\tau+p \\ t\leq s\leq g\leq h\leq v\leq w \\ w-v\geq\max\{v-h,h-g\},w-v>0}}^{(r-1)\tau+\tau_1+p-1}2\left(2^{\frac{1}{5}}+1\right)\left[a_1\exp\left\{-a_2\left(w-v\right)\right\}\right]^{\frac{1}{30}}\overline{C}^{\frac{25}{28}}\overline{C}^{\frac{1}{7}} \\
\leq\ & \frac{C_1\overline{C}^{\frac{57}{28}}}{q\tau_1^6}\sum_{r=1}^{q}\sum_{i\in H^c}\sum_{\substack{t,s,g,h,v,w=(r-1)\tau+p \\ t\leq s\leq g\leq h\leq v\leq w \\ w-v\geq\max\{v-h,h-g\},w-v>0}}^{(r-1)\tau+\tau_1+p-1}2\left(2^{\frac{1}{5}}+1\right)\left[a_1\exp\left\{-a_2\left(w-v\right)\right\}\right]^{\frac{1}{30}} \\
\leq\ & \frac{C^*}{q\tau_1^6}\sum_{r=1}^{q}\sum_{i\in H^c}\sum_{\substack{t,s,g,h,v,w=(r-1)\tau+p \\ t\leq s\leq g\leq h\leq v\leq w \\ w-v\geq\max\{v-h,h-g\},w-v>0}}^{(r-1)\tau+\tau_1+p-1}\exp\left\{-\frac{a_2}{30}\rho_3\right\} \\
& \left(\text{for some constant } C^* \text{ such that } 2\left(2^{\frac{1}{5}}+1\right)C_1\overline{C}^{\frac{57}{28}}a_1^{\frac{1}{30}}\leq C^*<\infty\right) \\
\leq\ & \frac{C^*}{q\tau_1^6}\sum_{r=1}^{q}\sum_{i\in H^c}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\sum_{s=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\sum_{g=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\sum_{\rho_3=1}^{\infty}\sum_{\rho_1=0}^{\rho_3}\sum_{\rho_2=0}^{\rho_3}\exp\left\{-\frac{a_2}{30}\rho_3\right\} \\
\leq\ & \frac{C^*}{q\tau_1^6}\sum_{r=1}^{q}\sum_{i\in H^c}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\sum_{s=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\sum_{g=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\sum_{\rho_3=1}^{\infty}\left(\rho_3+1\right)^2\exp\left\{-\frac{a_2}{30}\rho_3\right\} \\
=\ & C^*\frac{N_1}{\tau_1^3}\left[\sum_{\rho_3=1}^{\infty}\rho_3^2\exp\left\{-\frac{a_2}{30}\rho_3\right\}+2\sum_{\rho_3=1}^{\infty}\rho_3\exp\left\{-\frac{a_2}{30}\rho_3\right\}+\sum_{\rho_3=1}^{\infty}\exp\left\{-\frac{a_2}{30}\rho_3\right\}\right] \\
=\ & O\left(\frac{N_1}{\tau_1^3}\right)\quad\text{(by Lemma OA-1)}. \qquad (21)
\end{aligned}$$

Now, consider $\mathcal{T}_3$. Here, we can apply Lemma OA-3 with $p = 3/2$ and $r = 7/2$ to obtain

$$\begin{aligned}
\mathcal{T}_3 &= \frac{C_1 \overline{C}}{q\tau_1^6} \sum_{r=1}^{q} \sum_{i \in H^c} \sum_{\substack{t,s,g,h,v,w=(r-1)\tau+p \\ t \leq s \leq g \leq h \leq v \leq w \\ v-h \geq \max\{w-v,h-g\}, v-h>0}}^{(r-1)\tau+\tau_1+p-1} \left| E\left[\left\{ u_{it}u_{is}u_{ig}u_{ih} - E\left(u_{it}u_{is}u_{ig}u_{ih}\right) \right\} u_{iv}u_{iw} \right] \right| \\
&\leq \frac{C_1 \overline{C}}{q\tau_1^6} \sum_{r=1}^{q} \sum_{i \in H^c} \sum_{\substack{t,s,g,h,v,w=(r-1)\tau+p \\ t \leq s \leq g \leq h \leq v \leq w \\ v-h \geq \max\{w-v,h-g\}, v-h>0}}^{(r-1)\tau+\tau_1+p-1} \Big\{ 2\left(2^{1-\frac{2}{3}}+1\right) \left[a_1 \exp\left\{-a_2\left(v-h\right)\right\}\right]^{1-\frac{2}{3}-\frac{2}{7}} \\
&\qquad \times \left(E\left| \left\{ u_{it}u_{is}u_{ig}u_{ih} - E\left(u_{it}u_{is}u_{ig}u_{ih}\right) \right\} \right|^{\frac{3}{2}} \right)^{\frac{2}{3}} \left(E\left|u_{iv}u_{iw}\right|^{\frac{7}{2}} \right)^{\frac{2}{7}} \Big\}
\end{aligned}$$

Next, note that applications of Hölder's inequality yield

$$\begin{aligned}
E\left|u_{iv}u_{iw}\right|^{\frac{7}{2}} &\leq \left(E\left|u_{iv}\right|^7\right)^{\frac{1}{2}} \left(E\left|u_{iw}\right|^7\right)^{\frac{1}{2}} \\
&\leq \left(\overline{C}\right)^{\frac{1}{2}} \left(\overline{C}\right)^{\frac{1}{2}} \quad \text{(by Assumption 2-3(b))} \\
&= \overline{C} < \infty
\end{aligned}$$

and

$$\begin{aligned}
E\left| \left\{ u_{it}u_{is}u_{ig}u_{ih} - E\left(u_{it}u_{is}u_{ig}u_{ih}\right) \right\} \right|^{\frac{3}{2}} &\leq 2^{\frac{1}{2}} \left(E\left|u_{it}u_{is}u_{ig}u_{ih}\right|^{\frac{3}{2}} + E\left|u_{it}u_{is}u_{ig}u_{ih}\right|^{\frac{3}{2}} \right) \\
&\qquad \text{(by Loève's } c_r \text{ inequality)} \\
&\leq 2^{\frac{3}{2}} E\left|u_{it}u_{is}u_{ig}u_{ih}\right|^{\frac{3}{2}} \\
&\leq 2^{\frac{3}{2}} \left(E\left|u_{it}u_{is}\right|^3\right)^{\frac{1}{2}} \left(E\left|u_{ig}u_{ih}\right|^3\right)^{\frac{1}{2}} \\
&\leq 2^{\frac{3}{2}} \left(\left(E\left|u_{it}\right|^6\right)^{\frac{1}{2}} \left(E\left|u_{is}\right|^6\right)^{\frac{1}{2}} \right)^{\frac{1}{2}} \left(\left(E\left|u_{ig}\right|^6\right)^{\frac{1}{2}} \left(E\left|u_{ih}\right|^6\right)^{\frac{1}{2}} \right)^{\frac{1}{2}} \\
&\leq 2^{\frac{3}{2}} \left[\left(E\left|u_{it}\right|^6\right)^{\frac{1}{6}} \left(E\left|u_{is}\right|^6\right)^{\frac{1}{6}} \left(E\left|u_{ig}\right|^6\right)^{\frac{1}{6}} \left(E\left|u_{ih}\right|^6\right)^{\frac{1}{6}} \right]^{\frac{3}{2}} \\
&\leq 2^{\frac{3}{2}} \left[\left(E\left|u_{it}\right|^7\right)^{\frac{1}{7}} \left(E\left|u_{is}\right|^7\right)^{\frac{1}{7}} \left(E\left|u_{ig}\right|^7\right)^{\frac{1}{7}} \left(E\left|u_{ih}\right|^7\right)^{\frac{1}{7}} \right]^{\frac{3}{2}} \\
&\qquad \text{(by Liapunov's inequality)} \\
&\leq 2^{\frac{3}{2}} \left[\left(\sup_{i,t} E\left|u_{it}\right|^7 \right)^{\frac{4}{7}} \right]^{\frac{3}{2}} \\
&= 2^{\frac{3}{2}} \overline{C}^{\frac{6}{7}} \quad \text{(by Assumption 2-3(b))}
\end{aligned}$$

Again, let $\rho_1 = h - g$, $\rho_2 = v - h$, and $\rho_3 = w - v$, so that $h = g + \rho_1$, $v = h + \rho_2 = g + \rho_1 + \rho_2$, $w = v + \rho_3 = g + \rho_1 + \rho_2 + \rho_3$. Using these notations and the boundedness of $E\left|u_{iv}u_{iw}\right|^{\frac{7}{2}}$

and $E\left|\left\{u_{it}u_{is}u_{ig}u_{ih}-E\left(u_{it}u_{is}u_{ig}u_{ih}\right)\right\}\right|^{\frac{3}{2}}$ as shown above, we can further write

$$\begin{aligned}
\mathcal{T}_3 &= \frac{C_1\overline{C}}{q\tau_1^6}\sum_{r=1}^{q}\sum_{i\in H^c}\sum_{\substack{t,s,g,h,v,w=(r-1)\tau+p\\ t\leq s\leq g\leq h\leq v\leq w\\ v-h\geq\max\{w-v,h-g\},v-h>0}}^{(r-1)\tau+\tau_1+p-1}\left|E\left[\left\{u_{it}u_{is}u_{ig}u_{ih}-E\left(u_{it}u_{is}u_{ig}u_{ih}\right)\right\}u_{iv}u_{iw}\right]\right| \\
&\leq \frac{C_1\overline{C}}{q\tau_1^6}\sum_{r=1}^{q}\sum_{i\in H^c}\sum_{\substack{t,s,g,h,v,w=(r-1)\tau+p\\ t\leq s\leq g\leq h\leq v\leq w\\ v-h\geq\max\{w-v,h-g\},v-h>0}}^{(r-1)\tau+\tau_1+p-1}\Big\{2\left(2^{1-\frac{2}{3}}+1\right)\left[a_1\exp\left\{-a_2\left(v-h\right)\right\}\right]^{1-\frac{2}{3}-\frac{2}{7}} \\
&\qquad\qquad \times\left(E\left|\left\{u_{it}u_{is}u_{ig}u_{ih}-E\left(u_{it}u_{is}u_{ig}u_{ih}\right)\right\}\right|^{\frac{3}{2}}\right)^{\frac{2}{3}}\left(E\left|u_{iv}u_{iw}\right|^{\frac{7}{2}}\right)^{\frac{2}{7}}\Big\} \\
&\leq \frac{C_1\overline{C}}{q\tau_1^6}\sum_{r=1}^{q}\sum_{i\in H^c}\sum_{\substack{t,s,g,h,v,w=(r-1)\tau+p\\ t\leq s\leq g\leq h\leq v\leq w\\ v-h\geq\max\{w-v,h-g\},v-h>0}}^{(r-1)\tau+\tau_1+p-1} 2\left(2^{\frac{1}{3}}+1\right)\left[a_1\exp\left\{-a_2\left(v-h\right)\right\}\right]^{\frac{1}{21}}\left(2^{\frac{3}{2}}\overline{C}^{\frac{6}{7}}\right)^{\frac{2}{3}}\left(\overline{C}\right)^{\frac{2}{7}} \\
&\leq \frac{C^*}{q\tau_1^6}\sum_{r=1}^{q}\sum_{i\in H^c}\sum_{\substack{t,s,g,h,v,w=(r-1)\tau+p\\ t\leq s\leq g\leq h\leq v\leq w\\ v-h\geq\max\{w-v,h-g\},v-h>0}}^{(r-1)\tau+\tau_1+p-1}\exp\left\{-\frac{a_2}{21}\varrho_2\right\} \\
&\qquad \left(\text{for some constant } C^* \text{ such that } 4\left(2^{\frac{1}{3}}+1\right)C_1\overline{C}^{\frac{13}{7}}a_1^{\frac{1}{21}}\leq C^*<\infty\right) \\
&\leq \frac{C^*}{q\tau_1^6}\sum_{r=1}^{q}\sum_{i\in H^c}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\sum_{s=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\sum_{g=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\sum_{\varrho_2=1}^{\infty}\sum_{\varrho_1=0}^{\varrho_2}\sum_{\varrho_3=0}^{\varrho_2}\exp\left\{-\frac{a_2}{21}\varrho_2\right\} \\
&\leq C^*\frac{N_1}{\tau_1^3}\sum_{\varrho_2=1}^{\infty}\left(\varrho_2+1\right)^2\exp\left\{-\frac{a_2}{21}\varrho_2\right\} \\
&= C^*\frac{N_1}{\tau_1^3}\left[\sum_{\varrho_2=1}^{\infty}\varrho_2^2\exp\left\{-\frac{a_2}{21}\varrho_2\right\}+2\sum_{\varrho_2=1}^{\infty}\varrho_2\exp\left\{-\frac{a_2}{21}\varrho_2\right\}+\sum_{\varrho_2=1}^{\infty}\exp\left\{-\frac{a_2}{21}\varrho_2\right\}\right] \\
&= O\left(\frac{N_1}{\tau_1^3}\right) \quad \text{(by Lemma OA-1)}. \qquad (22)
\end{aligned}$$

Turning our attention to the term $\mathcal{T}_4$, note that, from the upper bounds given in the proofs of parts (a) and (c) of Lemma OA-4, it is clear that there exists a positive constant C such that

$$\frac{1}{\tau_1^4}\sum_{\substack{t,s,g,h=(r-1)\tau+p\\ t\leq s\leq g\leq h}}^{(r-1)\tau+\tau_1+p-1}\left|E\left(u_{it}u_{is}u_{ig}u_{ih}\right)\right|\leq\frac{C}{\tau_1^2}$$

and

$$\frac{1}{\tau_1^2} \sum_{\substack{v,w=(r-1)\tau+p \\ v \leq w}}^{(r-1)\tau+\tau_1+p-1} \left| E\left(u_{iv}u_{iw}\right)\right| \leq \frac{C}{\tau_1}$$

from which it follows that

$$\begin{aligned}
\mathcal{T}_4 &= \frac{C_1\overline{C}}{q\tau_1^6} \sum_{r=1}^{q} \sum_{i \in H^c} \sum_{\substack{t,s,g,h,v,w=(r-1)\tau+p \\ t \leq s \leq g \leq h \leq v \leq w \\ v-h \geq \max\{w-v,h-g\}, v-h>0}}^{(r-1)\tau+\tau_1+p-1} \left| E\left(u_{it}u_{is}u_{ig}u_{ih}\right)\right| \left| E\left(u_{iv}u_{iw}\right)\right| \\
&\leq \frac{C_1\overline{C}}{q} \sum_{r=1}^{q} \sum_{i \in H^c} \left(\frac{1}{\tau_1^4} \sum_{\substack{t,s,g,h=(r-1)\tau+p \\ t \leq s \leq g \leq h}}^{(r-1)\tau+\tau_1+p-1} \left| E\left(u_{it}u_{is}u_{ig}u_{ih}\right)\right| \right) \left(\frac{1}{\tau_1^2} \sum_{\substack{v,w=(r-1)\tau+p \\ v \leq w}}^{(r-1)\tau+\tau_1+p-1} \left| E\left(u_{iv}u_{iw}\right)\right| \right) \\
&\leq \frac{C_1\overline{C}}{q} \sum_{r=1}^{q} \sum_{i \in H^c} \left(\frac{C}{\tau_1^2}\right)\left(\frac{C}{\tau_1}\right) \\
&= C_1\overline{C}C^2 \frac{N_1}{\tau_1^3} \\
&= O\left(\frac{N_1}{\tau_1^3}\right). \qquad (23)
\end{aligned}$$

Consider now $\mathcal{T}_5$. In this case, we apply Lemma OA-3 with $p = 2$ and $r = 9/4$ to obtain

$$\begin{aligned}
\mathcal{T}_5 &= \frac{C_1\overline{C}}{q\tau_1^6} \sum_{r=1}^{q} \sum_{i \in H^c} \sum_{\substack{t,s,g,h,v,w=(r-1)\tau+p \\ t \leq s \leq g \leq h \leq v \leq w \\ h-g \geq \max\{w-v,v-h\}, h-g>0}}^{(r-1)\tau+\tau_1+p-1} \left| E\left[\left\{u_{it}u_{is}u_{ig} - E\left(u_{it}u_{is}u_{ig}\right)\right\} u_{ih}u_{iv}u_{iw}\right]\right| \\
&\leq \frac{C_1\overline{C}}{q\tau_1^6} \sum_{r=1}^{q} \sum_{i \in H^c} \sum_{\substack{t,s,g,h,v,w=(r-1)\tau+p \\ t \leq s \leq g \leq h \leq v \leq w \\ h-g \geq \max\{w-v,v-h\}, h-g>0}}^{(r-1)\tau+\tau_1+p-1} \Big\{ 2\left(2^{1-\frac{1}{2}}+1\right)\left[a_1 \exp\left\{-a_2\left(h-g\right)\right\}\right]^{1-\frac{1}{2}-\frac{4}{9}} \\
&\qquad \times \left(E\left|\left\{u_{it}u_{is}u_{ig} - E\left(u_{it}u_{is}u_{ig}\right)\right\}\right|^2\right)^{\frac{1}{2}} \left(E\left|u_{ih}u_{iv}u_{iw}\right|^{\frac{9}{4}}\right)^{\frac{4}{9}} \Big\}
\end{aligned}$$

Next, by repeated application of Hölder's inequality, we obtain

$$
\begin{aligned}
& E\left|u_{ih}u_{iv}u_{iw}\right|^{\frac{9}{4}} \\
\leq\ & \left[E\left|u_{ih}\right|^{7}\right]^{\frac{9}{28}}\left[E\left|u_{iv}u_{iw}\right|^{\frac{63}{19}}\right]^{\frac{19}{28}} \\
\leq\ & \left[E\left|u_{ih}\right|^{7}\right]^{\frac{9}{28}}\left[\left(E\left|u_{iv}\right|^{\frac{126}{19}}\right)^{\frac{1}{2}}\left(E\left|u_{iw}\right|^{\frac{126}{19}}\right)^{\frac{1}{2}}\right]^{\frac{19}{28}} \\
=\ & \left[E\left|u_{ih}\right|^{7}\right]^{\frac{9}{28}}\left(E\left|u_{iv}\right|^{\frac{126}{19}}\right)^{\frac{19}{56}}\left(E\left|u_{iw}\right|^{\frac{126}{19}}\right)^{\frac{19}{56}} \\
=\ & \left[E\left|u_{ih}\right|^{7}\right]^{\frac{9}{28}}\left[\left(E\left|u_{iv}\right|^{\frac{126}{19}}\right)^{\frac{19}{126}}\left(E\left|u_{iw}\right|^{\frac{126}{19}}\right)^{\frac{19}{126}}\right]^{\frac{9}{4}} \\
\leq\ & \left[E\left|u_{ih}\right|^{7}\right]^{\frac{9}{28}}\left[\left(E\left|u_{iv}\right|^{7}\right)^{\frac{1}{7}}\left(E\left|u_{iw}\right|^{7}\right)^{\frac{1}{7}}\right]^{\frac{9}{4}} \quad \text{(by Liapunov's inequality)} \\
\leq\ & \left(\sup_{i,t} E\left|u_{it}\right|^{7}\right)^{\frac{27}{28}} \\
\leq\ & \overline{C}^{\frac{27}{28}} \quad \text{(by Assumption 2-3(b))}
\end{aligned}
$$

and

$$
\begin{aligned}
E\left|\left\{u_{it}u_{is}u_{ig}-E\left(u_{it}u_{is}u_{ig}\right)\right\}\right|^{2} \leq\ & 2\left(E\left|u_{it}u_{is}u_{ig}\right|^{2}+E\left|u_{it}u_{is}u_{ig}\right|^{2}\right) \\
& \text{(by Loève's } c_r \text{ inequality)} \\
\leq\ & 4E\left|u_{it}u_{is}u_{ig}\right|^{2} \\
\leq\ & 4\left(E\left|u_{it}\right|^{6}\right)^{\frac{1}{3}}\left(E\left|u_{is}u_{ig}\right|^{3}\right)^{\frac{2}{3}} \\
\leq\ & 4\left(E\left|u_{it}\right|^{6}\right)^{\frac{1}{3}}\left(\sqrt{E\left|u_{is}\right|^{6}}\sqrt{E\left|u_{ig}\right|^{6}}\right)^{\frac{2}{3}} \\
=\ & 4\left[\left(E\left|u_{it}\right|^{6}\right)^{\frac{1}{6}}\right]^{2}\left[\left(E\left|u_{is}\right|^{6}\right)^{\frac{1}{6}}\left(E\left|u_{ig}\right|^{6}\right)^{\frac{1}{6}}\right]^{2} \\
\leq\ & 4\left[\left(E\left|u_{it}\right|^{7}\right)^{\frac{1}{7}}\right]^{2}\left[\left(E\left|u_{is}\right|^{7}\right)^{\frac{1}{7}}\left(E\left|u_{ig}\right|^{7}\right)^{\frac{1}{7}}\right]^{2} \\
& \text{(by Liapunov's inequality)} \\
\leq\ & 4\left[\left(\sup_{i,t} E\left|u_{it}\right|^{7}\right)^{\frac{1}{7}}\right]^{6} \\
\leq\ & 4\overline{C}^{\frac{6}{7}} \quad \text{(by Assumption 2-3(b))}
\end{aligned}
$$

Define again $\rho_1 = h - g$, $\rho_2 = v - h$, and $\rho_3 = w - v$, so that $h = g + \rho_1$, $v = h + \rho_2 = g + \rho_1 + \rho_2$, $w = v + \rho_3 = g + \rho_1 + \rho_2 + \rho_3$. Using these notations and the boundedness of $E\left|u_{ih}u_{iv}u_{iw}\right|^{\frac{9}{4}}$

and $E\left|\left\{u_{it}u_{is}u_{ig}-E\left(u_{it}u_{is}u_{ig}\right)\right\}\right|^{2}$ as shown above, we can further write

$$\begin{aligned}
&\mathcal{T}_5 \\
\leq\ & \frac{C_1\overline{C}}{q\tau_1^6}\sum_{r=1}^{q}\sum_{i\in H^c}\sum_{\substack{t,s,g,h,v,w=(r-1)\tau+p\\ t\leq s\leq g\leq h\leq v\leq w\\ h-g\geq\max\{w-v,v-h\},h-g>0}}^{(r-1)\tau+\tau_1+p-1}\left\{2\left(2^{1-\frac{1}{2}}+1\right)\left[a_1\exp\left\{-a_2\left(h-g\right)^{\theta}\right\}\right]^{1-\frac{1}{2}-\frac{4}{9}}\right. \\
&\qquad\qquad\left.\times\left(E\left|\left\{u_{it}u_{is}u_{ig}-E\left(u_{it}u_{is}u_{ig}\right)\right\}\right|^{2}\right)^{\frac{1}{2}}\left(E\left|u_{ih}u_{iv}u_{iw}\right|^{\frac{9}{4}}\right)^{\frac{4}{9}}\right\} \\
\leq\ & \frac{C_1\overline{C}}{q\tau_1^6}\sum_{r=1}^{q}\sum_{i\in H^c}\sum_{\substack{t,s,g,h,v,w=(r-1)\tau+p\\ t\leq s\leq g\leq h\leq v\leq w\\ h-g\geq\max\{w-v,v-h\},h-g>0}}^{(r-1)\tau+\tau_1+p-1}2\left(2^{\frac{1}{2}}+1\right)\left[a_1\exp\left\{-a_2\left(h-g\right)\right\}\right]^{\frac{1}{18}}\left(4\overline{C}^{\frac{6}{7}}\right)^{\frac{1}{2}}\left(\overline{C}^{\frac{27}{28}}\right)^{\frac{4}{9}} \\
\leq\ & \frac{C^*}{q\tau_1^6}\sum_{r=1}^{q}\sum_{i\in H^c}\sum_{\substack{t,s,g,h,v,w=(r-1)\tau+p\\ t\leq s\leq g\leq h\leq v\leq w\\ h-g\geq\max\{w-v,v-h\},h-g>0}}^{(r-1)\tau+\tau_1+p-1}\exp\left\{-\frac{a_2}{18}\varrho_1\right\} \\
& \left(\text{for some constant } C^* \text{ such that } 4\left(2^{\frac{1}{2}}+1\right)C_1\overline{C}^{\frac{13}{7}}a_1^{\frac{1}{18}}\leq C^*<\infty\right) \\
\leq\ & \frac{C^*}{q\tau_1^6}\sum_{r=1}^{q}\sum_{i\in H^c}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\sum_{s=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\sum_{g=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\sum_{\varrho_1=1}^{\infty}\sum_{\varrho_2=0}^{\varrho_1}\sum_{\varrho_3=0}^{\varrho_1}\exp\left\{-\frac{a_2}{18}\varrho_1\right\} \\
\leq\ & C^*\frac{N_1}{\tau_1^3}\sum_{\varrho_1=1}^{\infty}\left(\varrho_1+1\right)^2\exp\left\{-\frac{a_2}{18}\varrho_1\right\} \\
=\ & C^*\frac{N_1}{\tau_1^3}\left[\sum_{\varrho_1=1}^{\infty}\varrho_1^2\exp\left\{-\frac{a_2}{18}\varrho_1\right\}+2\sum_{\varrho_1=1}^{\infty}\varrho_1\exp\left\{-\frac{a_2}{18}\varrho_1\right\}+\sum_{\varrho_1=1}^{\infty}\exp\left\{-\frac{a_2}{18}\varrho_1\right\}\right] \\
=\ & O\left(\frac{N_1}{\tau_1^3}\right)\quad\text{(by Lemma OA-1)} \qquad (24)
\end{aligned}$$

Finally, consider $\mathcal{T}_6$. Note that, from the upper bounds given in the proofs of part (b) of Lemma OA-4, it is clear that there exists a positive constant C such that

$$\frac{1}{\tau_1^3}\sum_{\substack{t,s,g=(r-1)\tau+p\\ t\leq s\leq g}}^{(r-1)\tau+\tau_1+p-1}\left|E\left(u_{it}u_{is}u_{ig}\right)\right|\leq\frac{C}{\tau_1^2}$$

and

$$\frac{1}{\tau_1^3}\sum_{\substack{h,v,w=(r-1)\tau+p\\ h\leq v\leq w}}^{(r-1)\tau+\tau_1+p-1}\left|E\left(u_{ih}u_{iv}u_{iw}\right)\right|\leq\frac{C}{\tau_1^2}$$

from which it follows that

$$\begin{aligned}
\mathcal{T}_6 &= \frac{C_1\overline{C}}{q\tau_1^6}\sum_{r=1}^{q}\sum_{i\in H^c}\sum_{\substack{t,s,g,h,v,w=(r-1)\tau+p\\ t\leq s\leq g\leq h\leq v\leq w\\ h-g\geq\max\{w-v,v-h\},h-g>0}}^{(r-1)\tau+\tau_1+p-1}\left|E\left(u_{it}u_{is}u_{ig}\right)\right|\left|E\left(u_{ih}u_{iv}u_{iw}\right)\right| \\
&\leq \frac{C_1\overline{C}}{q}\sum_{r=1}^{q}\sum_{i\in H^c}\left(\frac{1}{\tau_1^3}\sum_{\substack{t,s,g=(r-1)\tau+p\\ t\leq s\leq g}}^{(r-1)\tau+\tau_1+p-1}\left|E\left(u_{it}u_{is}u_{ig}\right)\right|\right)\left(\frac{1}{\tau_1^3}\sum_{\substack{h,v,w=(r-1)\tau+p\\ h\leq v\leq w}}^{(r-1)\tau+\tau_1+p-1}\left|E\left(u_{ih}u_{iv}u_{iw}\right)\right|\right) \\
&\leq \frac{C_1\overline{C}}{q}\sum_{r=1}^{q}\sum_{i\in H^c}\left(\frac{C}{\tau_1^2}\right)\left(\frac{C}{\tau_1^2}\right) \\
&= C_1C\overline{C}^2\frac{N_1}{\tau_1^4} \\
&= O\left(\frac{N_1}{\tau_1^4}\right). \qquad (25)
\end{aligned}$$

It follows from expressions (18)-(25) that, for any $\epsilon>0$,

$$\begin{aligned}
& P\left\{\max_{1\leq\ell\leq d}\max_{i\in H^c}\left|\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}y_{\ell,t+1}u_{it}\right|\geq\epsilon\right\} \\
\leq\ & \frac{1}{\epsilon^6}\frac{1}{q}\sum_{r=1}^{q}\sum_{\ell=1}^{d}\sum_{i\in H^c}E\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}y_{\ell,t+1}u_{it}\right)^6 \\
\leq\ & \frac{1}{\epsilon^4}\left(\mathcal{T}_1+\mathcal{T}_2+\mathcal{T}_3+\mathcal{T}_4+\mathcal{T}_5+\mathcal{T}_6\right) \\
=\ & O\left(\frac{N_1}{\tau_1^5}\right)+O\left(\frac{N_1}{\tau_1^3}\right)+O\left(\frac{N_1}{\tau_1^3}\right)+O\left(\frac{N_1}{\tau_1^3}\right)+O\left(\frac{N_1}{\tau_1^3}\right)+O\left(\frac{N_1}{\tau_1^4}\right) \\
=\ & O\left(\frac{N_1}{\tau_1^3}\right) \\
=\ & o(1)\quad\left(\text{by Assumption 2-9(b) which stipulates that }\frac{N_1}{\tau_1^3}\sim\frac{N_1}{T^{3\alpha_1}}\to 0\right)
\end{aligned}$$

which proves the required result.

Turning our attention to part (d), note that, for any $\epsilon > 0$,

$$\begin{aligned}
& P\left\{\max_{1\leq\ell\leq d}\max_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}y_{\ell,t+1}u_{it}\right)^2 \geq \epsilon\right\} \\
= \; & P\left\{\max_{1\leq\ell\leq d}\max_{i\in H^c}\left|\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}y_{\ell,t+1}u_{it}\right)^2\right|^3 \geq \epsilon^3\right\} \\
\leq \; & P\left\{\max_{1\leq\ell\leq d}\max_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}y_{\ell,t+1}u_{it}\right)^6 \geq \epsilon^3\right\} \\
& \text{(by Jensen's inequality)} \\
\leq \; & P\left\{\sum_{\ell=1}^{d}\sum_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}y_{\ell,t+1}u_{it}\right)^6 \geq \epsilon^3\right\} \\
\leq \; & \frac{1}{\epsilon^3}\frac{1}{q}\sum_{r=1}^{q}\sum_{\ell=1}^{d}\sum_{i\in H^c}E\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}y_{\ell,t+1}u_{it}\right)^6.
\end{aligned}$$

The rest of the proof for part (d) then follows in a manner similar to the argument given for part (c) above.

For part (e), note that, by the Cauchy-Schwarz inequality,

$$\begin{aligned}
& \max_{1\leq\ell\leq d}\max_{i\in H^c}\left|\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\underline{F}_t\varepsilon_{\ell,t+1}\right)\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}y_{\ell,t+1}u_{it}\right)\right| \\
\leq \; & \max_{1\leq\ell\leq d}\max_{i\in H^c}\sqrt{\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\underline{F}_t\varepsilon_{\ell,t+1}\right)^2}\sqrt{\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}y_{\ell,t+1}u_{it}\right)^2} \\
\leq \; & \left\{\sqrt{\max_{1\leq\ell\leq d}\max_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\underline{F}_t\varepsilon_{\ell,t+1}\right)^2}\right. \\
& \left.\times\sqrt{\max_{1\leq\ell\leq d}\max_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}y_{\ell,t+1}u_{it}\right)^2}\right\} \\
= \; & o_p(1),
\end{aligned}$$

where the convergence in probability to zero in the last line above follows from applying the results in parts (b) and (d) of this lemma. □

Lemma OA-7: Suppose that Assumptions 2-1 and 2-6 hold. Then, the following statements are true.

(a) There exists a positive constant $C^{\dagger}$ such that

$$\left\|A_{YY}\right\|_2 \leq C^{\dagger}\phi_{\max}$$

where $\phi_{\max} = \max\left\{\left|\lambda_{\max}\left(A\right)\right|, \left|\lambda_{\min}\left(A\right)\right|\right\}$ with $0 < \phi_{\max} < 1$.

(b) There exists a positive constant $C^{\dagger}$ such that

$$\left\|A_{YF}\right\|_2 \leq C^{\dagger}\phi_{\max}$$

where $\phi_{\max}$ is as defined in part (a).

Proof of Lemma OA-7:

To proceed, recall first that the FAVAR model, i.e.,

$$\begin{aligned} Y_t &= \mu_Y + A_{YY}\underline{Y}_{t-1} + A_{YF}\underline{F}_{t-1} + \varepsilon_t^Y \\ F_t &= \mu_F + A_{FY}\underline{Y}_{t-1} + A_{FF}\underline{F}_{t-1} + \varepsilon_t^F, \end{aligned}$$

can be written in the companion form

$$\underline{W}_t = \alpha + A\underline{W}_{t-1} + E_t$$

where $\underline{W}_t = \begin{pmatrix} W_t' & W_{t-1}' & \cdots & W_{t-p+2}' & W_{t-p+1}' \end{pmatrix}'$ with $W_t = \begin{pmatrix} Y_t' & F_t' \end{pmatrix}'$ and where

$$\alpha = \begin{pmatrix} \mu \\ 0 \\ \vdots \\ 0 \\ 0 \end{pmatrix}, A = \begin{pmatrix} A_1 & A_2 & \cdots & A_{p-1} & A_p \\ I_{d+K} & 0 & \cdots & 0 & 0 \\ 0 & I_{d+K} & \ddots & \vdots & 0 \\ \vdots & \ddots & \ddots & 0 & \vdots \\ 0 & \cdots & 0 & I_{d+K} & 0 \end{pmatrix}, \text{ and } E_t = \begin{pmatrix} \varepsilon_t \\ 0 \\ \vdots \\ 0 \\ 0 \end{pmatrix}$$

with $\mu = \begin{pmatrix} \mu_Y' & \mu_F' \end{pmatrix}'$, $\varepsilon_t = \begin{pmatrix} \varepsilon_t^{Y\prime} & \varepsilon_t^{F\prime} \end{pmatrix}'$, and

$$A_\ell = \begin{pmatrix} A_{YY,\ell} & A_{YF,\ell} \\ A_{FY,\ell} & A_{FF,\ell} \end{pmatrix} \text{ for } \ell = 1, ..., p.$$

Let $\mathcal{P}_{(d+K)p}$ be the $(d+K)\,p \times (d+K)\,p$ permutation matrix defined by expression (17) in the proof of Lemma OA-5; and it is easy to see that $\overline{A} = \mathcal{P}_{(d+K)p}A\mathcal{P}_{(d+K)p}'$ has the partitioned form

$$\overline{A} = \mathcal{P}_{(d+K)p} A \mathcal{P}_{(d+K)p}' = \begin{pmatrix} \underset{d \times dp}{\overline{A}_{11}} & \underset{d \times Kp}{\overline{A}_{12}} \\ \underset{d(p-1) \times dp}{\overline{A}_{21}} & \underset{d(p-1) \times Kp}{\overline{A}_{22}} \\ \underset{K \times dp}{\overline{A}_{31}} & \underset{K \times Kp}{\overline{A}_{32}} \\ \underset{K(p-1) \times dp}{\overline{A}_{41}} & \underset{K(p-1) \times Kp}{\overline{A}_{42}} \end{pmatrix}$$

where $\overline{A}_{11} = A_{YY}$ and $\overline{A}_{12} = A_{YF}$, i.e., the first d rows of the matrix $\overline{A}$ as given by the submatrix $\left[\begin{array}{cc} A_{YY} & A_{YF} \end{array} \right]$.

Now, to show part (a), let $\overline{v} \in \mathbb{R}^{dp}$ such that $\left\| \overline{v} \right\|_2 = 1$ and such that

$$\left\| A_{YY} \right\|_2 = \overline{v}' A_{YY}' A_{YY} \overline{v} = \max_{\left\| v \right\|_2 = 1} v' A_{YY}' A_{YY} v = \overline{v}' \overline{A}_{11}' \overline{A}_{11} \overline{v}$$

and let $S_d = \begin{pmatrix} I_{dp} & \underset{dp \times Kp}{0} \end{pmatrix}'$. It follows that

$$\begin{aligned}
\left\| A_{YY} \right\|_2 &= \sqrt{\overline{v}' A_{YY}' A_{YY} \overline{v}} \\
&= \sqrt{\overline{v}' \overline{A}_{11}' \overline{A}_{11} \overline{v}} \\
&\leq \sqrt{\overline{v}' \overline{A}_{11}' \overline{A}_{11} \overline{v} + \overline{v}' \overline{A}_{21}' \overline{A}_{21} \overline{v} + \overline{v}' \overline{A}_{31}' \overline{A}_{31} \overline{v} + \overline{v}' \overline{A}_{41}' \overline{A}_{41} \overline{v}} \\
&= \sqrt{\overline{v}' S_d' \overline{A}' \overline{A} S_d \overline{v}} \\
&= \sqrt{\overline{v}' S_d' \mathcal{P}_{(d+K)p} A' \mathcal{P}_{(d+K)p}' \mathcal{P}_{(d+K)p} A \mathcal{P}_{(d+K)p}' S_d \overline{v}} \\
&= \sqrt{\overline{v}' S_d' \mathcal{P}_{(d+K)p} A' A \mathcal{P}_{(d+K)p}' S_d \overline{v}} \ \left(\text{since } \mathcal{P}_{(d+K)p} \text{ is an orthogonal matrix} \right) \\
&\leq \sqrt{\max_{\left\| v \right\|_2 = 1} v' A' A v} \ \left(\text{noting that } \left\| \mathcal{P}_{(d+K)p}' S_d \overline{v} \right\|_2 = \sqrt{\overline{v}' S_d' \mathcal{P}_{(d+K)p} \mathcal{P}_{(d+K)p}' S_d \overline{v}} = 1 \right) \\
&= \left\| A \right\|_2 \\
&= \sigma_{\max} \left(A \right) \\
&\leq C^{\dagger} \phi_{\max} \ \text{(by Assumption 2-6)}
\end{aligned}$$

where $\phi_{\max} = \max \left\{ \left| \lambda_{\max} \left(A \right) \right|, \left| \lambda_{\min} \left(A \right) \right| \right\}$. Note further that $0 < \phi_{\max} < 1$ since, by Assumption 2-1, all eigenvalues of A have modulus less than 1.

To show part (b), let $\widetilde{v} \in \mathbb{R}^{Kp}$ such that $\left\| \widetilde{v} \right\|_2 = 1$ and such that

$$\left\| A_{YF} \right\|_2 = \widetilde{v}' A_{YF}' A_{YF} \widetilde{v} = \max_{\left\| v \right\|_2 = 1} v' A_{YF}' A_{YF} v = \widetilde{v}' \overline{A}_{12}' \overline{A}_{12} \widetilde{v}$$

and let

$$\underset{(d+K)p \times Kp}{S_K} = \begin{pmatrix} 0 \\ I_{Kp} \end{pmatrix}.$$

It follows that

$$\begin{aligned}
\left\| A_{YF} \right\|_2 &= \sqrt{\widetilde{\upsilon}' A_{YF}' A_{YF} \widetilde{\upsilon}} \\
&= \sqrt{\widetilde{\upsilon}' \overline{A}_{12}' \overline{A}_{12} \widetilde{\upsilon}} \\
&\leq \sqrt{\widetilde{\upsilon}' \overline{A}_{12}' \overline{A}_{12} \widetilde{\upsilon} + \widetilde{\upsilon}' \overline{A}_{22}' \overline{A}_{22} \widetilde{\upsilon} + \widetilde{\upsilon}' \overline{A}_{32}' \overline{A}_{32} \widetilde{\upsilon} + \widetilde{\upsilon}' \overline{A}_{42}' \overline{A}_{42} \widetilde{\upsilon}} \\
&= \sqrt{\widetilde{\upsilon}' S_K' \overline{A}' \overline{A} S_K \widetilde{\upsilon}} \\
&= \sqrt{\widetilde{\upsilon}' S_K' \mathcal{P}_{(d+K)p} A' \mathcal{P}_{(d+K)p}' \mathcal{P}_{(d+K)p} A \mathcal{P}_{(d+K)p}' S_K \widetilde{\upsilon}} \\
&= \sqrt{\widetilde{\upsilon}' S_K' \mathcal{P}_{(d+K)p} A' A \mathcal{P}_{(d+K)p}' S_K \widetilde{\upsilon}} \;\; \left(\text{since } \mathcal{P}_{(d+K)p} \text{ is an orthogonal matrix}\right) \\
&\leq \sqrt{\max_{\left\| \upsilon \right\|_2 = 1} \upsilon' A' A \upsilon} \;\; \left(\text{noting that } \left\| \mathcal{P}_{(d+K)p}' S_K \widetilde{\upsilon} \right\|_2 = \sqrt{\widetilde{\upsilon}' S_K' \mathcal{P}_{(d+K)p} \mathcal{P}_{(d+K)p}' S_K \widetilde{\upsilon}} = 1\right) \\
&= \left\| A \right\|_2 \\
&= \sigma_{\max}\left(A\right) \\
&\leq C^{\dagger} \phi_{\max} \;\; \text{(by Assumption 2-6)}
\end{aligned}$$

where $\phi_{\max} = \max\left\{\left|\lambda_{\max}\left(A\right)\right|, \left|\lambda_{\min}\left(A\right)\right|\right\}$. As noted in the proof for part (a), $0 < \phi_{\max} < 1$ since, by Assumption 2-1, all eigenvalues of A have modulus less than 1. $\square$

Lemma OA-8: Consider the linear process

$$\xi_t = \sum_{j=0}^{\infty} \Psi_j \varepsilon_{t-j}$$

Suppose the process satisfies the following assumptions

(i) Let $\{\varepsilon_t\}$ is an independent sequence of random vectors with $E\left[\varepsilon_t\right] = 0$ for all t. For some $\delta > 0$, suppose that there exists a positive constant K such that

$$E \left\| \varepsilon_t \right\|_2^{1+\delta} \leq K < \infty \text{ for all } t.$$

(ii) Suppose that ε_t has p.d.f. g_{ε_t} such that, for some positive constant $M < \infty$,

$$\sup_t \int \left| g_{\varepsilon_t}\left(\upsilon - u\right) - g_{\varepsilon_t}\left(\upsilon\right) \right| d\varepsilon \leq M \left| u \right|$$

whenever $\left| u \right| \leq \overline{\kappa}$ for some constant $\overline{\kappa} > 0$.

(iii) Suppose that

$$\sum_{j=0}^{\infty} \left\| \Psi_j \right\|_2 < \infty$$

and

$$\det\left\{\sum_{j=0}^{\infty}\Psi_j z^j\right\} \neq 0 \text{ for all } z \text{ with } |z| \leq 1$$

Under these conditions, suppose further that

$$\sum_{j=0}^{\infty}\left(\sum_{k=j}^{\infty}\|\Psi_j\|_2\right)^{\frac{\delta}{1+\delta}} < \infty;$$

then, for some positive constant $\overline{K}$,

$$\beta_{\xi}(m) \leq \overline{K}\sum_{j=m}^{\infty}\left(\sum_{k=j}^{\infty}\|\Psi_k\|_2\right)^{\frac{\delta}{1+\delta}}$$

where

$$\beta_{\xi}(m) = \sup_t E\left[\sup\left\{\left|P\left(B|\mathcal{F}_{\xi,-\infty}^{t}\right) - P(B)\right| : B \in \mathcal{F}_{\xi,t+m}^{\infty}\right\}\right].$$

with $\mathcal{F}_{\xi,-\infty}^{t} = \sigma\left(....,\xi_{t-2},\xi_{t-1},\xi_t\right)$ and $\mathcal{F}_{\xi,t+m}^{\infty} = \sigma\left(\xi_{t+m},\xi_{t+m+1},\xi_{t+m+2},....\right)$.
Remark: This is Theorem 2.1 of Pham and Tran (1985) restated here in our notation. For a proof, see Pham and Tran (1985).

Lemma OA-9: Let A be an $n \times n$ square matrix with (ordered) singular values given by

$$\sigma_{(1)}(A) \geq \sigma_{(2)}(A) \geq \cdots \geq \sigma_{(n)}(A) \geq 0.$$

Suppose that A is diagonalizable, i.e.,

$$A = S\Lambda S^{-1}$$

where Λ is diagonal matrix whose diagonal elements are the eigenvalues of A. Let the modulus of these eigenvalues be ordered as follows:

$$\left|\lambda_{(1)}(A)\right| \geq \left|\lambda_{(2)}(A)\right| \geq \cdots \geq \left|\lambda_{(n)}(A)\right|.$$

Then, for $k \in \{1,...,n\}$ and for any positive integer j, we have

$$\chi(S)^{-1}\left|\lambda_{(k)}\left(A^j\right)\right| \leq \sigma_{(k)}\left(A^j\right) \leq \chi(S)\left|\lambda_{(k)}\left(A^j\right)\right|$$

where

$$\chi(S) = \sigma_{(1)}(S)\,\sigma_{(1)}\left(S^{-1}\right).$$

Proof of Lemma OA-9: Observe first that we can assume, without loss of generality, that the decomposition

$$A = S\Lambda S^{-1} = S \cdot diag\left(\lambda_1,\lambda_2,...,\lambda_n\right) \cdot S^{-1}$$

is such that

$$\lambda_i = \lambda_{(i)}\left(A\right) \text{ for } i = 1, ..., n$$

with

$$\left|\lambda_{(1)}\left(A\right)\right| \geq \left|\lambda_{(2)}\left(A\right)\right| \geq \cdots \geq \left|\lambda_{(n)}\left(A\right)\right|.$$

This is because suppose we have the alternative representation where

$$A = \widetilde{S}\widetilde{\Lambda}\widetilde{S}^{-1} = \widetilde{S} \cdot diag\left(\widetilde{\lambda}_1, \widetilde{\lambda}_2, ..., \widetilde{\lambda}_n\right) \cdot \widetilde{S}^{-1}$$

and where $\widetilde{\lambda}_i \neq \lambda_{(i)}\left(A\right)$ for at least some of the $i's$. Then, we can always define a permutation matrix $\mathcal{P}$ such that

$$\mathcal{P}'\widetilde{\Lambda}\mathcal{P} = \Lambda$$

so that, given that $\mathcal{P}$ is an orthogonal matrix, we have

$$A = \widetilde{S}\widetilde{\Lambda}\widetilde{S}^{-1} = \widetilde{S}\mathcal{P}\mathcal{P}'\widetilde{\Lambda}\mathcal{P}\mathcal{P}'\widetilde{S}^{-1} = S\Lambda S^{-1}$$

where $S = \widetilde{S}\mathcal{P}$ and, thus, $S^{-1} = \left(\widetilde{S}\mathcal{P}\right)^{-1} = \mathcal{P}'\widetilde{S}^{-1}$.

Next, note that, for any positive integer j,

$$A^j = S\Lambda S^{-1} \times S\Lambda S^{-1} \times \cdots \times S\Lambda S^{-1} = S\Lambda^j S^{-1}$$

where

$$\Lambda^j = diag\left(\lambda_1^j, \lambda_2^j, ..., \lambda_n^j\right) = diag\left(\lambda_{(1)}^j\left(A\right), \lambda_{(2)}^j\left(A\right), ..., \lambda_{(n)}^j\left(A\right)\right).$$

Moreover, since $\lambda_{(k)}\left(A^j\right) = \lambda_{(k)}^j\left(A\right)$ for any $k \in \{1, ..., m\}$, we also have

$$\Lambda^j = diag\left(\lambda_1^j, \lambda_2^j, ..., \lambda_n^j\right) = diag\left(\lambda_{(1)}\left(A^j\right), \lambda_{(2)}\left(A^j\right), ..., \lambda_{(n)}\left(A^j\right)\right).$$

In addition, let $\overline{\lambda_{(k)}\left(A^j\right)}$ denote the complex conjugate of $\lambda_{(k)}\left(A^j\right)$ for $k \in \{1, ..., m\}$, and note that, by definition,

$$\sigma_{(k)}\left(\Lambda^j\right) = \sqrt{\overline{\lambda_{(k)}\left(A^j\right)}\lambda_{(k)}\left(A^j\right)} = \left|\lambda_{(k)}\left(A^j\right)\right|$$

Since $\left|\lambda_{(k)}\left(A^j\right)\right| = \left|\lambda_{(k)}^j\left(A\right)\right| = \left|\lambda_{(k)}\left(A\right)\right|^j$, the ordering

$$\left|\lambda_{(1)}\left(A\right)\right| \geq \left|\lambda_{(2)}\left(A\right)\right| \geq \cdots \geq \left|\lambda_{(n)}\left(A\right)\right|$$

implies that

$$\left|\lambda_{(1)}\left(A^j\right)\right| \geq \left|\lambda_{(2)}\left(A^j\right)\right| \geq \cdots \geq \left|\lambda_{(n)}\left(A^j\right)\right|$$

and, thus,

$$\sigma_{(1)}\left(\Lambda^j\right) \geq \sigma_{(2)}\left(\Lambda^j\right) \geq \cdots \geq \sigma_{(n)}\left(\Lambda^j\right)$$

for any positive integer j.

Now, apply the inequality

$$\sigma_{(i+\ell-1)}(BC) \leq \sigma_{(i)}(B)\,\sigma_{(\ell)}(C)$$

for $i, \ell \in \{1, ..., n\}$ and $i + \ell \leq n + 1$; we have

$$\begin{aligned}
\sigma_{(k)}\left(A^j\right) &= \sigma_{(k)}\left(S\Lambda^j S^{-1}\right) \\
&\leq \sigma_{(k)}\left(S\Lambda^j\right)\sigma_{(1)}\left(S^{-1}\right) \\
&\leq \sigma_{(k)}\left(\Lambda^j\right)\sigma_{(1)}(S)\,\sigma_{(1)}\left(S^{-1}\right) \\
&= \sigma_{(1)}(S)\,\sigma_{(1)}\left(S^{-1}\right)\left|\lambda_{(k)}\left(A^j\right)\right| \\
&= \chi(S)\left|\lambda_{(k)}\left(A^j\right)\right| \text{ for any } k \in \{1, ..., n\}
\end{aligned}$$

Moreover, for any $k \in \{1, ..., n\}$,

$$\begin{aligned}
\left|\lambda_{(k)}\left(A^j\right)\right| &= \sigma_{(k)}\left(\Lambda^j\right) \\
&= \sigma_{(k)}\left(S^{-1}S\Lambda^j S^{-1}S\right) \\
&= \sigma_{(k)}\left(S^{-1}A^j S\right) \\
&\leq \sigma_{(1)}\left(S^{-1}\right)\sigma_{(k)}\left(A^j\right)\sigma_{(1)}(S)
\end{aligned}$$

or

$$\frac{\left|\lambda_{(k)}\left(A^j\right)\right|}{\chi(S)} = \frac{\left|\lambda_{(k)}\left(A^j\right)\right|}{\sigma_{(1)}(S)\,\sigma_{(1)}\left(S^{-1}\right)} \leq \sigma_{(k)}\left(A^j\right)$$

Putting these two inequalities together, we have, for any $k \in \{1, ..., n\}$ and for all positive integer j,

$$\chi(S)^{-1}\left|\lambda_{(k)}\left(A^j\right)\right| \leq \sigma_{(k)}\left(A^j\right) \leq \chi(S)\left|\lambda_{(k)}\left(A^j\right)\right|. \;\square$$

Remark: Note that the case where $j = 1$ in Lemma OA-9 has previously been obtained in Theorem 1 of Ruhe (1975). Hence, Lemma C-9 can be viewed as providing an extension to the first part of that theorem.

Lemma OA-10: Let ρ be such that $|\rho| < 1$. Then,

$$\sum_{j=0}^{\infty}(j+1)\,\rho^j = \frac{1}{(1-\rho)^2} < \infty$$

Proof of Lemma OA-10: Define

$$S_n(\rho) = 1 + \rho + \rho^2 + \cdots + \rho^n = \frac{1-\rho^{n+1}}{1-\rho}$$

Note that

$$\begin{aligned} S_n'(\rho) &= 1+2\rho+3\rho^2+\cdots+n\rho^{n-1} \\ &= -\frac{(n+1)\rho^n}{1-\rho}+\frac{1-\rho^{n+1}}{(1-\rho)^2} \\ &= \frac{1-\rho^{n+1}-(n+1)\rho^n(1-\rho)}{(1-\rho)^2} \\ &= \frac{1-\rho^{n+1}-(n+1)\rho^n+(n+1)\rho^{n+1}}{(1-\rho)^2} \\ &= \frac{1-(n+1)\rho^n+n\rho^{n+1}}{(1-\rho)^2} \\ &= \frac{1-\rho^n-n\rho^n(1-\rho)}{(1-\rho)^2} \end{aligned}$$

It follows that

$$S_n'(\rho)=\sum_{j=0}^{n-1}(j+1)\rho^j=\frac{1-\rho^n-n\rho^n(1-\rho)}{(1-\rho)^2}\to\frac{1}{(1-\rho)^2} \text{ as } n\to\infty. \ \square$$

Lemma OA-11: Let $W_t=(Y_t',F_t')'$ be generated by the factor-augmented VAR process

$$W_{t+1}=\mu+A_1W_t+\cdots+A_pW_{t-p+1}+\varepsilon_{t+1}$$

described in section 3 of the main paper. Under Assumptions 2-1, 2-2, and 2-6; $\{W_t\}$ is a β-mixing process with β-mixing coefficient $\beta_W(m)$ such that

$$\beta_W(m)\leq C_1\exp\{-C_2m\}$$

for some positive constants C_1 and C_2. Here,

$$\beta_W(m)=\sup_t E\left[\sup\left\{\left|P\left(B|\mathcal{A}_{-\infty}^t\right)-P(B)\right|:B\in\mathcal{A}_{t+m}^\infty\right\}\right]$$

with $\mathcal{A}_{-\infty}^t=\sigma(...,W_{t-2},W_{t-1},W_t)$ and $\mathcal{A}_{t+m}^\infty=\sigma(W_{t+m},W_{t+m+1},W_{t+m+2},....)$.

Proof of Lemma OA-11:

To prove this lemma, we shall verify the conditions of Lemma OA-8 given above for the vector moving-average representation of W_t, i.e.,

$$W_t=J_{d+K}\left(I_{(d+K)p}-A\right)^{-1}J_{d+K}'\mu+\sum_{j=0}^\infty J_{d+K}A^jJ_{d+K}'\varepsilon_{t-j}=\mu_*+\sum_{j=0}^\infty\Psi_j\varepsilon_{t-j},$$

where

$$\begin{aligned}
\mu_* &= J_{d+K}\left(I_{(d+K)p} - A\right)^{-1} J_{d+K}'\mu,\ \Psi_j = J_{d+K}A^j J_{d+K}', \\
\underset{(d+K)\times(d+K)p}{J_{d+K}} &= \left[\begin{array}{ccccc} I_{d+K} & 0 & \cdots & 0 & 0 \end{array}\right], \text{ and } A = \begin{pmatrix} A_1 & A_2 & \cdots & A_{p-1} & A_p \\ I_{d+K} & 0 & \cdots & \cdots & 0 \\ 0 & \ddots & \ddots & & \vdots \\ \vdots & \ddots & \ddots & \ddots & \vdots \\ 0 & \cdots & 0 & I_{d+K} & 0 \end{pmatrix}
\end{aligned}$$

To proceed, set

$$\xi_t = \sum_{j=0}^{\infty} \Psi_j \varepsilon_{t-j} \tag{26}$$

and note first that, setting $\delta = 5$ in Lemma OA-8, and we see that Assumptions (i) and (ii) of Lemma OA-8 are the same as the conditions specified in Assumption 2-2 (a)-(c). Next, note that, since in this case $\Psi_j = J_{d+K}A^j J_{d+K}'$, we have

$$\begin{aligned}
\|\Psi_j\|_2 &\leq \|J_{d+K}\|_2 \left\|A^j\right\|_2 \left\|J_{d+K}'\right\|_2 \\
&\leq \sqrt{\lambda_{\max}\left(J_{d+K}'J_{d+K}\right)} \left(\sqrt{\lambda_{\max}\left\{\left(A^j\right)' A^j\right\}}\right) \sqrt{\lambda_{\max}\left(J_{d+K}J_{d+K}'\right)} \\
&= \lambda_{\max}\left(J_{d+K}J_{d+K}'\right) \left(\sqrt{\lambda_{\max}\left\{\left(A^j\right)' A^j\right\}}\right) \\
&= \sqrt{\lambda_{\max}\left\{\left(A^j\right)' A^j\right\}} \\
&= \sigma_{\max}\left(A^j\right) \\
&\leq C\left[\max\left\{\left|\lambda_{\max}\left(A^j\right)\right|, \left|\lambda_{\min}\left(A^j\right)\right|\right\}\right] \quad \text{(by Assumption 2-6)} \\
&= C\left[\max\left\{\left|\lambda_{\max}(A)\right|, \left|\lambda_{\min}(A)\right|\right\}\right]^j \\
&= C\phi_{\max}^j
\end{aligned}$$

where $\phi_{\max} = \max\{|\lambda_{\max}(A)|, |\lambda_{\min}(A)|\}$ and where $0 < \phi_{\max} < 1$ since, by Assumption 2-1, all eigenvalues of A have modulus less than 1. It follows that

$$\sum_{j=0}^{\infty} \|\Psi_j\|_2 \leq C \sum_{j=0}^{\infty} \phi_{\max}^j = \frac{C}{1-\phi_{\max}} < \infty.$$

Moreover, by Assumption 2-1,

$$\det\left\{I_{(d+K)p} - A_1 z - \cdots - A_p z^p\right\} \neq 0 \text{ for all } z \text{ such that } |z| \leq 1$$

and, by definition,

$$\sum_{j=0}^{\infty} \Psi_j z^j = \Psi(z) = \left(I_{(d+K)p} - A_1 z - \cdots - A_p z^p\right)^{-1} \text{ for all } z \text{ such that } |z| \leq 1$$

so that

$$\Psi(z)\left(I_{(d+K)p} - A_1 z - \cdots - A_p z^p\right) = I_{(d+K)p} \text{ for all } z \text{ such that } |z| \leq 1$$

In addition, since

$$\begin{aligned} & \det\{\Psi(z)\} \det\left\{I_{(d+K)p} - A_1 z - \cdots - A_p z^p\right\} \\ = \ & \det\left\{\Psi(z)\left(I_{(d+K)p} - A_1 z - \cdots - A_p z^p\right)\right\} \\ = \ & \det\left\{I_{(d+K)p}\right\} \\ = \ & 1, \end{aligned}$$

and since

$$\left|\det\left\{I_{(d+K)p} - A_1 z - \cdots - A_p z^p\right\}\right| < \infty \text{ for all } z \text{ such that } |z| \leq 1,$$

it follows that

$$\begin{aligned} \det\left\{\sum_{j=0}^{\infty} \Psi_j z^j\right\} &= \det\{\Psi(z)\} \\ &= \frac{1}{\det\left\{I_{(d+K)p} - A_1 z - \cdots - A_p z^p\right\}} \\ &\neq 0 \text{ for all } z \text{ such that } |z| \leq 1. \end{aligned}$$

Finally, note that, setting $\delta = 5$,

$$\begin{aligned}
\sum_{j=0}^{\infty}\left(\sum_{k=j}^{\infty}\left\|\Psi_k\right\|_2\right)^{\frac{\delta}{1+\delta}} &= \sum_{j=0}^{\infty}\left(\sum_{k=j}^{\infty}\left\|\Psi_k\right\|_2\right)^{\frac{5}{6}} \\
&\leq \sum_{j=0}^{\infty}\left(\sum_{k=j}^{\infty} C\phi_{\max}^{k}\right)^{\frac{5}{6}} \\
&= C^{\frac{5}{6}}\sum_{j=0}^{\infty}\left(\sum_{k=j}^{\infty} \phi_{\max}^{k}\right)^{\frac{5}{6}} \\
&\leq C^{\frac{5}{6}}\sum_{j=0}^{\infty}\sum_{k=j}^{\infty}\left(\phi_{\max}^{\frac{5}{6}}\right)^{k} \\
&\quad \left(\text{by the inequality } \left|\sum_{i=1}^{\infty} a_i\right|^{r} \leq \sum_{i=1}^{\infty}\left|a_i\right|^{r} \text{ for } r \leq 1\right) \\
&= C^{\frac{5}{6}}\sum_{j=0}^{\infty}(j+1)\left(\phi_{\max}^{\frac{5}{6}}\right)^{j} \\
&= C^{\frac{5}{6}}\left[1-\phi_{\max}^{\frac{5}{6}}\right]^{-2} \text{ (by Lemma OA-10)} \\
&< \infty \quad \left(\text{since } 0 < \phi_{\max}^{\frac{5}{6}} < 1 \text{ given that } 0 < \phi_{\max} < 1\right).
\end{aligned}$$

Hence, all conditions of Lemma OA-8 are fulfilled. Applying Lemma OA-8, we then obtain that there exists a constant $\overline{C}$ such that

$$\begin{aligned}
\beta_{\xi}(m) &\leq \overline{C}\sum_{j=m}^{\infty}\left(\sum_{k=j}^{\infty}\left\|\Psi_k\right\|_2\right)^{\frac{5}{6}} \\
&\leq \overline{C}\sum_{j=m}^{\infty}\left(\sum_{k=j}^{\infty}C\phi_{\max}^{k}\right)^{\frac{5}{6}} \\
&= \overline{C}C^{\frac{5}{6}}\sum_{j=m}^{\infty}\left(\sum_{k=j}^{\infty}\phi_{\max}^{k}\right)^{\frac{5}{6}} \\
&\leq \overline{C}C^{\frac{5}{6}}\sum_{j=m}^{\infty}\sum_{k=j}^{\infty}\left(\phi_{\max}^{\frac{5}{6}}\right)^{k} \\
&= \overline{C}C^{\frac{5}{6}}\left(\phi_{\max}^{\frac{5}{6}}\right)^{m}\sum_{j=0}^{\infty}(j+1)\left(\phi_{\max}^{\frac{5}{6}}\right)^{j} \\
&= \overline{C}C^{\frac{5}{6}}\left(\phi_{\max}^{\frac{5}{6}}\right)^{m}\left[1-\phi_{\max}^{\frac{5}{6}}\right]^{-2} \\
&= \overline{C}C^{\frac{5}{6}}\left[1-\phi_{\max}^{\frac{5}{6}}\right]^{-2}\exp\left\{-\left[\frac{5}{6}\left|\ln\phi_{\max}\right|\right]m\right\} \quad (\text{since } 0<\phi_{\max}<1) \\
&\leq C_1\exp\left\{-C_2 m\right\}\to 0 \text{ as } m\to\infty.
\end{aligned}$$

for some positive constants C_1 and C_2 such that

$$C_1 \geq \overline{C}C^{\frac{5}{6}}\left[1-\phi_{\max}^{\frac{5}{6}}\right]^{-2} \text{ and } C_2 \leq \frac{5}{6}\left|\ln\phi_{\max}\right|$$

It follows that the process $\{\xi_t\}$ (as defined in expression (26)) is β mixing with beta coefficient $\beta_{\xi}(m)$ satisfying

$$\beta_{\xi}(m) \leq C_1\exp\left\{-C_2 m\right\}.$$

Since

$$W_t = \mu_* + \sum_{j=0}^{\infty}\Psi_j\varepsilon_{t-j} = \mu_* + \xi_t$$

and since μ_* is a nonrandom parameter, we can then apply part (a) of Lemma OA-2 to deduce that $\{W_t\}$ is a β mixing process with β coefficient $\beta_W(m)$ satisfying the inequality

$$\beta_W(m) \leq C_1\exp\left\{-C_2 m\right\}. \ \square$$

Lemma OA-12: Let $\underline{Y}_t = \begin{pmatrix} Y_t' & Y_{t-1}' & \cdots & Y_{t-p+2}' & Y_{t-p+1}' \end{pmatrix}'$ and $\underline{F}_t = \begin{pmatrix} F_t' & F_{t-1}' & \cdots & F_{t-p+2}' & F_{t-p+1}' \end{pmatrix}'$. Under Assumptions 2-1, 2-2, 2-5, 2-6, and 2-9(b); the following statements are true as $N,T\to\infty$

(a)

$$\max_{1\le\ell\le d}\max_{i\in H^c}\left|\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\left(\underline{F}_t\underline{Y}_t'-E\left[\underline{F}_t\underline{Y}_t'\right]\right)\alpha_{YY,\ell}\right|\xrightarrow{p}0$$

(b)

$$\max_{1\le\ell\le d}\max_{i\in H^c}\left|\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\left(\underline{F}_t\underline{F}_t'-E\left[\underline{F}_t\underline{F}_t'\right]\right)\alpha_{YF,\ell}\right|\xrightarrow{p}0$$

(c)

$$\max_{1\le\ell\le d}\max_{i\in H^c}\left|\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\left(\underline{F}_t-E\left[\underline{F}_t\right]\right)\mu_{Y,\ell}\right|\xrightarrow{p}0$$

(d)

$$\begin{aligned}\max_{1\le\ell\le d}\max_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\Bigg(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\big\{&\left(\underline{F}_t-E\left[\underline{F}_t\right]\right)\mu_{Y,\ell}+\left(\underline{F}_t\underline{Y}_t'-E\left[\underline{F}_t\underline{Y}_t'\right]\right)\alpha_{YY,\ell}\\&+\left(\underline{F}_t\underline{F}_t'-E\left[\underline{F}_t\underline{F}_t'\right]\right)\alpha_{YF,\ell}\big\}\Bigg)^2\\\xrightarrow{p}0\end{aligned}$$

(e)

$$\max_{1\le\ell\le d}\max_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\underline{F}_t\left[\mu_{Y,\ell}+\underline{Y}_t'\alpha_{YY,\ell}+\underline{F}_t'\alpha_{YF,\ell}\right]\right)^2=O_p\left(1\right).$$

(f)

$$\begin{aligned}&\max_{1\le\ell\le d}\max_{i\in H^c}\Bigg|\frac{1}{q}\sum_{r=1}^{q}\Bigg\{\Bigg(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\left(\underline{F}_t-E\left[\underline{F}_t\right]\right)\mu_{Y,\ell}\\&\quad+\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\left\{\gamma_i'\left(\underline{F}_t\underline{Y}_t'-E\left[\underline{F}_t\underline{Y}_t'\right]\right)\alpha_{YY,\ell}+\gamma_i'\left(\underline{F}_t\underline{F}_t'-E\left[\underline{F}_t\underline{F}_t'\right]\right)\alpha_{YF,\ell}\right\}\Bigg)\\&\quad\times\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\left\{\gamma_i'E\left[\underline{F}_t\right]\mu_{Y,\ell}+\gamma_i'E\left[\underline{F}_t\underline{Y}_t'\right]\alpha_{YY,\ell}+\gamma_i'E\left[\underline{F}_t\underline{F}_t'\right]\alpha_{YF,\ell}\right\}\right)\Bigg\}\Bigg|\\&\xrightarrow{p}0\end{aligned}$$

(g)

$$\max_{1\le\ell\le d}\max_{i\in H^c}\left|\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\underline{F}_t\left[\mu_{Y,\ell}+\underline{Y}_t'\alpha_{YY,\ell}+\underline{F}_t'\alpha_{YF,\ell}\right]\right)\right.$$
$$\left.\times\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}y_{\ell,t+1}u_{it}\right)\right|$$
$$\xrightarrow{p}0$$

(h)

$$\max_{1\le\ell\le d}\max_{i\in H^c}\left|\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\underline{F}_t\left[\mu_{Y,\ell}+\underline{Y}_t'\alpha_{YY,\ell}+\underline{F}_t'\alpha_{YF,\ell}\right]\right)\right.$$
$$\left.\times\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\underline{F}_t\varepsilon_{\ell,t+1}\right)\right|$$
$$\xrightarrow{p}0$$

Proof of Lemma OA-12:

To show part (a), note that, for any $\epsilon > 0$,

$$\begin{aligned}
& P\left\{\max_{1\le\ell\le d}\max_{i\in H^c}\left|\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\left(\underline{F}_t\underline{Y}_t'-E\left[\underline{F}_t\underline{Y}_t'\right]\right)\alpha_{YY,\ell}\right|\ge\epsilon\right\}\\
= \; & P\left\{\max_{1\le\ell\le d}\max_{i\in H^c}\left(\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\left(\underline{F}_t\underline{Y}_t'-E\left[\underline{F}_t\underline{Y}_t'\right]\right)\alpha_{YY,\ell}\right)^2\ge\epsilon^2\right\}\\
\le \; & P\left\{\max_{1\le\ell\le d}\max_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\left(\underline{F}_t\underline{Y}_t'-E\left[\underline{F}_t\underline{Y}_t'\right]\right)\alpha_{YY,\ell}\right)^2\ge\epsilon^2\right\}
\end{aligned}$$

(by Jensen's inequality)

$$\begin{aligned}
= \; & P\left\{\max_{i\in H^c}\max_{1\le\ell\le d}\frac{1}{q}\sum_{r=1}^{q}\left(\gamma_i'\left[\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\left(\underline{F}_t\underline{Y}_t'-E\left[\underline{F}_t\underline{Y}_t'\right]\right)\alpha_{YY,\ell}\right]\right)^2\ge\epsilon^2\right\}\\
\le \; & P\left\{\max_{i\in H^c}\sum_{\ell=1}^{d}\frac{1}{q}\sum_{r=1}^{q}\left(\gamma_i'\left[\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\left(\underline{F}_t\underline{Y}_t'-E\left[\underline{F}_t\underline{Y}_t'\right]\right)\alpha_{YY,\ell}\right]\right)^2\ge\epsilon^2\right\}\\
\le \; & P\Bigg\{\max_{i\in H^c}\left\|\gamma_i\right\|_2^2\sum_{\ell=1}^{d}\Bigg(\frac{1}{q}\sum_{r=1}^{q}\left[\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\left(\underline{F}_t\underline{Y}_t'-E\left[\underline{F}_t\underline{Y}_t'\right]\right)\alpha_{YY,\ell}\right]'\\
& \qquad\qquad\qquad\qquad \times\left[\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\left(\underline{F}_t\underline{Y}_t'-E\left[\underline{F}_t\underline{Y}_t'\right]\right)\alpha_{YY,\ell}\right]\Bigg)\ge\epsilon^2\Bigg\}\\
= \; & P\Bigg\{\max_{i\in H^c}\left\|\gamma_i\right\|_2^2\sum_{\ell=1}^{d}\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1^2}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\;\sum_{s=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\alpha_{YY,\ell}'\left(\underline{F}_t\underline{Y}_t'-E\left[\underline{F}_t\underline{Y}_t'\right]\right)'\\
& \qquad\qquad\qquad\qquad\qquad\qquad \times\left(\underline{F}_s\underline{Y}_s'-E\left[\underline{F}_s\underline{Y}_s'\right]\right)\alpha_{YY,\ell}\ge\epsilon^2\Bigg\}\\
\le \; & \frac{\max_{i\in H^c}\left\|\gamma_i\right\|_2^2}{\epsilon^2}\sum_{\ell=1}^{d}\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1^2}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\;\sum_{s=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\Big\{\alpha_{YY,\ell}'\\
& \qquad\qquad\qquad \times E\left[\left(\underline{F}_t\underline{Y}_t'-E\left[\underline{F}_t\underline{Y}_t'\right]\right)'\left(\underline{F}_s\underline{Y}_s'-E\left[\underline{F}_s\underline{Y}_s'\right]\right)\right]\alpha_{YY,\ell}\Big\}
\end{aligned}$$

(by Markov's inequality)

$$\begin{aligned}
\le \; & \frac{C}{\epsilon^2}\sum_{\ell=1}^{d}\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1^2}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\;\sum_{s=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\Big\{\alpha_{YY,\ell}'\\
& \qquad\qquad \times E\left[\left(\underline{F}_t\underline{Y}_t'-E\left[\underline{F}_t\underline{Y}_t'\right]\right)'\left(\underline{F}_s\underline{Y}_s'-E\left[\underline{F}_s\underline{Y}_s'\right]\right)\right]\alpha_{YY,\ell}\Big\}
\end{aligned}\tag{27}$$

(by Assumption 2-5)

Next, write

$$
\begin{aligned}
& \sum_{\ell=1}^{d}\left(\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1^2}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\;\sum_{s=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\left\{\alpha_{YY,\ell}'\right.\right. \\
& \qquad\qquad \left.\left.\times E\left[\left(\underline{F}_t\underline{Y}_t' - E\left[\underline{F}_t\underline{Y}_t'\right]\right)'\left(\underline{F}_s\underline{Y}_s' - E\left[\underline{F}_s\underline{Y}_s'\right]\right)\right]\alpha_{YY,\ell}\right\}\right) \\
= \; & \sum_{\ell=1}^{d}\left(\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1^2}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\alpha_{YY,\ell}'E\left[\left(\underline{F}_t\underline{Y}_t' - E\left[\underline{F}_t\underline{Y}_t'\right]\right)'\left(\underline{F}_t\underline{Y}_t' - E\left[\underline{F}_t\underline{Y}_t'\right]\right)\right]\alpha_{YY,\ell}\right) \\
& +\sum_{\ell=1}^{d}\left(\frac{2}{q}\sum_{r=1}^{q}\frac{1}{\tau_1^2}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-2}\;\sum_{m=1}^{(r-1)\tau+\tau_1+p-t-1}\left\{\alpha_{YY,\ell}'\right.\right. \\
& \qquad\qquad \left.\left.\times E\left[\left(\underline{F}_t\underline{Y}_t' - E\left[\underline{F}_t\underline{Y}_t'\right]\right)'\left(\underline{F}_{t+m}\underline{Y}_{t+m}' - E\left[\underline{F}_{t+m}\underline{Y}_{t+m}'\right]\right)\right]\alpha_{YY,\ell}\right\}\right) \\
\leq \; & \sum_{\ell=1}^{d}\left(\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1^2}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\alpha_{YY,\ell}'E\left[\left(\underline{F}_t\underline{Y}_t' - E\left[\underline{F}_t\underline{Y}_t'\right]\right)'\left(\underline{F}_t\underline{Y}_t' - E\left[\underline{F}_t\underline{Y}_t'\right]\right)\right]\alpha_{YY,\ell}\right) \\
& +\sum_{\ell=1}^{d}\left(\frac{2}{q}\sum_{r=1}^{q}\frac{1}{\tau_1^2}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-2}\;\sum_{m=1}^{(r-1)\tau+\tau_1+p-t-1}\left|\alpha_{YY,\ell}'\right.\right. \\
& \qquad \left.\left.\times E\left[\left(\underline{F}_t\underline{Y}_t' - E\left[\underline{F}_t\underline{Y}_t'\right]\right)'\left(\underline{F}_{t+m}\underline{Y}_{t+m}' - E\left[\underline{F}_{t+m}\underline{Y}_{t+m}'\right]\right)\right]\alpha_{YY,\ell}\right|\right) \qquad (28)
\end{aligned}
$$

Let $e_{\ell,d}$ be a $d\times 1$ elementary vector whose ℓ^{th} component is 1 and all other components are

0, and note that

$$\begin{aligned}
& \sum_{\ell=1}^{d}\left(\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1^2}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\alpha_{YY,\ell}' E\left[\left(\underline{F}_t\underline{Y}_t'-E\left[\underline{F}_t\underline{Y}_t'\right]\right)'\left(\underline{F}_t\underline{Y}_t'-E\left[\underline{F}_t\underline{Y}_t'\right]\right)\right]\alpha_{YY,\ell}\right) \\
= \ & \sum_{\ell=1}^{d}\left(\frac{1}{q\tau_1^2}\sum_{r=1}^{q}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1} e_{\ell,d}' A_{YY} E\left[\left(\underline{F}_t\underline{Y}_t'-E\left[\underline{F}_t\underline{Y}_t'\right]\right)'\left(\underline{F}_t\underline{Y}_t'-E\left[\underline{F}_t\underline{Y}_t'\right]\right)\right]A_{YY}' e_{\ell,d}\right) \\
= \ & \sum_{\ell=1}^{d}\frac{1}{q\tau_1^2}\sum_{r=1}^{q}\left(\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1} e_{\ell,d}' A_{YY} E\left[\underline{Y}_t\underline{F}_t'\underline{F}_t\underline{Y}_t'\right]A_{YY}' e_{\ell,d}\right. \\
& \qquad\qquad \left. -\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1} e_{\ell,d}' A_{YY} E\left[\underline{Y}_t\underline{F}_t'\right]E\left[\underline{F}_t\underline{Y}_t'\right]A_{YY}' e_{\ell,d}\right) \\
\leq \ & \sum_{\ell=1}^{d}\frac{1}{q\tau_1^2}\sum_{r=1}^{q}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1} E\left[\left\|\underline{F}_t\right\|_2^2\left(e_{\ell,d}' A_{YY}\underline{Y}_t\right)^2\right] \\
\leq \ & \sum_{\ell=1}^{d}\frac{1}{q\tau_1^2}\sum_{r=1}^{q}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1} \sqrt{E\left[\left\|\underline{F}_t\right\|_2^4\right]}\sqrt{E\left(e_{\ell,d}' A_{YY}\underline{Y}_t\underline{Y}_t' A_{YY}' e_{\ell,d}\right)^2} \ \text{(by CS inequality)} \\
\leq \ & \sum_{\ell=1}^{d}\frac{1}{q\tau_1^2}\sum_{r=1}^{q}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1} \sqrt{E\left[\left\|\underline{F}_t\right\|_2^4\right]}\sqrt{E\left[\left\|\underline{Y}_t\right\|_2^4\right]}\sqrt{\left(e_{\ell,d}' A_{YY} A_{YY}' e_{\ell,d}\right)^2} \\
\leq \ & \sum_{\ell=1}^{d}\frac{1}{q\tau_1^2}\sum_{r=1}^{q}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1} \sqrt{E\left[\left\|\underline{F}_t\right\|_2^4\right]}\sqrt{E\left[\left\|\underline{Y}_t\right\|_2^4\right]}\left\|A_{YY}\right\|_2^2\sqrt{\left(e_{\ell,d}' e_{\ell,d}\right)^2} \\
\leq \ & \frac{d\left(C^{\dagger}\right)^2}{q\tau_1^2}\sum_{r=1}^{q}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1} \sqrt{E\left[\left\|\underline{F}_t\right\|_2^4\right]}\sqrt{E\left[\left\|\underline{Y}_t\right\|_2^4\right]}\phi_{\max}^2 \\
& \text{(by part (a) of Lemma OA-7 and by the fact that } e_{\ell,d} \text{ is an elementary vector)} \\
\leq \ & \frac{\overline{C}}{\tau_1} = O\left(\frac{1}{\tau_1}\right). \qquad (29)
\end{aligned}$$

for some positive constant $\overline{C} \geq d\left(C^{\dagger}\right)^2\sqrt{E\left[\left\|\underline{F}_t\right\|_2^4\right]}\sqrt{E\left[\left\|\underline{Y}_t\right\|_2^4\right]}\phi_{\max}^2$, which exists in light of Lemma OA-5 and the fact that $0 < \phi_{\max} < 1$ given Assumption 2-1.

To analyze the second term on the right-hand side of expression (28), note first that by Lemma OA-11, $\left\{\left(Y_t', F_t'\right)'\right\}$ is β-mixing with β mixing coefficient satisfying

$$\beta_W(m) \leq C_1 \exp\left\{-C_2 m\right\} \text{ for some positive constants } C_1 \text{ and } C_2.$$

Since $\alpha_{W,m} \leq \beta_W(m)$, it follows that $W_t = \left(Y_t', F_t'\right)'$ is α-mixing as well, with α mixing coefficient satisfying

$$\alpha_{W,m} \leq C_1 \exp\left\{-C_2 m\right\}$$

Moreover, by applying part (b) of Lemma OA-2, we further deduce that $X_{1t} = \underline{F}_t \underline{Y}'_t A'_{YY} e_{\ell,d}$ is also α-mixing with α mixing coefficient satisfying

$$\begin{aligned} \alpha_{X_1,m} &\leq C_1 \exp\left\{-C_2\left(m-p+1\right)\right\} \\ &\leq C_1^* \exp\left\{-C_2 m\right\} \end{aligned}$$

for some positive constant $C_1^* \geq C_1 \exp\left\{C_2\left(p-1\right)\right\}$. Hence, we can apply Lemma OA-3 with $p = 3$ and $r = 3$ to obtain

$$\begin{aligned} & \left|\alpha'_{YY,\ell} E\left[\left(\underline{F}_t\underline{Y}'_t - E\left[\underline{F}_t\underline{Y}'_t\right]\right)'\left(\underline{F}_{t+m}\underline{Y}'_{t+m} - E\left[\underline{F}_{t+m}\underline{Y}'_{t+m}\right]\right)\right]\alpha_{YY,\ell}\right| \\ = & \left|e'_{\ell,d} A_{YY} E\left[\left(\underline{F}_t\underline{Y}'_t - E\left[\underline{F}_t\underline{Y}'_t\right]\right)'\left(\underline{F}_{t+m}\underline{Y}'_{t+m} - E\left[\underline{F}_{t+m}\underline{Y}'_{t+m}\right]\right)\right] A'_{YY} e_{\ell,d}\right| \\ = & \left|\sum_{h=1}^{Kp} e'_{\ell,d} A_{YY} E\left[\left(\underline{F}_t\underline{Y}'_t - E\left[\underline{F}_t\underline{Y}'_t\right]\right)' e_{h,Kp} e'_{h,Kp}\left(\underline{F}_{t+m}\underline{Y}'_{t+m} - E\left[\underline{F}_{t+m}\underline{Y}'_{t+m}\right]\right)\right] A'_{YY} e_{\ell,d}\right| \\ \leq & \sum_{h=1}^{Kp}\left\{2\left(2^{\frac{2}{3}}+1\right)\alpha_{X_1,m}^{\frac{1}{3}}\left(E\left|e'_{\ell,d} A_{YY}\left(\underline{F}_t\underline{Y}'_t - E\left[\underline{F}_t\underline{Y}'_t\right]\right)' e_{h,Kp}\right|^3\right)^{\frac{1}{3}}\right. \\ & \qquad \left.\times\left(E\left|e'_{h,Kp}\left(\underline{F}_{t+m}\underline{Y}'_{t+m} - E\left[\underline{F}_{t+m}\underline{Y}'_{t+m}\right]\right) A'_{YY} e_{\ell,d}\right|^3\right)^{1/3}\right\} \end{aligned}$$

where $\alpha_{X,m}$ denotes the α mixing coefficient for the process $\{X_{1t}\}$ and where, by our previous calculations,

$$\alpha_{X_1,m}^{\frac{1}{3}} \leq \left(C_1^*\right)^{\frac{1}{3}} \exp\left\{-\frac{C_2 m}{3}\right\} \text{ for all } m \text{ sufficiently large.}$$

It further follows that there exists a positive constant C_3 such that

$$\begin{aligned} \sum_{m=1}^{\infty} \alpha_{X_1,m}^{\frac{1}{3}} &\leq \left(C_1^*\right)^{\frac{1}{3}} \sum_{m=1}^{\infty} \exp\left\{-\frac{C_2 m}{3}\right\} \\ &\leq \left(C_1^*\right)^{\frac{1}{3}} \sum_{m=0}^{\infty} \exp\left\{-\frac{C_2 m}{3}\right\} \\ &= \left(C_1^*\right)^{\frac{1}{3}} \left[1-\exp\left\{-\frac{C_2}{3}\right\}\right]^{-1} \\ &\leq C_3 \end{aligned}$$

where the last inequality stems from the fact that $\sum_{m=0}^{\infty} \exp\left\{-\left(C_2 m/3\right)\right\}$ is a convergent geometric series given that $0 < \exp\{-(C_2/3)\} < 1$ for $C_2 > 0$. Next, note that

$$\begin{aligned}
& E\left|e'_{\ell,d}A_{YY}\left(\underline{F}_t\underline{Y}'_t - E\left[\underline{F}_t\underline{Y}'_t\right]\right)'e_{h,Kp}\right|^3 \\
\leq\ & 2^2\left\{E\left|e'_{\ell,d}A_{YY}\underline{Y}_t\underline{F}'_te_{h,Kp}\right|^3 + \left|E\left[e'_{\ell,d}A_{YY}\underline{Y}_t\underline{F}'_te_{h,Kp}\right]\right|^3\right\} \text{(by Loève's } c_r \text{ inequality)} \\
\leq\ & 2^2\left\{E\left|e'_{\ell,d}A_{YY}\underline{Y}_t\underline{F}'_te_{h,Kp}\right|^3 + \left(E\left[\left|e'_{\ell,d}A_{YY}\underline{Y}_t\underline{F}'_te_{h,Kp}\right|\right]\right)^3\right\} \ \text{(by Jensen's inequality)} \\
\leq\ & 2^2\left\{E\left|\frac{e'_{\ell,d}A_{YY}\underline{Y}_t\underline{Y}'_tA'_{YY}e_{\ell,d}}{2} + \frac{e'_{h,Kp}\underline{F}_t\underline{F}'_te_{h,Kp}}{2}\right|^3 + \left(E\left[\left|e'_{\ell,d}A_{YY}\underline{Y}_t\underline{F}'_te_{h,Kp}\right|\right]\right)^3\right\} \\
\leq\ & \frac{4}{8}\left[E\left|e'_{\ell,d}A_{YY}\underline{Y}_t\underline{Y}'_tA'_{YY}e_{\ell,d}\right|^3 + E\left|e'_{h,Kp}\underline{F}_t\underline{F}'_te_{h,Kp}\right|^3\right] \\
& +4\left(\sqrt{E\left[e'_{\ell,d}A_{YY}\underline{Y}_t\underline{Y}'_tA'_{YY}e_{\ell,d}\right]}\sqrt{E\left[e_{h,Kp}\underline{F}_t\underline{F}'_te_{h,Kp}\right]}\right)^3 \\
& \text{(by Loève's } c_r \text{ inequality and by the CS inequality)} \\
\leq\ & \frac{1}{2}\left|e'_{\ell,d}A_{YY}A'_{YY}e_{\ell,d}\right|^3 E\left\|\underline{Y}_t\right\|_2^6 + \frac{1}{2}E\left\|\underline{F}_t\right\|_2^6 + 4\left(E\left\|\underline{Y}_t\right\|_2^2\right)^{\frac{3}{2}}\left(e'_{\ell,d}A_{YY}A'_{YY}e_{\ell,d}\right)^{\frac{3}{2}}\left(E\left\|\underline{F}_t\right\|_2^2\right)^{\frac{3}{2}} \\
\leq\ & \frac{1}{2}\left\|e_{\ell,d}\right\|_2^6\left(C^{\dagger}\right)^6\phi_{\max}^6 E\left\|\underline{Y}_t\right\|_2^6 + \frac{1}{2}E\left\|\underline{F}_t\right\|_2^6 + 4\left(E\left\|\underline{Y}_t\right\|_2^2\right)^{\frac{3}{2}}\left\|e_{\ell,d}\right\|_2^3\left(C^{\dagger}\right)^3\phi_{\max}^3\left(E\left\|\underline{F}_t\right\|_2^2\right)^{\frac{3}{2}} \\
=\ & \frac{1}{2}\left(C^{\dagger}\right)^6\phi_{\max}^6 E\left\|\underline{Y}_t\right\|_2^6 + \frac{1}{2}E\left\|\underline{F}_t\right\|_2^6 + 4\left(E\left\|\underline{Y}_t\right\|_2^2\right)^{\frac{3}{2}}\left(C^{\dagger}\right)^3\phi_{\max}^3\left(E\left\|\underline{F}_t\right\|_2^2\right)^{\frac{3}{2}} \\
& \left(\text{since } \left\|e_{\ell,d}\right\|_2 = 1 \text{ for every } \ell \in \{1, ..., d\} \text{ given that } e_{\ell,d}\text{'s are elementary vectors}\right) \\
\leq\ & C_4
\end{aligned}$$

for some positive constant $C_4 \geq (1/2)\left(C^{\dagger}\right)^6\phi_{\max}^6 E\left\|\underline{Y}_t\right\|_2^6 + (1/2)E\left\|\underline{F}_t\right\|_2^6$ $+4\left(E\left\|\underline{Y}_t\right\|_2^2\right)^{\frac{3}{2}}\left(C^{\dagger}\right)^3\phi_{\max}^3\left(E\left\|\underline{F}_t\right\|_2^2\right)^{\frac{3}{2}}$ which exists in light of Lemma OA-5 and the fact that $0 < \phi_{\max} < 1$ given Assumption 2-1. In a similar way, we can also show that there exists a positive constant C_5 such that

$$\begin{aligned}
& E\left|e'_{h,Kp}\left(\underline{F}_{t+m}\underline{Y}'_{t+m} - E\left[\underline{F}_{t+m}\underline{Y}'_{t+m}\right]\right)A'_{YY}e_{\ell,d}\right|^3 \\
\leq\ & (1/2)\left\|e_{\ell,d}\right\|_2^6\left(C^{\dagger}\right)^6\phi_{\max}^6 E\left\|\underline{Y}_{t+m}\right\|_2^6 + (1/2)E\left\|\underline{F}_{t+m}\right\|_2^6 \\
& +4\left(E\left\|\underline{Y}_{t+m}\right\|_2^2\right)^{\frac{3}{2}}\left\|e_{\ell,d}\right\|_2^3\left(C^{\dagger}\right)^3\phi_{\max}^3\left(E\left\|\underline{F}_{t+m}\right\|_2^2\right)^{\frac{3}{2}} \\
\leq\ & C_5 < \infty
\end{aligned}$$

Hence,

$$\begin{aligned}
& \frac{2}{\tau_1^2}\sum_{\ell=1}^{d}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-2}\sum_{m=1}^{(r-1)\tau+\tau_1+p-t-1}\Big|e'_{\ell,d}A_{YY} \\
& \qquad \times E\left[\left(\underline{F}_t\underline{Y}'_t - E\left[\underline{F}_t\underline{Y}'_t\right]\right)'\left(\underline{F}_{t+m}\underline{Y}'_{t+m} - E\left[\underline{F}_{t+m}\underline{Y}'_{t+m}\right]\right)\right]A'_{YY}e_{\ell,d}\Big| \\
\leq\ & \frac{4\left(2^{\frac{2}{3}}+1\right)}{\tau_1^2}\sum_{\ell=1}^{d}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-2}\sum_{m=1}^{(r-1)\tau+\tau_1+p-t-1}\sum_{h=1}^{Kp}\alpha_{X_1,m}^{\frac{1}{3}}\left(E\left|e'_{\ell,d}A_{YY}\left(\underline{F}_t\underline{Y}'_t - E\left[\underline{F}_t\underline{Y}'_t\right]\right)'e_{h,Kp}\right|^3\right)^{\frac{1}{3}} \\
& \qquad \times\left(E\left|e'_{h,Kp}\left(\underline{F}_{t+m}\underline{Y}'_{t+m} - E\left[\underline{F}_{t+m}\underline{Y}'_{t+m}\right]\right)A'_{YY}e_{\ell,d}\right|^3\right)^{1/3} \\
\leq\ & \frac{4dKp\left(2^{\frac{2}{3}}+1\right)C_4^{\frac{1}{3}}C_5^{\frac{1}{3}}}{\tau_1^2}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-2}\sum_{m=1}^{\infty}\left(C_1^*\right)^{\frac{1}{3}}\exp\left\{-\frac{C_2 m}{3}\right\} \\
\leq\ & \frac{C^*}{\tau_1}\left(\frac{\tau_1-1}{\tau_1}\right)\sum_{m=1}^{\infty}\exp\left\{-\frac{C_2 m}{3}\right\}\quad\left(\text{where } C^*\geq 4dKp\left(2^{\frac{2}{3}}+1\right)\left(C_1^*\right)^{\frac{1}{3}}C_4^{\frac{1}{3}}C_5^{\frac{1}{3}}\right) \\
\leq\ & \frac{C^*}{\tau_1}\sum_{m=1}^{\infty}\exp\left\{-\frac{C_2 m}{3}\right\} \\
=\ & O\left(\frac{1}{\tau_1}\right) \qquad (30)
\end{aligned}$$

It then follows from expressions (27), (28), (29), and (30) that

$$\begin{aligned}
& P\left\{\max_{1\leq\ell\leq d}\max_{i\in H^c}\left|\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\left(\underline{F}_t\underline{Y}_t'-E\left[\underline{F}_t\underline{Y}_t'\right]\right)\alpha_{YY,\ell}\right|\geq\epsilon\right\} \\
\leq\ & \frac{C}{\epsilon^2}\sum_{\ell=1}^{d}\left(\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1^2}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\ \sum_{s=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}e_{\ell,d}'A_{YY}\right. \\
& \qquad\qquad \left.\times E\left[\left(\underline{F}_t\underline{Y}_t'-E\left[\underline{F}_t\underline{Y}_t'\right]\right)'\left(\underline{F}_s\underline{Y}_s'-E\left[\underline{F}_s\underline{Y}_s'\right]\right)\right]A_{YY}'e_{\ell,d}\right) \\
\leq\ & \frac{C}{\epsilon^2}\sum_{\ell=1}^{d}\left(\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1^2}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}e_{\ell,d}'A_{YY}E\left[\left(\underline{F}_t\underline{Y}_t'-E\left[\underline{F}_t\underline{Y}_t'\right]\right)'\left(\underline{F}_t\underline{Y}_t'-E\left[\underline{F}_t\underline{Y}_t'\right]\right)\right]A_{YY}'e_{\ell,d}\right) \\
& +\frac{C}{\epsilon^2}\sum_{\ell=1}^{d}\frac{1}{q}\sum_{r=1}^{q}\frac{2}{\tau_1^2}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-2}\ \sum_{m=1}^{(r-1)\tau+\tau_1+p-t-1}\left|e_{\ell,d}'A_{YY}\right. \\
& \qquad\qquad \left.\times E\left[\left(\underline{F}_t\underline{Y}_t'-E\left[\underline{F}_t\underline{Y}_t'\right]\right)'\left(\underline{F}_{t+m}\underline{Y}_{t+m}'-E\left[\underline{F}_{t+m}\underline{Y}_{t+m}'\right]\right)\right]A_{YY}'e_{\ell,d}\right| \\
\leq\ & \frac{C}{\epsilon^2}\frac{1}{q}\sum_{r=1}^{q}\frac{\overline{C}}{\tau_1}+\frac{C}{\epsilon^2}\frac{1}{q}\sum_{r=1}^{q}\frac{C^*}{\tau_1}\sum_{m=1}^{\infty}\exp\left\{-\frac{C_2m}{3}\right\} \\
=\ & \frac{C\overline{C}}{\epsilon^2}\frac{1}{\tau_1}+\frac{CC^*}{\epsilon^2}\frac{1}{\tau_1}\sum_{m=1}^{\infty}\exp\left\{-\frac{C_2m}{3}\right\} \\
=\ & O\left(\frac{1}{\tau_1}\right)+O\left(\frac{1}{\tau_1}\right) \\
=\ & O\left(\frac{1}{\tau_1}\right)=o\left(1\right).
\end{aligned}$$

Next, to show part (b), note that, for any $\epsilon > 0$,

$$
\begin{aligned}
& P\left\{\max_{1\leq\ell\leq d}\max_{i\in H^c}\left|\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\left(\underline{F}_t\underline{F}_t'-E\left[\underline{F}_t\underline{F}_t'\right]\right)\alpha_{YF,\ell}\right|\geq\epsilon\right\} \\
= \;& P\left\{\max_{1\leq\ell\leq d}\max_{i\in H^c}\left(\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\left(\underline{F}_t\underline{F}_t'-E\left[\underline{F}_t\underline{F}_t'\right]\right)\alpha_{YF,\ell}\right)^2\geq\epsilon^2\right\} \\
\leq \;& P\left\{\max_{1\leq\ell\leq d}\max_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\left(\underline{F}_t\underline{F}_t'-E\left[\underline{F}_t\underline{F}_t'\right]\right)\alpha_{YF,\ell}\right)^2\geq\epsilon^2\right\}
\end{aligned}
$$

(by Jensen's inequality)

$$
\begin{aligned}
= \;& P\left\{\max_{1\leq\ell\leq d}\max_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left(\gamma_i'\left[\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\left(\underline{F}_t\underline{F}_t'-E\left[\underline{F}_t\underline{F}_t'\right]\right)\alpha_{YF,\ell}\right]\right)^2\geq\epsilon^2\right\} \\
\leq \;& P\left\{\max_{i\in H^c}\sum_{\ell=1}^{d}\frac{1}{q}\sum_{r=1}^{q}\left(\gamma_i'\left[\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\left(\underline{F}_t\underline{F}_t'-E\left[\underline{F}_t\underline{F}_t'\right]\right)\alpha_{YF,\ell}\right]\right)^2\geq\epsilon^2\right\} \\
\leq \;& P\left\{\max_{i\in H^c}\left\|\gamma_i\right\|_2^2\sum_{\ell=1}^{d}\left(\frac{1}{q}\sum_{r=1}^{q}\left[\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\left(\underline{F}_t\underline{F}_t'-E\left[\underline{F}_t\underline{F}_t'\right]\right)\alpha_{YF,\ell}\right]'\right.\right. \\
& \qquad\qquad\left.\left.\times\left[\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\left(\underline{F}_t\underline{F}_t'-E\left[\underline{F}_t\underline{F}_t'\right]\right)\alpha_{YF,\ell}\right]\right)\geq\epsilon^2\right\} \\
= \;& P\left\{\max_{i\in H^c}\left\|\gamma_i\right\|_2^2\sum_{\ell=1}^{d}\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1^2}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\sum_{s=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\alpha_{YF,\ell}'\right. \\
& \qquad\qquad\left.\times\left(\underline{F}_t\underline{F}_t'-E\left[\underline{F}_t\underline{F}_t'\right]\right)'\left(\underline{F}_s\underline{F}_s'-E\left[\underline{F}_s\underline{F}_s'\right]\right)\alpha_{YF,\ell}\geq\epsilon^2\right\} \\
\leq \;& \frac{\max_{i\in H^c}\left\|\gamma_i\right\|_2^2}{\epsilon^2}\sum_{\ell=1}^{d}\left(\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1^2}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\sum_{s=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\alpha_{YF,\ell}'\right. \\
& \qquad\qquad\left.\times E\left[\left(\underline{F}_t\underline{F}_t'-E\left[\underline{F}_t\underline{F}_t'\right]\right)'\left(\underline{F}_s\underline{F}_s'-E\left[\underline{F}_s\underline{F}_s'\right]\right)\right]\alpha_{YF,\ell}\right)
\end{aligned}
$$

(by Markov's inequality)

$$
\begin{aligned}
\leq \;& \frac{C}{\epsilon^2}\sum_{\ell=1}^{d}\left(\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1^2}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\sum_{s=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\alpha_{YF,\ell}'\right. \\
& \qquad\qquad\left.\times E\left[\left(\underline{F}_t\underline{F}_t'-E\left[\underline{F}_t\underline{F}_t'\right]\right)'\left(\underline{F}_s\underline{F}_s'-E\left[\underline{F}_s\underline{F}_s'\right]\right)\right]\alpha_{YF,\ell}\right) \qquad (31)
\end{aligned}
$$

(by Assumption 2-5)

Note first that

$$
\begin{aligned}
& \sum_{\ell=1}^{d}\Bigg(\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1^2}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\ \sum_{s=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\alpha_{YF,\ell}' \\
& \qquad\qquad \times E\left[\left(\underline{F}_t\underline{F}_t' - E\left[\underline{F}_t\underline{F}_t'\right]\right)'\left(\underline{F}_s\underline{F}_s' - E\left[\underline{F}_s\underline{F}_s'\right]\right)\right]\alpha_{YF,\ell}\Big) \\
= & \sum_{\ell=1}^{d}\left(\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1^2}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\alpha_{YF,\ell}'E\left[\left(\underline{F}_t\underline{F}_t' - E\left[\underline{F}_t\underline{F}_t'\right]\right)'\left(\underline{F}_t\underline{F}_t' - E\left[\underline{F}_t\underline{F}_t'\right]\right)\right]\alpha_{YF,\ell}\right) \\
& +\sum_{\ell=1}^{d}\Bigg(\frac{2}{q}\sum_{r=1}^{q}\frac{1}{\tau_1^2}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-2}\ \sum_{m=1}^{(r-1)\tau+\tau_1+p-t-1}\alpha_{YF,\ell}' \\
& \qquad\qquad \times E\left[\left(\underline{F}_t\underline{F}_t' - E\left[\underline{F}_t\underline{F}_t'\right]\right)'\left(\underline{F}_{t+m}\underline{F}_{t+m}' - E\left[\underline{F}_{t+m}\underline{F}_{t+m}'\right]\right)\right]\alpha_{YF,\ell}\Big) \\
\leq & \sum_{\ell=1}^{d}\left(\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1^2}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\alpha_{YF,\ell}'E\left[\left(\underline{F}_t\underline{F}_t' - E\left[\underline{F}_t\underline{F}_t'\right]\right)'\left(\underline{F}_t\underline{F}_t' - E\left[\underline{F}_t\underline{F}_t'\right]\right)\right]\alpha_{YF,\ell}\right) \\
& +\sum_{\ell=1}^{d}\frac{2}{q}\sum_{r=1}^{q}\frac{1}{\tau_1^2}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-2}\ \sum_{m=1}^{(r-1)\tau+\tau_1+p-t-1}\Big|\alpha_{YF,\ell}' \\
& \qquad\qquad \times E\left[\left(\underline{F}_t\underline{F}_t' - E\left[\underline{F}_t\underline{F}_t'\right]\right)'\left(\underline{F}_{t+m}\underline{F}_{t+m}' - E\left[\underline{F}_{t+m}\underline{F}_{t+m}'\right]\right)\right]\alpha_{YF,\ell}\Big| \qquad (32)
\end{aligned}
$$

Consider the first term on the majorant side of expression (32), whose order of magnitude we can analyze as follows

$$\begin{aligned}
& \sum_{\ell=1}^{d}\left(\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1^2}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\alpha_{YF,\ell}' E\left[\left(\underline{F}_t\underline{F}_t' - E\left[\underline{F}_t\underline{F}_t'\right]\right)'\left(\underline{F}_t\underline{F}_t' - E\left[\underline{F}_t\underline{F}_t'\right]\right)\right]\alpha_{YF,\ell}\right) \\
= \; & \sum_{\ell=1}^{d}\left(\frac{1}{q\tau_1^2}\sum_{r=1}^{q}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1} e_{\ell,d}' A_{YF} E\left[\left(\underline{F}_t\underline{F}_t' - E\left[\underline{F}_t\underline{F}_t'\right]\right)'\left(\underline{F}_t\underline{F}_t' - E\left[\underline{F}_t\underline{F}_t'\right]\right)\right] A_{YF}' e_{\ell,d}\right) \\
= \; & \sum_{\ell=1}^{d}\frac{1}{q\tau_1^2}\sum_{r=1}^{q}\left(\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\left\{e_{\ell,d}' A_{YF} E\left[\underline{F}_t\underline{F}_t'\underline{F}_t\underline{F}_t'\right] A_{YF}' e_{\ell,d} - e_{\ell,d}' A_{YF} E\left[\underline{F}_t\underline{F}_t'\right] E\left[\underline{F}_t\underline{F}_t'\right] A_{YF}' e_{\ell,d}\right\}\right) \\
\leq \; & \sum_{\ell=1}^{d}\frac{1}{q\tau_1^2}\sum_{r=1}^{q}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1} E\left[\left\|\underline{F}_t\right\|_2^2\left(e_{\ell,d}' A_{YF}\underline{F}_t\right)^2\right] \\
\leq \; & \sum_{\ell=1}^{d}\frac{1}{q\tau_1^2}\sum_{r=1}^{q}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\sqrt{E\left[\left\|\underline{F}_t\right\|_2^4\right]}\sqrt{E\left(e_{\ell,d}' A_{YF}\underline{F}_t\underline{F}_t' A_{YF}' e_{\ell,d}\right)^2} \text{ (by CS inequality)} \\
\leq \; & \sum_{\ell=1}^{d}\frac{1}{q\tau_1^2}\sum_{r=1}^{q}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\sqrt{E\left[\left\|\underline{F}_t\right\|_2^4\right]}\sqrt{E\left[\left\|\underline{F}_t\right\|_2^4\right]}\sqrt{\left(e_{\ell,d}' A_{YF} A_{YF}' e_{\ell,d}\right)^2} \\
\leq \; & \frac{1}{q\tau_1^2}\sum_{\ell=1}^{d}\sum_{r=1}^{q}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\sqrt{E\left[\left\|\underline{F}_t\right\|_2^4\right]}\sqrt{E\left[\left\|\underline{F}_t\right\|_2^4\right]}\left\|A_{YF}\right\|_2^2\sqrt{\left(e_{\ell,d}' e_{\ell,d}\right)^2} \\
\leq \; & \frac{\left(C^{\dagger}\right)^2}{q\tau_1^2}\sum_{\ell=1}^{d}\sum_{r=1}^{q}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1} E\left[\left\|\underline{F}_t\right\|_2^4\right]\phi_{\max}^2 \\
& \text{(by part (b) of Lemma OA-7 and by the fact that } e_{\ell,d} \text{ is an elementary vector)} \\
\leq \; & \frac{\overline{C}}{\tau_1} = O\left(\frac{1}{\tau_1}\right). \qquad (33)
\end{aligned}$$

for some positive constant $\overline{C} \geq d\left(C^{\dagger}\right)^2 E\left[\left\|\underline{F}_t\right\|_2^4\right]\phi_{\max}^2$, which exists in light of Lemma OA-5 and the fact that $0 < \phi_{\max} < 1$ given Assumption 2-1.

To analyze the second term on the right-hand side of expression (32), note first that by Lemma OA-11, $\{F_t\}$ is β-mixing with β mixing coefficient satisfying

$$\beta_F(m) \leq C_1 \exp\{-C_2 m\} \text{ for some positive constants } C_1 \text{ and } C_2.$$

Since $\alpha_{F,m} \leq \beta_F(m)$, it follows that F_t is α-mixing as well, with α mixing coefficient satisfying

$$\alpha_{F,m} \leq C_1 \exp\{-C_2 m\}$$

Moreover, by applying part (b) of Lemma OA-2, we further deduce that $X_{2t} = \underline{F}_t\underline{F}_t' A_{YF}' e_{\ell,d}$

is also α-mixing with α mixing coefficient satisfying

$$\begin{aligned}\alpha_{X_2,m} &\leq C_1 \exp\{-C_2(m-p+1)\} \\ &\leq C_1^* \exp\{-C_2 m\}\end{aligned}$$

for some positive constant $C_1^* \geq C_1 \exp\{C_2(p-1)\}$. Hence, we can apply Lemma OA-3 with $p = 3$ and $r = 3$ to obtain

$$\begin{aligned}
& \left|\alpha_{YF,\ell}' E\left[\left(\underline{F}_t \underline{F}_t' - E\left[\underline{F}_t \underline{F}_t'\right]\right)' \left(\underline{F}_{t+m} \underline{F}_{t+m}' - E\left[\underline{F}_{t+m} \underline{F}_{t+m}'\right]\right)\right] \alpha_{YF,\ell}\right| \\
= & \left|e_{\ell,d}' A_{YF} E\left[\left(\underline{F}_t \underline{F}_t' - E\left[\underline{F}_t \underline{F}_t'\right]\right)' \left(\underline{F}_{t+m} \underline{F}_{t+m}' - E\left[\underline{F}_{t+m} \underline{F}_{t+m}'\right]\right)\right] A_{YF}' e_{\ell,d}\right| \\
= & \left|\sum_{h=1}^{Kp} e_{\ell,d}' A_{YF} E\left[\left(\underline{F}_t \underline{F}_t' - E\left[\underline{F}_t \underline{F}_t'\right]\right)' e_{h,Kp} e_{h,Kp}' \left(\underline{F}_{t+m} \underline{F}_{t+m}' - E\left[\underline{F}_{t+m} \underline{F}_{t+m}'\right]\right)\right] A_{YF}' e_{\ell,d}\right| \\
\leq & \sum_{h=1}^{Kp} \left\{2\left(2^{\frac{2}{3}}+1\right) \alpha_{X_2,m}^{\frac{1}{3}} \left(E\left|e_{\ell,d}' A_{YF} \left(\underline{F}_t \underline{F}_t' - E\left[\underline{F}_t \underline{F}_t'\right]\right)' e_{h,Kp}\right|^3\right)^{\frac{1}{3}}\right. \\
& \qquad \left. \times \left(E\left|e_{h,Kp}' \left(\underline{F}_{t+m} \underline{F}_{t+m}' - E\left[\underline{F}_{t+m} \underline{F}_{t+m}'\right]\right) A_{YF}' e_{\ell,d}\right|^3\right)^{1/3}\right\}
\end{aligned}$$

where $\alpha_{X_2,m}$ denotes the alpha mixing coefficient for the process $\{X_{2t}\}$ and where, by our previous calculations,

$$\alpha_{X_2,m}^{\frac{1}{3}} \leq (C_1^*)^{\frac{1}{3}} \exp\left\{-\frac{C_2 m}{3}\right\} \text{ for all } m \text{ sufficiently large,}$$

It further follows that there exists a positive constant C_3 such that

$$\begin{aligned}
\sum_{m=1}^{\infty} \alpha_{X_2,m}^{\frac{1}{3}} &\leq (C_1^*)^{\frac{1}{3}} \sum_{m=1}^{\infty} \exp\left\{-\frac{C_2 m}{3}\right\} \\
&\leq (C_1^*)^{\frac{1}{3}} \sum_{m=0}^{\infty} \exp\left\{-\frac{C_2 m}{3}\right\} \\
&= (C_1^*)^{\frac{1}{3}} \left[1 - \exp\left\{-\frac{C_2}{3}\right\}\right]^{-1} \\
&\leq C_3
\end{aligned}$$

Next, note that

$$\begin{aligned}
& E\left|e_{\ell,d}' A_{YF}\left(\underline{F}_t\underline{F}_t' - E\left[\underline{F}_t\underline{F}_t'\right]\right)' e_{h,Kp}\right|^3 \\
\leq\ & 2^2\left\{E\left|e_{\ell,d}' A_{YF}\underline{F}_t\underline{F}_t' e_{h,Kp}\right|^3 + \left|E\left[e_{\ell,d}' A_{YF}\underline{F}_t\underline{F}_t' e_{h,Kp}\right]\right|^3\right\} \text{ (by Loève's } c_r \text{ inequality)} \\
\leq\ & 2^2\left\{E\left|e_{\ell,d}' A_{YF}\underline{F}_t\underline{F}_t' e_{h,Kp}\right|^3 + \left(E\left[\left|e_{\ell,d}' A_{YF}\underline{F}_t\underline{F}_t' e_{h,Kp}\right|\right]\right)^3\right\} \quad \text{(by Jensen's inequality)} \\
\leq\ & 2^2\left\{E\left|\frac{e_{\ell,d}' A_{YF}\underline{F}_t\underline{F}_t' A_{YF}' e_{\ell,d}}{2} + \frac{e_{h,Kp}'\underline{F}_t\underline{F}_t' e_{h,Kp}}{2}\right|^3 + \left(E\left[\left|e_{\ell,d}' A_{YF}\underline{F}_t\underline{F}_t' e_{h,Kp}\right|\right]\right)^3\right\} \\
\leq\ & \frac{4}{8}\left[E\left|e_{\ell,d}' A_{YF}\underline{F}_t\underline{F}_t' A_{YF}' e_{\ell,d}\right|^3 + E\left|e_{h,Kp}'\underline{F}_t\underline{F}_t' e_{h,Kp}'\right|^3\right] \\
& +4\left(\sqrt{E\left[e_{\ell,d}' A_{YF}\underline{F}_t\underline{F}_t' A_{YF}' e_{\ell,d}\right]}\sqrt{E\left[e_{h,Kp}\underline{F}_t\underline{F}_t' e_{h,Kp}\right]}\right)^3 \\
& \text{(by Loève's } c_r \text{ inequality and by the CS inequality)} \\
\leq\ & \frac{1}{2}\left|e_{\ell,d}' A_{YF} A_{YF}' e_{\ell,d}\right|^3 E\left\|\underline{F}_t\right\|_2^6 + \frac{1}{2}E\left\|\underline{F}_t\right\|_2^6 + 4\left(E\left\|\underline{F}_t\right\|_2^2\right)^3\left(e_{\ell,d}' A_{YF} A_{YF}' e_{\ell,d}\right)^{\frac{3}{2}} \\
\leq\ & \frac{1}{2}\left\|e_{\ell,d}\right\|_2^6\left(C^{\dagger}\right)^6\phi_{\max}^6 E\left\|\underline{F}_t\right\|_2^6 + \frac{1}{2}E\left\|\underline{F}_t\right\|_2^6 + 4\left(E\left\|\underline{F}_t\right\|_2^2\right)^3\left\|e_{\ell,d}\right\|_2^3\left(C^{\dagger}\right)^3\phi_{\max}^3 \\
=\ & \frac{1}{2}\left(C^{\dagger}\right)^6\phi_{\max}^6 E\left\|\underline{F}_t\right\|_2^6 + \frac{1}{2}E\left\|\underline{F}_t\right\|_2^6 + 4\left(E\left\|\underline{F}_t\right\|_2^2\right)^3\left(C^{\dagger}\right)^3\phi_{\max}^3 \\
& \left(\text{since } \left\|e_{\ell,d}\right\|_2 = 1 \text{ for every } \ell \in \{1, ..., d\} \text{ given that } e_{\ell,d}\text{'s are elementary vectors}\right) \\
\leq\ & C_6
\end{aligned}$$

for some positive constant $C_6 \geq (1/2)\left(C^{\dagger}\right)^6\phi_{\max}^6 E\left\|\underline{F}_t\right\|_2^6 + (1/2)E\left\|\underline{F}_t\right\|_2^6 + 4\left(E\left\|\underline{F}_t\right\|_2^2\right)^3\left(C^{\dagger}\right)^3\phi_{\max}^3$ which exists in light of Lemma OA-5 and the fact that $0 < \phi_{\max} < 1$ given Assumption 2-1. In a similar way, we can also show that there exists a positive constant C_7 such that

$$\begin{aligned}
& E\left|e_{h,Kp}'\left(\underline{F}_{t+m}\underline{F}_{t+m}' - E\left[\underline{F}_{t+m}\underline{F}_{t+m}'\right]\right) A_{YY}' e_{\ell,d}\right|^3 \\
\leq\ & \frac{1}{2}\left\|e_{\ell,d}\right\|_2^6\left(C^{\dagger}\right)^6\phi_{\max}^6 E\left\|\underline{F}_{t+m}\right\|_2^6 + \frac{1}{2}E\left\|\underline{F}_{t+m}\right\|_2^6 \\
& +4\left(E\left\|\underline{F}_{t+m}\right\|_2^2\right)^3\left\|e_{\ell,d}\right\|_2^3\left(C^{\dagger}\right)^3\phi_{\max}^3 \\
\leq\ & C_7 < \infty
\end{aligned}$$

Hence,

$$
\begin{aligned}
& \frac{2}{\tau_1^2}\sum_{\ell=1}^{d}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-2}\sum_{m=1}^{(r-1)\tau+\tau_1+p-t-1}\Big|e'_{\ell,d}A_{YF} \\
& \qquad \times E\left[\left(\underline{F}_t\underline{F}'_t - E\left[\underline{F}_t\underline{F}'_t\right]\right)'\left(\underline{F}_{t+m}\underline{F}'_{t+m} - E\left[\underline{F}_{t+m}\underline{F}'_{t+m}\right]\right)\right]A'_{YF}e_{\ell,d}\Big| \\
\leq\ & \frac{4\left(2^{\frac{2}{3}}+1\right)}{\tau_1^2}\sum_{\ell=1}^{d}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-2}\sum_{m=1}^{(r-1)\tau+\tau_1+p-t-1}\sum_{h=1}^{Kp}\Bigg\{\alpha_{X_2,m}^{\frac{1}{3}}\left(E\left|e'_{\ell,d}A_{YF}\left(\underline{F}_t\underline{F}'_t - E\left[\underline{F}_t\underline{F}'_t\right]\right)'e_{h,Kp}\right|^3\right)^{\frac{1}{3}} \\
& \qquad \times\left(E\left|e'_{h,Kp}\left(\underline{F}_{t+m}\underline{F}'_{t+m} - E\left[\underline{F}_{t+m}\underline{F}'_{t+m}\right]\right)A'_{YF}e_{\ell,d}\right|^3\right)^{1/3}\Bigg\} \\
\leq\ & \frac{4dKp\left(2^{\frac{2}{3}}+1\right)C_6^{\frac{1}{3}}C_7^{\frac{1}{3}}}{\tau_1^2}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-2}\sum_{m=1}^{\infty}\left(C_1^*\right)^{\frac{1}{3}}\exp\left\{-\frac{C_2m}{3}\right\} \\
\leq\ & \frac{C^*}{\tau_1}\left(\frac{\tau_1-1}{\tau_1}\right)\sum_{m=1}^{\infty}\exp\left\{-\frac{C_2m}{3}\right\}\quad\left(\text{where } C^*\geq 4dKp\left(2^{\frac{2}{3}}+1\right)\left(C_1^*\right)^{\frac{1}{3}}C_6^{\frac{1}{3}}C_7^{\frac{1}{3}}\right) \\
\leq\ & \frac{C^*}{\tau_1}\sum_{m=1}^{\infty}\exp\left\{-\frac{C_2m}{3}\right\} \\
=\ & O\left(\frac{1}{\tau_1}\right) \qquad (34)
\end{aligned}
$$

It then follows from expressions (31), (32), (33), and (34) that

$$
\begin{aligned}
& P\left\{ \max_{1\leq \ell\leq d}\max_{i\in H^{c}}\left|\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\left(\underline{F}_t\underline{F}_t' - E\left[\underline{F}_t\underline{F}_t'\right]\right)\alpha_{YF,\ell}\right| \geq \epsilon\right\} \\
\leq\ & \frac{C}{\epsilon^2}\sum_{\ell=1}^{d}\left(\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1^2}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\sum_{s=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\alpha_{YF,\ell}'E\left[\left(\underline{F}_t\underline{F}_t' - E\left[\underline{F}_t\underline{F}_t'\right]\right)'\left(\underline{F}_s\underline{F}_s' - E\left[\underline{F}_s\underline{F}_s'\right]\right)\right]\alpha_{YF,\ell}\right) \\
\leq\ & \frac{C}{\epsilon^2}\sum_{\ell=1}^{d}\left(\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1^2}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\alpha_{YF,\ell}'E\left[\left(\underline{F}_t\underline{F}_t' - E\left[\underline{F}_t\underline{F}_t'\right]\right)'\left(\underline{F}_t\underline{F}_t' - E\left[\underline{F}_t\underline{F}_t'\right]\right)\right]\alpha_{YF,\ell}\right) \\
& +\frac{C}{\epsilon^2}\sum_{\ell=1}^{d}\frac{1}{q}\sum_{r=1}^{q}\frac{2}{\tau_1^2}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-2}\sum_{m=1}^{(r-1)\tau+\tau_1+p-t-1}\Big|\alpha_{YF,\ell}' \\
& \qquad\qquad \times E\left[\left(\underline{F}_t\underline{F}_t' - E\left[\underline{F}_t\underline{F}_t'\right]\right)'\left(\underline{F}_{t+m}\underline{F}_{t+m}' - E\left[\underline{F}_{t+m}\underline{F}_{t+m}'\right]\right)\right]\alpha_{YF,\ell}\Big| \\
\leq\ & \frac{C}{\epsilon^2}\frac{1}{q}\sum_{r=1}^{q}\frac{\overline{C}}{\tau_1} + \frac{C}{\epsilon^2}\frac{1}{q}\sum_{r=1}^{q}\frac{C^*}{\tau_1}\sum_{m=1}^{\infty}\exp\left\{-\frac{C_2 m}{3}\right\} \\
=\ & \frac{C\overline{C}}{\epsilon^2}\frac{1}{\tau_1} + \frac{CC^*}{\epsilon^2}\frac{1}{\tau_1}\sum_{m=1}^{\infty}\exp\left\{-\frac{C_2 m}{3}\right\} \\
=\ & O\left(\frac{1}{\tau_1}\right) + O\left(\frac{1}{\tau_1}\right) \\
=\ & O\left(\frac{1}{\tau_1}\right) = o\left(1\right).
\end{aligned}
$$

Now, to show part (c), note that, for any $\epsilon > 0$,

$$\begin{aligned}
& P\left\{\max_{1\leq\ell\leq d}\max_{i\in H^c}\left|\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\left(\underline{F}_t - E\left[\underline{F}_t\right]\right)\mu_{Y,\ell}\right| \geq \epsilon\right\} \\
= \;& P\left\{\max_{1\leq\ell\leq d}\max_{i\in H^c}\left(\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\left(\underline{F}_t - E\left[\underline{F}_t\right]\right)\mu_{Y,\ell}\right)^2 \geq \epsilon^2\right\} \\
\leq \;& P\left\{\max_{1\leq\ell\leq d}\max_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\left(\underline{F}_t - E\left[\underline{F}_t\right]\right)\mu_{Y,\ell}\right)^2 \geq \epsilon^2\right\} \text{ (by Jensen's inequality)} \\
= \;& P\left\{\max_{1\leq\ell\leq d}\max_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left(\gamma_i'\left[\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\left(\underline{F}_t - E\left[\underline{F}_t\right]\right)\mu_{Y,\ell}\right]\right)^2 \geq \epsilon^2\right\} \\
\leq \;& P\left\{\max_{i\in H^c}\sum_{\ell=1}^{d}\frac{1}{q}\sum_{r=1}^{q}\left(\gamma_i'\left[\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\left(\underline{F}_t - E\left[\underline{F}_t\right]\right)\mu_{Y,\ell}\right]\right)^2 \geq \epsilon^2\right\} \\
\leq \;& P\left\{\max_{i\in H^c}\left\|\gamma_i\right\|_2^2\sum_{\ell=1}^{d}\left(\frac{1}{q}\sum_{r=1}^{q}\left[\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\left(\underline{F}_t - E\left[\underline{F}_t\right]\right)\mu_{Y,\ell}\right]'\right.\right. \\
& \qquad\qquad\left.\left.\times\left[\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\left(\underline{F}_t - E\left[\underline{F}_t\right]\right)\mu_{Y,\ell}\right]\right) \geq \epsilon^2\right\} \\
= \;& P\left\{\max_{i\in H^c}\left\|\gamma_i\right\|_2^2\sum_{\ell=1}^{d}\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1^2}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\sum_{s=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\mu_{Y,\ell}\left(\underline{F}_t - E\left[\underline{F}_t\right]\right)'\left(\underline{F}_s - E\left[\underline{F}_s\right]\right)\mu_{Y,\ell} \geq \epsilon^2\right\} \\
\leq \;& \frac{\max_{i\in H^c}\left\|\gamma_i\right\|_2^2}{\epsilon^2}\sum_{\ell=1}^{d}\left(\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1^2}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\sum_{s=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\mu_{Y,\ell}^2 E\left[\left(\underline{F}_t - E\left[\underline{F}_t\right]\right)'\left(\underline{F}_s - E\left[\underline{F}_s\right]\right)\right]\right) \\
& \text{(by Markov's inequality)} \\
\leq \;& \frac{C}{\epsilon^2}\sum_{\ell=1}^{d}\left(\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1^2}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\sum_{s=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\mu_{Y,\ell}^2 E\left[\left(\underline{F}_t - E\left[\underline{F}_t\right]\right)'\left(\underline{F}_s - E\left[\underline{F}_s\right]\right)\right]\right) \qquad (35) \\
& \text{(by Assumption 2-5)}
\end{aligned}$$

Note that

$$\begin{aligned}
& \sum_{\ell=1}^{d}\left(\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1^2}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\sum_{s=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\mu_{Y,\ell}^2 E\left[\left(\underline{F}_t - E\left[\underline{F}_t\right]\right)'\left(\underline{F}_s - E\left[\underline{F}_s\right]\right)\right]\right) \\
= & \sum_{\ell=1}^{d}\left(\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1^2}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\mu_{Y,\ell}^2 E\left[\left(\underline{F}_t - E\left[\underline{F}_t\right]\right)'\left(\underline{F}_t - E\left[\underline{F}_t\right]\right)\right]\right) \\
& +\sum_{\ell=1}^{d}\left(\frac{2}{q}\sum_{r=1}^{q}\frac{1}{\tau_1^2}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-2}\sum_{m=1}^{(r-1)\tau+\tau_1+p-t-1}\mu_{Y,\ell}^2 E\left[\left(\underline{F}_t - E\left[\underline{F}_t\right]\right)'\left(\underline{F}_{t+m} - E\left[\underline{F}_{t+m}\right]\right)\right]\right) \\
\leq & \sum_{\ell=1}^{d}\left(\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1^2}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\mu_{Y,\ell}^2 E\left[\left(\underline{F}_t - E\left[\underline{F}_t\right]\right)'\left(\underline{F}_t - E\left[\underline{F}_t\right]\right)\right]\right) \\
& +\frac{2}{q\tau_1^2}\sum_{r=1}^{q}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-2}\sum_{m=1}^{(r-1)\tau+\tau_1+p-t-1}\left|E\left[\left(\underline{F}_t - E\left[\underline{F}_t\right]\right)'\left(\underline{F}_{t+m} - E\left[\underline{F}_{t+m}\right]\right)\right]\right|\sum_{\ell=1}^{d}\mu_{Y,\ell}^2 \quad (36)
\end{aligned}$$

Consider the first term on the majorant side of expression (36), whose order of magnitude we can analyze as follows

$$\begin{aligned}
& \sum_{\ell=1}^{d}\left(\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1^2}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\mu_{Y,\ell}^2 E\left[\left(\underline{F}_t - E\left[\underline{F}_t\right]\right)'\left(\underline{F}_t - E\left[\underline{F}_t\right]\right)\right]\right) \\
= & \sum_{\ell=1}^{d}\frac{1}{q\tau_1^2}\sum_{r=1}^{q}\left(\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\mu_{Y,\ell}^2\left\{E\left[\underline{F}_t'\underline{F}_t\right] - E\left[\underline{F}_t\right]'E\left[\underline{F}_t\right]\right\}\right) \\
\leq & \sum_{\ell=1}^{d}\frac{1}{q\tau_1^2}\sum_{r=1}^{q}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\mu_{Y,\ell}^2 E\left[\left\|\underline{F}_t\right\|_2^2\right] \\
= & \frac{1}{q\tau_1^2}\sum_{r=1}^{q}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}E\left[\left\|\underline{F}_t\right\|_2^2\right]\sum_{\ell=1}^{d}\left(\mu_{Y,\ell}^2\right) \\
\leq & \frac{1}{q\tau_1^2}\sum_{r=1}^{q}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}E\left[\left\|\underline{F}_t\right\|_2^2\right]\left\|\mu_Y\right\|_2^2 \\
\leq & \frac{\overline{C}}{\tau_1} = O\left(\frac{1}{\tau_1}\right). \qquad (37)
\end{aligned}$$

for some positive constant $\overline{C} \geq \left\|\mu_Y\right\|_2^2 E\left[\left\|\underline{F}_t\right\|_2^2\right]$, which exists in light of Assumption 2-5 and Lemma OA-5.

To analyze the second term on the right-hand side of expression (36), note first that by the same argument as given for part (b) above, we can apply Lemma OA-11 to deduce that $\{F_t\}$ is β-mixing and, thus, also α-mixing with α mixing coefficient satisfying

$$\alpha_{F,m} \leq C_1 \exp\{-C_2 m\}$$

Hence, we can apply Lemma OA-3 with $p = 3$ and $r = 3$ to obtain

$$\begin{aligned}
& \left|E\left[\left(\underline{F}_t - E\left[\underline{F}_t\right]\right)'\left(\underline{F}_{t+m} - E\left[\underline{F}_{t+m}\right]\right)\right]\right| \sum_{\ell=1}^{d} \mu_{Y,\ell}^2 \\
= & \left|\sum_{h=1}^{Kp} E\left[\left(\underline{F}_t - E\left[\underline{F}_t\right]\right)' e_{h,Kp} e_{h,Kp}' \left(\underline{F}_{t+m} - E\left[\underline{F}_{t+m}\right]\right)\right]\right| \sum_{\ell=1}^{d} \mu_{Y,\ell}^2 \\
\leq & \sum_{h=1}^{Kp} 2\left(2^{\frac{2}{3}} + 1\right) \alpha_{F,m}^{\frac{1}{3}} \left(E\left|\left(\underline{F}_t - E\left[\underline{F}_t\right]\right)' e_{h,Kp}\right|^3\right)^{\frac{1}{3}} \left(E\left|e_{h,Kp}'\left(\underline{F}_{t+m} - E\left[\underline{F}_{t+m}\right]\right)\right|^3\right)^{1/3} \sum_{\ell=1}^{d} \mu_{Y,\ell}^2
\end{aligned}$$

Moreover, there exists a positive constant C_3 such that

$$\sum_{m=1}^{\infty} \alpha_{F,m}^{\frac{1}{3}} \leq C_1^{\frac{1}{3}} \sum_{m=1}^{\infty} \exp\left\{-\frac{C_2 m}{3}\right\} = C_1^{\frac{1}{3}} \left[1 - \exp\left\{-\frac{C_2}{3}\right\}\right]^{-1} \leq C_3$$

where again the last inequality stems from the fact that $\sum_{m=0}^{\infty} \exp\{-(C_2 m/3)\}$ is a convergent geometric series given that $0 < \exp\{-(C_2/3)\} < 1$ for $C_2 > 0$. Next, note that

$$\begin{aligned}
& E\left|\left(\underline{F}_t - E\left[\underline{F}_t\right]\right)' e_{h,Kp}\right|^3 \\
\leq & \; 2^2\left\{E\left|\underline{F}_t' e_{h,Kp}\right|^3 + \left|E\left[\underline{F}_t' e_{h,Kp}\right]\right|^3\right\} \text{ (by Loève's } c_r \text{ inequality)} \\
\leq & \; 2^2\left\{E\left|\underline{F}_t' e_{h,Kp}\right|^3 + \left(E\left[\left|\underline{F}_t' e_{h,Kp}\right|\right]\right)^3\right\} \text{ (by Jensen's inequality)} \\
\leq & \; 2^2\left\{E\left[\left(\underline{F}_t'\underline{F}_t\right)^{\frac{3}{2}}\left(e_{h,Kp}' e_{h,Kp}\right)^{\frac{3}{2}}\right] + \left(\sqrt{E\left[\underline{F}_t'\underline{F}_t\right]}\sqrt{e_{h,Kp}' e_{h,Kp}}\right)^3\right\} \text{ (by CS inequality)} \\
\leq & \; 4\left\{E\left[\left\|\underline{F}_t\right\|_2^3\right] + \left(E\left[\left\|\underline{F}_t\right\|_2^2\right]\right)^{\frac{3}{2}}\right\} \\
\leq & \; C_8
\end{aligned}$$

for some positive constant $C_8 \geq 4\left\{E\left[\left\|\underline{F}_t\right\|_2^3\right] + \left(E\left[\left\|\underline{F}_t\right\|_2^2\right]\right)^{\frac{3}{2}}\right\}$ which exists in light of the result given in Lemma OA-5. In a similar way, we can also show that there exists a positive constant C_9 such that

$$\begin{aligned} E\left|e_\ell'\left(\underline{F}_{t+m}-E\left[\underline{F}_{t+m}\right]\right)\right|^3 &\leq 4\left\{E\left[\left\|\underline{F}_{t+m}\right\|_2^3\right]+\left(E\left[\left\|\underline{F}_{t+m}\right\|_2^2\right]\right)^{\frac{3}{2}}\right\} \\ &\leq C_9<\infty \end{aligned}$$

Finally, by Assumption 2-5, there exists a positive constant C_{10} such that $\max_{1\leq\ell\leq d}\mu_{Y,\ell}^2 \leq \left\|\mu_Y\right\|_2^2 \leq C_{10}<\infty$. Hence,

$$\begin{aligned} &\frac{2}{q}\sum_{r=1}^{q}\frac{1}{\tau_1^2}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-2}\sum_{m=1}^{(r-1)\tau+\tau_1+p-t-1}\left|E\left[\left(\underline{F}_t-E\left[\underline{F}_t\right]\right)'\left(\underline{F}_{t+m}-E\left[\underline{F}_{t+m}\right]\right)\right]\right|\sum_{\ell=1}^{d}\mu_{Y,\ell}^2 \\ \leq\ & \sum_{h=1}^{Kp}\frac{4\left(2^{\frac{2}{3}}+1\right)}{\tau_1^2}\left\|\mu_Y\right\|_2^2 \\ & \times\frac{1}{q}\sum_{r=1}^{q}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-2}\sum_{m=1}^{(r-1)\tau+\tau_1+p-t-1}\left\{\alpha_{F,m}^{\frac{1}{3}}\left(E\left|\left(\underline{F}_t-E\left[\underline{F}_t\right]\right)'e_{h,Kp}\right|^3\right)^{\frac{1}{3}}\right. \\ &\qquad\qquad\qquad\qquad\qquad\qquad\left.\times\left(E\left|e_{h,Kp}'\left(\underline{F}_{t+m}-E\left[\underline{F}_{t+m}\right]\right)\right|^3\right)^{1/3}\right\} \\ \leq\ & \frac{4Kp\left(2^{\frac{2}{3}}+1\right)C_8^{\frac{1}{3}}C_9^{\frac{1}{3}}C_{10}}{\tau_1^2}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-2}\sum_{m=1}^{\infty}C_1^{\frac{1}{3}}\exp\left\{-\frac{C_2 m}{3}\right\} \\ \leq\ & \frac{C^*}{\tau_1}\left(\frac{\tau_1-1}{\tau_1}\right)\sum_{m=1}^{\infty}\exp\left\{-\frac{C_2 m}{3}\right\}\ \left(\text{where } C^*\geq 4Kp\left(2^{\frac{2}{3}}+1\right)C_1^{\frac{1}{3}}C_8^{\frac{1}{3}}C_9^{\frac{1}{3}}C_{10}\right) \\ \leq\ & \frac{C^*}{\tau_1}\sum_{m=1}^{\infty}\exp\left\{-\frac{C_2 m}{3}\right\} \\ =\ & O\left(\frac{1}{\tau_1}\right) \qquad (38) \end{aligned}$$

It then follows from expressions (35), (36), (37), and (38) that

$$\begin{aligned}
& P\left\{\max_{1\leq\ell\leq d}\max_{i\in H^c}\left|\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\left(\underline{F}_t-E\left[\underline{F}_t\right]\right)\mu_{Y,\ell}\right|\geq\epsilon\right\} \\
\leq\ & \frac{C}{\epsilon^2}\sum_{\ell=1}^{d}\left(\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1^2}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\ \sum_{s=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\mu_{Y,\ell}^2E\left[\left(\underline{F}_t-E\left[\underline{F}_t\right]\right)'\left(\underline{F}_s-E\left[\underline{F}_s\right]\right)\right]\right) \\
\leq\ & \frac{C}{\epsilon^2}\sum_{\ell=1}^{d}\left(\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1^2}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\mu_{Y,\ell}^2E\left[\left(\underline{F}_t-E\left[\underline{F}_t\right]\right)'\left(\underline{F}_t-E\left[\underline{F}_t\right]\right)\right]\right) \\
& +\frac{C}{\epsilon^2}\frac{1}{q}\sum_{r=1}^{q}\frac{2}{\tau_1^2}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-2}\ \sum_{m=1}^{(r-1)\tau+\tau_1+p-t-1}\left|E\left[\left(\underline{F}_t-E\left[\underline{F}_t\right]\right)'\left(\underline{F}_{t+m}-E\left[\underline{F}_{t+m}\right]\right)\right]\right|\sum_{\ell=1}^{d}\mu_{Y,\ell}^2 \\
\leq\ & \frac{C}{\epsilon^2}\frac{1}{q}\sum_{r=1}^{q}\frac{\overline{C}}{\tau_1}+\frac{C}{\epsilon^2}\frac{1}{q}\sum_{r=1}^{q}\frac{C^*}{\tau_1}\sum_{m=1}^{\infty}\exp\left\{-\frac{C_2m}{3}\right\} \\
=\ & \frac{C\overline{C}}{\epsilon^2}\frac{1}{\tau_1}+\frac{CC^*}{\epsilon^2}\frac{1}{\tau_1}\sum_{m=1}^{\infty}\exp\left\{-\frac{C_2m}{3}\right\} \\
=\ & O\left(\frac{1}{\tau_1}\right)+O\left(\frac{1}{\tau_1}\right) \\
=\ & O\left(\frac{1}{\tau_1}\right)=o\left(1\right).
\end{aligned}$$

Turning our attention to part (d), note that, by apply Loève's c_r inequality, we obtain

$$\begin{aligned}
& \max_{1\leq\ell\leq d}\max_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\left\{\left(\underline{F}_t-E\left[\underline{F}_t\right]\right)\mu_{Y,\ell}+\left(\underline{F}_t\underline{Y}_t'-E\left[\underline{F}_t\underline{Y}_t'\right]\right)\alpha_{YY,\ell}\right.\right. \\
& \qquad\qquad\left.\left.+\left(\underline{F}_t\underline{F}_t'-E\left[\underline{F}_t\underline{F}_t'\right]\right)\alpha_{YF,\ell}\right\}\right)^2 \\
\leq\ & 3\max_{1\leq\ell\leq d}\max_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\left(\underline{F}_t-E\left[\underline{F}_t\right]\right)\mu_{Y,\ell}\right)^2 \\
& +3\max_{1\leq\ell\leq d}\max_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\left(\underline{F}_t\underline{Y}_t'-E\left[\underline{F}_t\underline{Y}_t'\right]\right)\alpha_{YY,\ell}\right)^2 \\
& +3\max_{1\leq\ell\leq d}\max_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\left(\underline{F}_t\underline{F}_t'-E\left[\underline{F}_t\underline{F}_t'\right]\right)\alpha_{YF,\ell}\right)^2
\end{aligned}$$

It follows from the arguments given in the proofs of parts (a)-(c) above that, for any $\epsilon > 0$,

$$
\begin{aligned}
& P\left\{ \max_{1\leq \ell \leq d}\max_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\left(\underline{F}_t\underline{Y}_t' - E\left[\underline{F}_t\underline{Y}_t'\right]\right)\alpha_{YY,\ell}\right)^2 \geq \epsilon\right\} \\
\leq\ & \frac{C}{\epsilon^2}\frac{1}{q\tau_1^2} \\
& \times\sum_{\ell=1}^{d}\left(\sum_{r=1}^{q}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\sum_{s=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\alpha_{YY,\ell}'E\left[\left(\underline{F}_t\underline{Y}_t' - E\left[\underline{F}_t\underline{Y}_t'\right]\right)'\left(\underline{F}_s\underline{Y}_s' - E\left[\underline{F}_s\underline{Y}_s'\right]\right)\right]\alpha_{YY,\ell}\right) \\
=\ & o\left(1\right),
\end{aligned}
$$

$$
\begin{aligned}
& P\left\{ \max_{1\leq \ell \leq d}\max_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\left(\underline{F}_t\underline{F}_t' - E\left[\underline{F}_t\underline{F}_t'\right]\right)\alpha_{YF,\ell}\right)^2 \geq \epsilon\right\} \\
\leq\ & \frac{C}{\epsilon^2}\frac{1}{q\tau_1^2} \\
& \times\sum_{\ell=1}^{d}\left(\sum_{r=1}^{q}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\sum_{s=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\alpha_{YF,\ell}'E\left[\left(\underline{F}_t\underline{F}_t' - E\left[\underline{F}_t\underline{F}_t'\right]\right)'\left(\underline{F}_s\underline{F}_s' - E\left[\underline{F}_s\underline{F}_s'\right]\right)\right]\alpha_{YF,\ell}\right) \\
=\ & o\left(1\right)
\end{aligned}
$$

and

$$
\begin{aligned}
& P\left\{ \max_{1\leq \ell \leq d}\max_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\left(\underline{F}_t - E\left[\underline{F}_t\right]\right)\mu_{Y,\ell}\right)^2 \geq \epsilon\right\} \\
\leq\ & \frac{C}{\epsilon^2}\frac{1}{q\tau_1^2} \\
& \times\sum_{\ell=1}^{d}\left(\sum_{r=1}^{q}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\sum_{s=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\mu_{Y,\ell}^2 E\left[\left(\underline{F}_t - E\left[\underline{F}_t\right]\right)'\left(\underline{F}_s - E\left[\underline{F}_s\right]\right)\right]\right) \\
=\ & o\left(1\right),
\end{aligned}
$$

from which we deduce via the Slutsky's theorem that

$$\begin{aligned} & \max_{1\leq\ell\leq d}\max_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\left\{\left(\underline{F}_t-E\left[\underline{F}_t\right]\right)\mu_{Y,\ell}+\left(\underline{F}_t\underline{Y}_t'-E\left[\underline{F}_t\underline{Y}_t'\right]\right)\alpha_{YY,\ell}\right.\right. \\ & \qquad\qquad \left.\left.+\left(\underline{F}_t\underline{F}_t'-E\left[\underline{F}_t\underline{F}_t'\right]\right)\alpha_{YF,\ell}\right\}\right)^2 \\ = & \quad o_p\left(1\right) \end{aligned}$$

as required.

To show part (e), note that

$$\begin{aligned} & \max_{1\leq\ell\leq d}\max_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\underline{F}_t\left[\mu_{Y,\ell}+\underline{Y}_t'\alpha_{YY,\ell}+\underline{F}_t'\alpha_{YF,\ell}\right]\right)^2 \\ \leq & \quad \max_{1\leq\ell\leq d}\max_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\left\{\left(\underline{F}_t-E\left[\underline{F}_t\right]\right)\mu_{Y,\ell}+\left(\underline{F}_t\underline{Y}_t'-E\left[\underline{F}_t\underline{Y}_t'\right]\right)\alpha_{YY,\ell}\right.\right. \\ & \qquad\qquad \left.+\left(\underline{F}_t\underline{F}_t'-E\left[\underline{F}_t\underline{F}_t'\right]\right)\alpha_{YF,\ell}\right\} \\ & \qquad \left.+\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\left\{E\left[\underline{F}_t\right]\mu_{Y,\ell}+E\left[\underline{F}_t\underline{Y}_t'\right]\alpha_{YY,\ell}+E\left[\underline{F}_t\underline{F}_t'\right]\alpha_{YF,\ell}\right\}\right)^2 \\ \leq & \quad \max_{1\leq\ell\leq d}\max_{i\in H^c}\frac{2}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\left\{\left(\underline{F}_t-E\left[\underline{F}_t\right]\right)\mu_{Y,\ell}+\left(\underline{F}_t\underline{Y}_t'-E\left[\underline{F}_t\underline{Y}_t'\right]\right)\alpha_{YY,\ell}\right.\right. \\ & \qquad\qquad \left.\left.+\left(\underline{F}_t\underline{F}_t'-E\left[\underline{F}_t\underline{F}_t'\right]\right)\alpha_{YF,\ell}\right\}\right)^2 \\ & \quad +\max_{1\leq\ell\leq d}\max_{i\in H^c}\frac{2}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\left\{E\left[\underline{F}_t\right]\mu_{Y,\ell}+E\left[\underline{F}_t\underline{Y}_t'\right]\alpha_{YY,\ell}+E\left[\underline{F}_t\underline{F}_t'\right]\alpha_{YF,\ell}\right\}\right)^2 \\ & \quad \text{(by Loève's } c_r \text{ inequality)} \\ = & \quad o_p\left(1\right)+O\left(1\right) \\ & \quad \text{(applying the results given in part (d) of this lemma and in Lemma A1 of the main paper)} \\ = & \quad O_p\left(1\right). \end{aligned}$$

To show part (f), we apply the Cauchy-Schwarz inequality as well as part (d) of this lemma and Lemma A1 of the main paper to obtain

$$\begin{aligned}
& \max_{1\leq\ell\leq d}\max_{i\in H^c}\left|\frac{1}{q}\sum_{r=1}^{q}\left\{\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\left\{\gamma_i'\left(\underline{F}_t-E\left[\underline{F}_t\right]\right)\mu_{Y,\ell}+\gamma_i'\left(\underline{F}_t\underline{Y}_t'-E\left[\underline{F}_t\underline{Y}_t'\right]\right)\alpha_{YY,\ell}\right.\right.\right.\right. \\
& \qquad \left.+\gamma_i'\left(\underline{F}_t\underline{F}_t'-E\left[\underline{F}_t\underline{F}_t'\right]\right)\alpha_{YF,\ell}\right\}\Big) \\
& \qquad \left.\left.\times\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\left\{\gamma_i'E\left[\underline{F}_t\right]\mu_{Y,\ell}+\gamma_i'E\left[\underline{F}_t\underline{Y}_t'\right]\alpha_{YY,\ell}+\gamma_i'E\left[\underline{F}_t\underline{F}_t'\right]\alpha_{YF,\ell}\right\}\right)\right\}\right| \\
\leq\ & \max_{1\leq\ell\leq d}\max_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left|\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\left\{\gamma_i'\left(\underline{F}_t-E\left[\underline{F}_t\right]\right)\mu_{Y,\ell}+\gamma_i'\left(\underline{F}_t\underline{Y}_t'-E\left[\underline{F}_t\underline{Y}_t'\right]\right)\alpha_{YY,\ell}\right.\right.\right. \\
& \qquad \left.+\gamma_i'\left(\underline{F}_t\underline{F}_t'-E\left[\underline{F}_t\underline{F}_t'\right]\right)\alpha_{YF,\ell}\right\}\Big) \\
& \qquad \left.\times\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\left\{\gamma_i'E\left[\underline{F}_t\right]\mu_{Y,\ell}+\gamma_i'E\left[\underline{F}_t\underline{Y}_t'\right]\alpha_{YY,\ell}+\gamma_i'E\left[\underline{F}_t\underline{F}_t'\right]\alpha_{YF,\ell}\right\}\right)\right| \\
\leq\ & \left[\max_{1\leq\ell\leq d}\max_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\left\{\gamma_i'\left(\underline{F}_t-E\left[\underline{F}_t\right]\right)\mu_{Y,\ell}+\gamma_i'\left(\underline{F}_t\underline{Y}_t'-E\left[\underline{F}_t\underline{Y}_t'\right]\right)\alpha_{YY,\ell}\right.\right.\right. \\
& \qquad \left.\left.\left.+\gamma_i'\left(\underline{F}_t\underline{F}_t'-E\left[\underline{F}_t\underline{F}_t'\right]\right)\alpha_{YF,\ell}\right\}\right)^2\right]^{1/2} \\
& \times\left[\max_{1\leq\ell\leq d}\max_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\left\{\gamma_i'E\left[\underline{F}_t\right]\mu_{Y,\ell}+\gamma_i'E\left[\underline{F}_t\underline{Y}_t'\right]\alpha_{YY,\ell}+\gamma_i'E\left[\underline{F}_t\underline{F}_t'\right]\alpha_{YF,\ell}\right\}\right)^2\right]^{1/2} \\
=\ & o_p(1)\,O(1) \\
=\ & o_p(1).
\end{aligned}$$

For part (g), we apply the Cauchy-Schwarz inequality as well as part (d) of Lemma

OA-6 and part (e) of this lemma to obtain

$$\begin{aligned}
&\max_{1\leq\ell\leq d}\max_{i\in H^c}\left|\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\underline{F}_t\left[\mu_{Y,\ell}+\underline{Y}_t'\alpha_{YY,\ell}+\underline{F}_t'\alpha_{YF,\ell}\right]\right)\right. \\
&\qquad\left.\times\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}y_{\ell,t+1}u_{it}\right)\right| \\
\leq\ &\max_{1\leq\ell\leq d}\max_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left|\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\underline{F}_t\left[\mu_{Y,\ell}+\underline{Y}_t'\alpha_{YY,\ell}+\underline{F}_t'\alpha_{YF,\ell}\right]\right)\right. \\
&\qquad\left.\times\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}y_{\ell,t+1}u_{it}\right)\right| \\
\leq\ &\sqrt{\max_{1\leq\ell\leq d}\max_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\underline{F}_t\left[\mu_{Y,\ell}+\underline{Y}_t'\alpha_{YY,\ell}+\underline{F}_t'\alpha_{YF,\ell}\right]\right)^2} \\
&\times\sqrt{\max_{1\leq\ell\leq d}\max_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}y_{\ell,t+1}u_{it}\right)^2} \\
=\ &O_p(1)\,o_p(1) \\
=\ &o_p(1)
\end{aligned}$$

Finally, for part (h), we apply the Cauchy-Schwarz inequality as well as part (b) of

Lemma OA-6 and part (e) of this lemma to obtain

$$\begin{aligned}
&\max_{1\leq \ell\leq d}\max_{i\in H^c}\left|\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\underline{F}_t\left[\mu_{Y,\ell}+\underline{Y}_t'\alpha_{YY,\ell}+\underline{F}_t'\alpha_{YF,\ell}\right]\right)\right.\\
&\qquad\left.\times\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\underline{F}_t\varepsilon_{\ell,t+1}\right)\right|\\
\leq\ &\max_{1\leq \ell\leq d}\max_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left|\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\underline{F}_t\left[\mu_{Y,\ell}+\underline{Y}_t'\alpha_{YY,\ell}+\underline{F}_t'\alpha_{YF,\ell}\right]\right)\right.\\
&\qquad\left.\times\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\underline{F}_t\varepsilon_{\ell,t+1}\right)\right|\\
\leq\ &\sqrt{\max_{1\leq \ell\leq d}\max_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\underline{F}_t\left[\mu_{Y,\ell}+\underline{Y}_t'\alpha_{YY,\ell}+\underline{F}_t'\alpha_{YF,\ell}\right]\right)^2}\\
&\times\sqrt{\max_{1\leq \ell\leq d}\max_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\underline{F}_t\varepsilon_{\ell,t+1}\right)^2}\\
=\ &O_p(1)\,o_p(1)\\
=\ &o_p(1).\ \square
\end{aligned}$$

Lemma OA-13: Let $a, b\in\mathbb{R}$ such that $a\geq 0$ and $b\geq 0$. Then,

$$\left|\sqrt{a}-\sqrt{b}\right|\leq\sqrt{|a-b|}$$

Proof of Lemma OA-13: Note that

$$\begin{aligned}
\left(\sqrt{a}-\sqrt{b}\right)^2 &= a-2\sqrt{a}\sqrt{b}+b\\
&= \sqrt{a}\left(\sqrt{a}-\sqrt{b}\right)+\sqrt{b}\left(\sqrt{b}-\sqrt{a}\right)\\
&\leq \sqrt{a}\left|\sqrt{a}-\sqrt{b}\right|+\sqrt{b}\left|\sqrt{b}-\sqrt{a}\right|\\
&= \left(\sqrt{a}+\sqrt{b}\right)\left|\sqrt{a}-\sqrt{b}\right|\\
&= \left|\left(\sqrt{a}+\sqrt{b}\right)\left(\sqrt{a}-\sqrt{b}\right)\right|\\
&= |a-b|
\end{aligned}$$

Taking principal square root on both sides, we obtain

$$\left|\sqrt{a}-\sqrt{b}\right| \leq \sqrt{|a-b|}. \ \square$$

Lemma OA-14:

$$P\left\{\bigcap_{i=1}^{m} A_i\right\} \geq \sum_{i=1}^{m} P\left(A_i\right)-(m-1)$$

Proof of Lemma OA-14:

$$\begin{aligned} P\left\{\bigcap_{i=1}^{m} A_i\right\} &= 1-P\left\{\left(\bigcap_{i=1}^{m} A_i\right)^c\right\} \\ &= 1-P\left\{\bigcup_{i=1}^{m} A_i^c\right\} \quad \text{(by DeMorgan's Law)} \\ &\geq 1-\sum_{i=1}^{m} P\left(A_i^c\right) \\ &= 1-\sum_{i=1}^{m}\left[1-P\left(A_i\right)\right] \\ &= \sum_{i=1}^{m} P\left(A_i\right)-m+1 \\ &= \sum_{i=1}^{m} P\left(A_i\right)-(m-1). \ \square \end{aligned}$$

Lemma OA-15:

(a) For $t>0$,

$$\overline{\Phi}(t)=1-\Phi(t) \leq \frac{\phi(t)}{t},$$

where $\phi(t)$ and $\Phi(t)$ denote, respectively, the pdf and the cdf of a standard normal random variable.

(b) Let $N=N_1+N_2$. Specify φ such that $\varphi \rightarrow 0$ as $N_1, N_2 \rightarrow \infty$ and such that, for some constant $a>0$,

$$\varphi \geq \frac{1}{N^a}$$

for all N_1, N_2 sufficiently large. Then, for all N_1, N_2 sufficiently large such that

$$1-\frac{\varphi}{2N} \geq \Phi(2)$$

we have

$$\Phi^{-1}\left(1-\frac{\varphi}{2N}\right)\leq\sqrt{2\left(1+a\right)}\sqrt{\ln N}.$$

Proof of Lemma OA-15:

(a)

$$\begin{aligned}1-\Phi\left(t\right) &= \int_{t}^{\infty}\frac{1}{\sqrt{2\pi}}\exp\left\{-\frac{z^{2}}{2}\right\}dz\\ &= \int_{t}^{\infty}\frac{1}{z}\frac{z}{\sqrt{2\pi}}\exp\left\{-\frac{z^{2}}{2}\right\}dz\\ &\leq \frac{1}{t}\int_{t}^{\infty}\frac{z}{\sqrt{2\pi}}\exp\left\{-\frac{z^{2}}{2}\right\}dz\end{aligned}$$

Let

$$u=-\frac{z^{2}}{2}\text{ and }du=-zdz$$

so that

$$\begin{aligned}\int_{t}^{\infty}\frac{z}{\sqrt{2\pi}}\exp\left\{-\frac{z^{2}}{2}\right\}dz &= -\int_{-\frac{t^{2}}{2}}^{-\infty}\frac{1}{\sqrt{2\pi}}\exp\left\{u\right\}du\\ &= \int_{-\infty}^{-\frac{t^{2}}{2}}\frac{1}{\sqrt{2\pi}}\exp\left\{u\right\}du\\ &= \frac{1}{\sqrt{2\pi}}\exp\left\{-\frac{t^{2}}{2}\right\}\\ &= \phi\left(t\right)\end{aligned}$$

It follows that

$$\overline{\Phi}\left(t\right)=1-\Phi\left(t\right)\leq\frac{\phi\left(t\right)}{t}.$$

(b) Let $t>0$ and set

$$\Phi\left(t\right)=\Pr\left(Z\leq t\right)=1-\frac{\varphi}{2N}.$$

It follows that

$$\Phi^{-1}\left(\Phi\left(t\right)\right)=\Phi^{-1}\left(1-\frac{\varphi}{2N}\right)=t$$

and, by the result given in part (a) above,

$$1-\Phi\left(t\right)=1-\left(1-\frac{\varphi}{2N}\right)=\frac{\varphi}{2N}\leq\frac{\phi\left(t\right)}{t}.$$

The latter inequality implies that

$$t \leq \phi(t)\,\frac{2N}{\varphi}$$

so that

$$\begin{aligned}
\ln t &\leq \ln\phi(t) + \ln 2 + \ln\left(\frac{N}{\varphi}\right)\\
&= -\frac{1}{2}t^2 - \frac{1}{2}\ln 2 - \frac{1}{2}\ln\pi + \ln 2 + \ln\left(\frac{N}{\varphi}\right)\\
&= -\frac{1}{2}t^2 + \frac{1}{2}\ln 2 - \frac{1}{2}\ln\pi + \ln\left(\frac{N}{\varphi}\right)\\
&< -\frac{1}{2}t^2 + \frac{1}{2}\ln 2 + \ln\left(\frac{N}{\varphi}\right)\\
&< -\frac{1}{2}t^2 + \ln 2 + \ln\left(\frac{N}{\varphi}\right)
\end{aligned}$$

or

$$\begin{aligned}
t^2 &\leq 2(\ln 2 - \ln t) + 2\ln\left(\frac{N}{\varphi}\right)\\
&= 2\ln\left(\frac{2}{t}\right) + 2\ln\left(\frac{N}{\varphi}\right)\\
&\leq 2\ln\left(\frac{N}{\varphi}\right) \text{ for any } t = \Phi^{-1}\left(1-\frac{\varphi}{2N}\right) \geq 2
\end{aligned}$$

so that

$$t \leq \sqrt{2}\sqrt{\ln\left(\frac{N}{\varphi}\right)} \text{ for any } t = \Phi^{-1}\left(1-\frac{\varphi}{2N}\right) \geq 2$$

Hence, for N_1, N_2 sufficiently large so that

$$1-\frac{\varphi}{2N} \geq \Phi(2) \text{ or, equivalently, } t = \Phi^{-1}\left(1-\frac{\varphi}{2N}\right) \geq 2,$$

we have

$$\begin{aligned}\Phi^{-1}\left(1-\frac{\varphi}{2N}\right) &= t \\ &\leq \sqrt{2}\sqrt{\ln\left(\frac{N}{\varphi}\right)} \\ &= \sqrt{2}\sqrt{\ln N - \ln\varphi} \\ &= \sqrt{2}\sqrt{\ln N}\sqrt{1-\frac{\ln\varphi}{\ln N}} \\ &\leq \sqrt{2}\sqrt{\ln N}\sqrt{1-\frac{\ln N^{-a}}{\ln N}} \\ &= \sqrt{2\left(1+a\right)}\sqrt{\ln N}. \ \square\end{aligned}$$

Lemma QA-16: Suppose that Assumptions 2-1, 2-2, 2-3, 2-5, 2-6, and 2-8 hold and suppose that $N_1, N_2, T \to \infty$ such that $N_1/\tau_1^3 = N_1/\left\lfloor T_0^{\alpha_1}\right\rfloor^3 \to 0$. Then, the following statements are true.

(a)

$$\max_{1\leq\ell\leq d}\max_{i\in H^c}\left|\frac{\overline{S}_{i,\ell,T}-\mu_{i,\ell,T}}{\mu_{i,\ell,T}}\right| \xrightarrow{p} 0$$

(b)

$$\max_{1\leq\ell\leq d}\max_{i\in H^c}\left|\frac{\overline{V}_{i,\ell,T}-\pi_{i,\ell,T}}{\pi_{i,\ell,T}}\right| \xrightarrow{p} 0$$

where

$$\overline{S}_{i,\ell,T} = \sum_{r=1}^{q}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1} Z_{it}y_{\ell,t+1} and \overline{V}_{i,\ell,T} = \sum_{r=1}^{q}\left[\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1} Z_{it}y_{\ell,t+1}\right]^2$$

Proof of Lemma QA-16:

To show part (a), note first that by applying parts (a) and (c) of Lemma OA-6, parts (a)-(c) of Lemma OA-12, and the Slutsky theorem; we obtain

$$\begin{aligned}
& \max_{1\leq\ell\leq d}\max_{i\in H^c}\left|\frac{\overline{S}_{i,\ell,T}-\mu_{i,\ell,T}}{q\tau_1}\right| \\
= & \max_{1\leq\ell\leq d}\max_{i\in H^c}\left|\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\underline{F}_t\left[\mu_{Y,\ell}+\underline{Y}_t'\alpha_{YY,\ell}+\underline{F}_t'\alpha_{YF,\ell}\right]\right. \\
& \qquad +\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\underline{F}_t\varepsilon_{\ell,t+1}+\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}y_{\ell,t+1}u_{it} \\
& \qquad \left.-\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\left\{\gamma_i'E\left[\underline{F}_t\right]\mu_{Y,\ell}+\gamma_i'E\left[\underline{F}_t\underline{Y}_t'\right]\alpha_{YY,\ell}+\gamma_i'E\left[\underline{F}_t\underline{F}_t'\right]\alpha_{YF,\ell}\right\}\right| \\
\leq & \max_{1\leq\ell\leq d}\max_{i\in H^c}\left|\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\left(\underline{F}_t-E\left[\underline{F}_t\right]\right)\mu_{Y,\ell}\right| \\
& +\max_{1\leq\ell\leq d}\max_{i\in H^c}\left|\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\left(\underline{F}_t\underline{Y}_t'-E\left[\underline{F}_t\underline{Y}_t'\right]\right)\alpha_{YY,\ell}\right| \\
& +\max_{1\leq\ell\leq d}\max_{i\in H^c}\left|\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\left(\underline{F}_t\underline{F}_t'-E\left[\underline{F}_t\underline{F}_t'\right]\right)\alpha_{YF,\ell}\right| \\
& +\max_{1\leq\ell\leq d}\max_{i\in H^c}\left|\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\underline{F}_t\varepsilon_{\ell,t+1}\right| \\
& +\max_{1\leq\ell\leq d}\max_{i\in H^c}\left|\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}y_{\ell,t+1}u_{it}\right| \\
= & \ o_p\left(1\right)
\end{aligned}$$

Moreover, by Assumption 2-8, there exist a positive constant $\underline{c}$ such that for all N and T sufficiently large

$$\begin{aligned}
& \min_{1\leq\ell\leq d}\min_{i\in H^c}\left|\frac{\mu_{i,\ell,T}}{q\tau_1}\right| \\
= & \min_{1\leq\ell\leq d}\min_{i\in H^c}\left|\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\left\{E\left[\underline{F}_t\right]\mu_{Y,\ell}+E\left[\underline{F}_t\underline{Y}_t'\right]\alpha_{YY,\ell}+E\left[\underline{F}_t\underline{F}_t'\right]\alpha_{YF,\ell}\right\}\right| \\
\geq & \ \underline{c}>0
\end{aligned}$$

It follows that

$$\max_{1 \leq \ell \leq d} \max_{i \in H^c} \left| \frac{\overline{S}_{i,\ell,T} - \mu_{i,\ell,T}}{\mu_{i,\ell,T}} \right| \leq \max_{1 \leq \ell \leq d} \max_{i \in H^c} \left| \frac{\overline{S}_{i,\ell,T} - \mu_{i,\ell,T}}{q\tau_1} \right| / \min_{1 \leq \ell \leq d} \min_{i \in H^c} \left| \frac{\mu_{i,\ell,T}}{q\tau_1} \right| = o_p\left(1\right).$$

Now, for part (b), note that, applying parts (d), (f), (g), and (h) of Lemma OA-12, parts (b), (d), and (e) of Lemma OA-6, and the Slutsky theorem; we have

$$
\begin{aligned}
& \max_{1\le\ell\le d}\max_{i\in H^c}\left|\frac{\overline{V}_{i,\ell,T}-\pi_{i,\ell,T}}{q\tau_1^2}\right| \\
= \; & \max_{1\le\ell\le d}\max_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\left\{\left(\underline{F}_t-E\left[\underline{F}_t\right]\right)\mu_{Y,\ell}+\left(\underline{F}_t\underline{Y}_t'-E\left[\underline{F}_t\underline{Y}_t'\right]\right)\alpha_{YY,\ell}\right.\right. \\
& \qquad\qquad\qquad \left.\left.+\left(\underline{F}_t\underline{F}_t'-E\left[\underline{F}_t\underline{F}_t'\right]\right)\alpha_{YF,\ell}\right\}\right)^2 \\
& +\max_{1\le\ell\le d}\max_{i\in H^c}\left|\frac{2}{q}\sum_{r=1}^{q}\left\{\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\left\{\left(\underline{F}_t-E\left[\underline{F}_t\right]\right)\mu_{Y,\ell}+\left(\underline{F}_t\underline{Y}_t'-E\left[\underline{F}_t\underline{Y}_t'\right]\right)\alpha_{YY,\ell}\right.\right.\right.\right. \\
& \qquad\qquad\qquad \left.\left.+\left(\underline{F}_t\underline{F}_t'-E\left[\underline{F}_t\underline{F}_t'\right]\right)\alpha_{YF,\ell}\right\}\right) \\
& \qquad \left.\left.\times\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\left\{E\left[\underline{F}_t\right]\mu_{Y,\ell}+E\left[\underline{F}_t\underline{Y}_t'\right]\alpha_{YY,\ell}+E\left[\underline{F}_t\underline{F}_t'\right]\alpha_{YF,\ell}\right\}\right)\right\}\right| \\
& +\max_{1\le\ell\le d}\max_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\underline{F}_t\varepsilon_{\ell,t+1}\right)^2 \\
& +\max_{1\le\ell\le d}\max_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}y_{\ell,t+1}u_{it}\right)^2 \\
& +2\max_{1\le\ell\le d}\max_{i\in H^c}\left|\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\underline{F}_t\varepsilon_{\ell,t+1}\right)\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}y_{\ell,t+1}u_{it}\right)\right| \\
& +2\max_{1\le\ell\le d}\max_{i\in H^c}\left|\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\underline{F}_t\left[\mu_{Y,\ell}+\underline{Y}_t'\alpha_{YY,\ell}+\underline{F}_t'\alpha_{YF,\ell}\right]\right)\right. \\
& \qquad\qquad \left.\times\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}y_{\ell,t+1}u_{it}\right)\right| \\
& +2\max_{1\le\ell\le d}\max_{i\in H^c}\left|\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\underline{F}_t\left[\mu_{Y,\ell}+\underline{Y}_t'\alpha_{YY,\ell}+\underline{F}_t'\alpha_{YF,\ell}\right]\right)\right. \\
& \qquad\qquad \left.\times\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\underline{F}_t\varepsilon_{\ell,t+1}\right)\right| \\
= \; & o_p\left(1\right)
\end{aligned}
$$

Moreover, note that, for all N and T sufficiently large,

$$
\begin{aligned}
& \min_{1\leq\ell\leq d}\min_{i\in H^c}\frac{\pi_{i,\ell,T}}{q\tau_1^2} \\
= \; & \min_{1\leq\ell\leq d}\min_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\left\{\gamma_i' E\left[\underline{F}_t\right]\mu_{Y,\ell}+\gamma_i' E\left[\underline{F}_t\underline{Y}_t'\right]\alpha_{YY,\ell}+\gamma_i' E\left[\underline{F}_t\underline{F}_t'\right]\alpha_{YF,\ell}\right\}\right)^2 \\
= \; & \min_{1\leq\ell\leq d}\min_{i\in H^c}\frac{1}{q}\sum_{r=1}^{q}\left(\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\left\{E\left[\underline{F}_t\right]\mu_{Y,\ell}+E\left[\underline{F}_t\underline{Y}_t'\right]\alpha_{YY,\ell}+E\left[\underline{F}_t\underline{F}_t'\right]\alpha_{YF,\ell}\right\}\right)^2 \\
\geq \; & \min_{1\leq\ell\leq d}\min_{i\in H^c}\left(\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\left\{E\left[\underline{F}_t\right]\mu_{Y,\ell}+E\left[\underline{F}_t\underline{Y}_t'\right]\alpha_{YY,\ell}+E\left[\underline{F}_t\underline{F}_t'\right]\alpha_{YF,\ell}\right\}\right)^2 \\
& \text{(by Jensen's inequality)} \\
= \; & \min_{1\leq\ell\leq d}\min_{i\in H^c}\left|\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\left\{E\left[\underline{F}_t\right]\mu_{Y,\ell}+E\left[\underline{F}_t\underline{Y}_t'\right]\alpha_{YY,\ell}+E\left[\underline{F}_t\underline{F}_t'\right]\alpha_{YF,\ell}\right\}\right|^2 \\
= \; & \left(\min_{1\leq\ell\leq d}\min_{i\in H^c}\left|\frac{1}{q}\sum_{r=1}^{q}\frac{1}{\tau_1}\sum_{t=(r-1)\tau+p}^{(r-1)\tau+\tau_1+p-1}\gamma_i'\left\{E\left[\underline{F}_t\right]\mu_{Y,\ell}+E\left[\underline{F}_t\underline{Y}_t'\right]\alpha_{YY,\ell}+E\left[\underline{F}_t\underline{F}_t'\right]\alpha_{YF,\ell}\right\}\right|\right)^2 \\
\geq \; & \underline{c}^2 > 0 \quad \text{(by Assumption 2-8)}.
\end{aligned}
$$

It follows that

$$
\max_{1\leq\ell\leq d}\max_{i\in H^c}\left|\frac{\overline{V}_{i,\ell,T}-\pi_{i,\ell,T}}{\pi_{i,\ell,T}}\right| \leq \max_{1\leq\ell\leq d}\max_{i\in H^c}\left|\frac{\overline{V}_{i,\ell,T}-\pi_{i,\ell,T}}{q\tau_1^2}\right| \Big/ \min_{1\leq\ell\leq d}\min_{i\in H^c}\left(\frac{\pi_{i,\ell,T}}{q\tau_1^2}\right) = o_p(1). \; \square
$$

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