

A Analysis of Debiased Multi-Task Fused Lasso

The following analysis is used to show the conditions under which the debias multi-task fused lasso achieves a negligible bias.

Let $\beta = [\beta_1; \beta_2], \beta_d = \beta_1 - \beta_2, \beta_a = \beta_1 + \beta_2$. Let $S_{1,2}$ bet the support of β . Define $\mathbf{X}_N = [\mathbf{X}_1/\sqrt{n_1}, 0; 0, \mathbf{X}_2/\sqrt{n_2}]$

Lemma 1. (*Basic Inequality*) $\|\mathbf{X}_N(\hat{\beta} - \beta)\|_2^2 + \lambda_1\|\hat{\beta}\|_1 + \lambda_2\|\hat{\beta}_d\| \leq 2\epsilon^T \mathbf{X}_N(\hat{\beta} - \beta) + \lambda_1\|\beta\|_1 + \lambda_2\|\beta_d\|_1$

This follows from the fact that $\hat{\beta}$ is the minimizer of the fused lasso objective.

The term, $\epsilon^T \mathbf{X}_N(\hat{\beta} - \beta)$, commonly known as the empirical process term [1] can be bound as follows:

$$\begin{aligned} 2|\epsilon^T \mathbf{X}_N(\hat{\beta} - \beta)| &= 2|\epsilon_1^T \mathbf{X}_1(\hat{\beta}_1 - \beta_1)/n_1 + \epsilon_2^T \mathbf{X}_2(\hat{\beta}_2 - \beta_2)/n_2| \leq \\ &2\|\hat{\beta}_1 - \beta_1\|_1 \max_{1 \leq j \leq p} |\epsilon_1^T \mathbf{X}_1^{(j)}/n_1| + 2\|\hat{\beta}_2 - \beta_2\|_1 \max_{1 \leq j \leq p} |\epsilon_2^T \mathbf{X}_2^{(j)}/n_2| \end{aligned}$$

Where we utilize holder's inequality in the last line. We define the random event \mathcal{F} for which the following holds: $\max_{1 \leq j \leq p} |\epsilon_1^T \mathbf{X}_1^{(j)}/n_1| \leq \lambda_0$ and $\max_{1 \leq j \leq p} |\epsilon_2^T \mathbf{X}_2^{(j)}/n_2| \leq \lambda_0$. furthermore we can select $2\lambda_0 \leq \lambda_1$

Lemma 2. Suppose $\hat{\Sigma}_{j,j} = 1$ for both \mathbf{X}_1 and \mathbf{X}_2 then we have for all $t > 0$ and $n_1 > n_2$

$$\lambda_0 = 2\sigma_2 \sqrt{\frac{t^2 + \log p}{n_2}} \quad (16)$$

$$P(\mathcal{F}) = 1 - 2 \exp(-t^2/2) \quad (17)$$

Proof. This follows directly from the [1, Lemma 6.2] and taking $n_1 > n_2$. \square

This allows us to get rid of the empirical process term on \mathcal{F} , with an appropriate choice of λ_1 .

Given a set, S , denote β_S the vector of equal size to β but all elements not in S set to zero. We can now show the following

Lemma 3. We have on \mathcal{F} with $\lambda_1 \geq 2\lambda_0$

$$\begin{aligned} &2\|\mathbf{X}_N(\hat{\beta} - \beta)\|_2^2 + \lambda_1\|\hat{\beta}_{S_{1,2}^c}\|_1 + 2\lambda_2\|\hat{\beta}_{d,S_d^c}\|_1 \\ &\leq 3\lambda_1\|\hat{\beta}_{S_{1,2}} - \beta_{S_{1,2}}\|_1 + 2\lambda_2\|\hat{\beta}_{d,S_d} - \beta_{d,S_d}\|_1 \end{aligned} \quad (18)$$

Proof. Following [1, Lemma 6.3] we start with the basic inequality on \mathcal{F} . Which gives

$$\begin{aligned} &2\|\mathbf{X}_N(\hat{\beta} - \beta)\|_2^2 + 2\lambda_1\|\hat{\beta}\|_1 + 2\lambda_2\|\hat{\beta}_d\| \\ &\leq \lambda_1\|\hat{\beta} - \beta\|_1 + 2\lambda_1\|\beta\|_1 + 2\lambda_2\|\beta_d\|_1 \end{aligned} \quad (19)$$

Since we assume the truth is in fact sparse,

$$\|\hat{\beta}_d - \beta_d\|_1 = \|\hat{\beta}_{d,S_d} - \beta_{d,S_d}\|_1 + \|\hat{\beta}_{d,S_d^c}\|_1 \quad (20)$$

$$\|\hat{\beta} - \beta\|_1 = \|\hat{\beta}_{S_{1,2}} - \beta_{S_{1,2}}\|_1 + \|\hat{\beta}_{S_{1,2}^c}\|_1 \quad (21)$$

Furthermore,

$$\|\hat{\beta}\|_1 \geq \|\beta_{S_{1,2}}\|_1 - \|\hat{\beta}_{S_{1,2}} - \beta_{S_{1,2}}\|_1 + \|\hat{\beta}_{S_{1,2}^c}\|_1 \quad (22)$$

$$\|\hat{\beta}_d\|_1 \geq \|\beta_{d,S_d}\|_1 - \|\hat{\beta}_{d,S_d} - \beta_{d,S_d}\|_1 + \|\hat{\beta}_{d,S_d^c}\|_1 \quad (23)$$

Substituting (22), (23), and (21) into (19) and rearranging completes the proof. \square

From the lemma above we can now justify the bounds in (14)

Proposition 3. Take $\lambda_1 > 2\sqrt{\frac{\log p}{n_2}}$ and $\lambda_2 = O(\lambda_1)$. Denote s_d the difference sparsity, $s_{1,2}$ the parameter sparsity $|S_1| + |S_2|$, $c > 1, a > 1$, and $0 < m \ll 1$. When the compatibility condition [1, 11] holds the following bounds gives $l_a u_2 = o(1)$ and $l_d u_1 = o(1)$ and thus $\|\Delta\|_\infty = o(1)$ with high probability.

$$\mu_1 \leq \frac{1}{c\lambda_2 s_d n_2^m} \quad \text{and} \quad \mu_2 \leq \frac{1}{a(\lambda_1 s_{1,2} + \lambda_2 s_d) n_2^m} \quad (24)$$

Proof. We first consider the bound associated with l_a

$$\begin{aligned} \lambda_1 \|\hat{\beta}_a - \beta_a\|_1 &\leq \lambda_1 \|\hat{\beta}_{S_{1,2}} - \beta_{S_{1,2}}\|_1 + \lambda_1 \|\hat{\beta}_{S_{1,2}^c} - \beta_{S_{1,2}^c}\|_1 \leq \\ 4\lambda_1 \|\hat{\beta}_{S_{1,2}} - \beta_{S_{1,2}}\|_1 + 2\lambda_2 \|\hat{\beta}_{S_d} - \beta_{S_d}\|_1 - 2\|\mathbf{X}_N(\hat{\beta} - \beta)\|_2^2 \end{aligned} \quad (25)$$

$$\begin{aligned} &\leq 4\lambda_1 \sqrt{s_{1,2}} \|\hat{\beta}_{S_{1,2}} - \beta_{S_{1,2}}\|_2 + 2\lambda_2 \sqrt{s_d} \|\hat{\beta}_{S_d} - \beta_{S_d}\|_2 \\ &\quad - 2\|\mathbf{X}_N(\hat{\beta} - \beta)\|_2^2 \end{aligned} \quad (26)$$

Invoking the compatibility assumption [1, 16, 11] with compatibility constant ϕ_{\min}

$$\begin{aligned} &\leq \frac{4\lambda_1 \sqrt{s_{1,2}}}{\phi_{\min}} \|\mathbf{X}_N(\hat{\beta} - \beta)\|_2 + \frac{2\lambda_2 \sqrt{s_d}}{\phi_{\min}} \|\mathbf{X}_N(\hat{\beta} - \beta)\|_2 \\ &\quad - 2\|\mathbf{X}_N(\hat{\beta} - \beta)\|_2^2 \end{aligned} \quad (27)$$

$$\leq \frac{4\lambda_1^2 s_{1,2}}{\phi_{\min}^2} + \frac{2\lambda_2^2 s_d}{\phi_{\min}^2} \quad (28)$$

The bound u_2 now follows by inverting the expression shown and adding a factor of n_2^m where $m \ll 1$.

Now we consider the bound for l_d .

$$\lambda_2 \|\hat{\beta}_d - \beta_d\|_1 = \lambda_2 \|\hat{\beta}_{d,S} - \beta_{d,S}\|_1 + \lambda_2 \|\hat{\beta}_{d,S^c} - \beta_{d,S^c}\|_1 \quad (29)$$

$$\leq 2\lambda_2 \|\hat{\beta}_{d,S} - \beta_{d,S}\|_1 + 3\lambda_1 \|\hat{\beta}_{S_{1,2}} - \beta_{S_{1,2}}\|_1/2 \quad (30)$$

$$- \|\mathbf{X}_N(\hat{\beta} - \beta)\|_2^2 - \lambda_1 \|\hat{\beta}_{S_{1,2}^c} - \beta_{S_{1,2}^c}\|_1/2 \quad (31)$$

In the domain of interest $n_1 \gg n_2$ if we select $\lambda_2 = O(\lambda_1)$ we can see the relevant terms related to the parameter support become small with respect to terms with $S_{1,2}$. Thus the error on the difference should dominate. In this region we can have $3\lambda_1 \|\hat{\beta}_{S_{1,2}} - \beta_{S_{1,2}}\|_1/2 - \lambda_1 \|\hat{\beta}_{S_{1,2}^c} - \beta_{S_{1,2}^c}\|_1/2 \leq c\lambda_2 \|\hat{\beta}_{d,S} - \beta_{d,S}\|_1$ where $c > 0$.

$$\lambda_2 \|\hat{\beta}_d - \beta_d\|_1 \leq 2\lambda_2 \|\hat{\beta}_{d,S} - \beta_{d,S}\|_1 - \|\mathbf{X}_N(\hat{\beta} - \beta)\|_2^2 \quad (32)$$

$$\leq 2c\lambda_2 \sqrt{s_d} \|\hat{\beta}_{d,S} - \beta_{d,S}\|_2 - \|\mathbf{X}_N(\hat{\beta} - \beta)\|_2^2 \quad (33)$$

Invoking the compatibility assumption [1]

$$\leq 2c\lambda_2 \sqrt{s_d} \|\mathbf{X}_N(\hat{\beta} - \beta)\|_2 / \phi_{\min} - \|\mathbf{X}_N(\hat{\beta} - \beta)\|_2^2 \quad (34)$$

$$\leq \frac{c^2 \lambda_2^2 s_d}{\phi_{\min}^2} + \|\mathbf{X}_N(\hat{\beta} - \beta)\|_2^2 - \|\mathbf{X}_N(\hat{\beta} - \beta)\|_2^2 \quad (35)$$

Thus $\|\hat{\beta}_d - \beta_d\|_1 \leq \frac{c^2 \lambda_2 s_d}{\phi_{\min}^2}$ and use of the bound prescribed gives $l_d u_1 = o(1)$.

□

B Additional Experimental Details

We show the corrected reproducibility results in Figure 6. For multiple testing correction in our experiments We use the Benjamin-Hochberg FDR procedure.

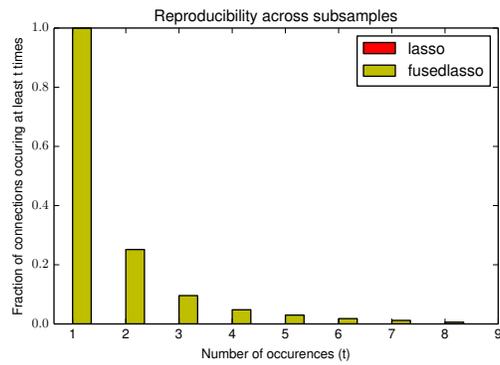


Figure 6: Reproducibility of results from sub-sampling using FDR of 5% Reproducibility of results from subsampling, debiased lasso does not produce any significant edge differences that correspond to a 5% error rate