An Explainable Framework for Particle Swarm Optimization using Landscape Analysis and Machine Learning

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1. Beeswarm plots

The beeswarm plot is an information-dense visualization that summarizes how a model's key features influence its predictions. For each important feature, every instance in the dataset is plotted as a dot on that feature's row. The dot's location on the x-axis is determined by its SHAP value, which quantifies how much and in what direction that feature shifted the model's prediction for that specific instance. These dots accumulate along the row to form a density plot, revealing common patterns of influence.

Simultaneously, the dot's color encodes the original value of the feature for that instance, allowing you to see relationships (e.g., high values of a feature consistently leading to positive SHAP values). The features are ordered from top to bottom by their mean absolute SHAP value. This ordering effectively prioritizes features with a consistent, broad impact across many predictions over those that might have a rare but very strong effect on a few instances.

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1.1. *Case 1: Star Topology*

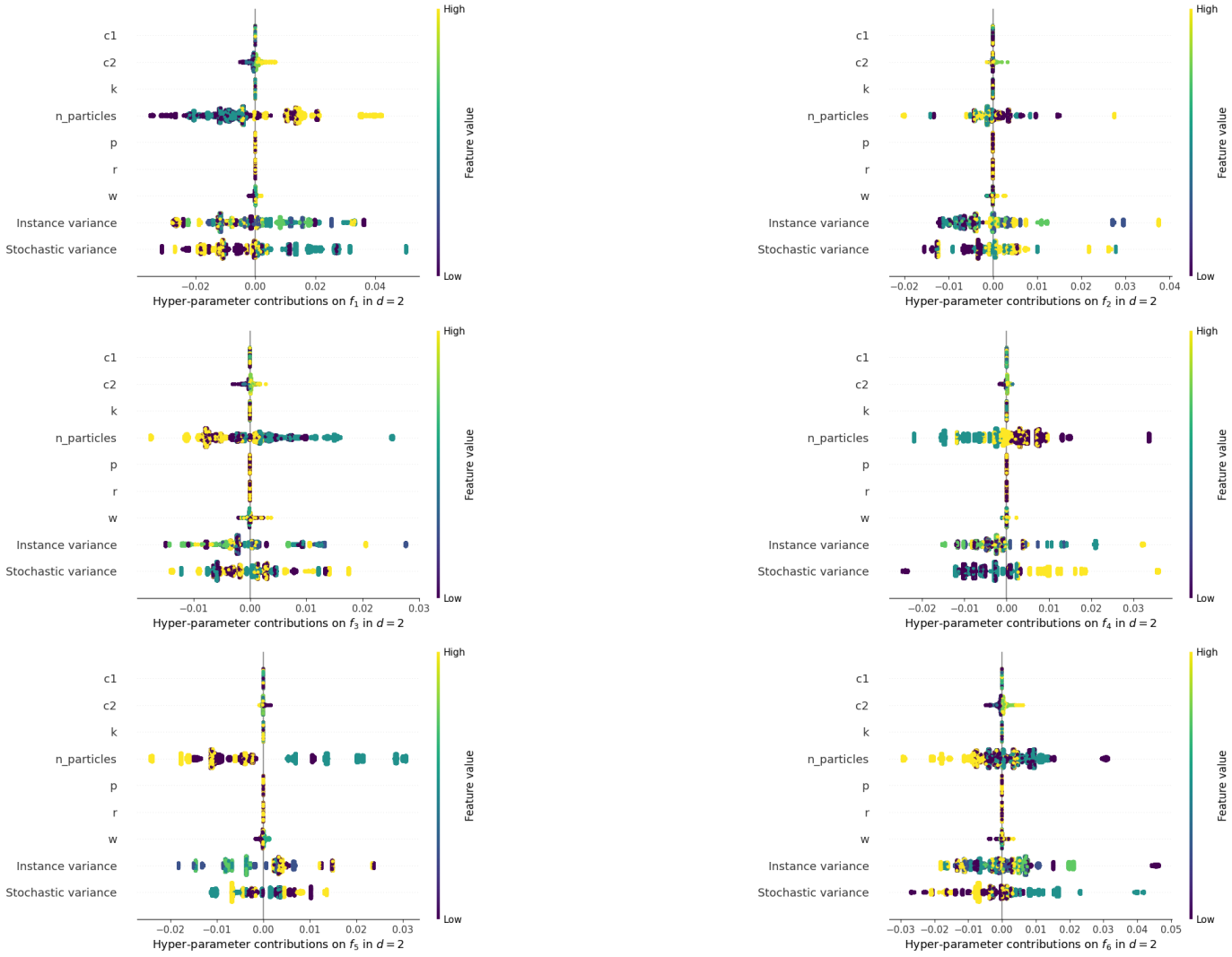


Figure 1: The Impact of Hyperparameters on Performance for Benchmark Function in a 2 d PSO with Star Topology

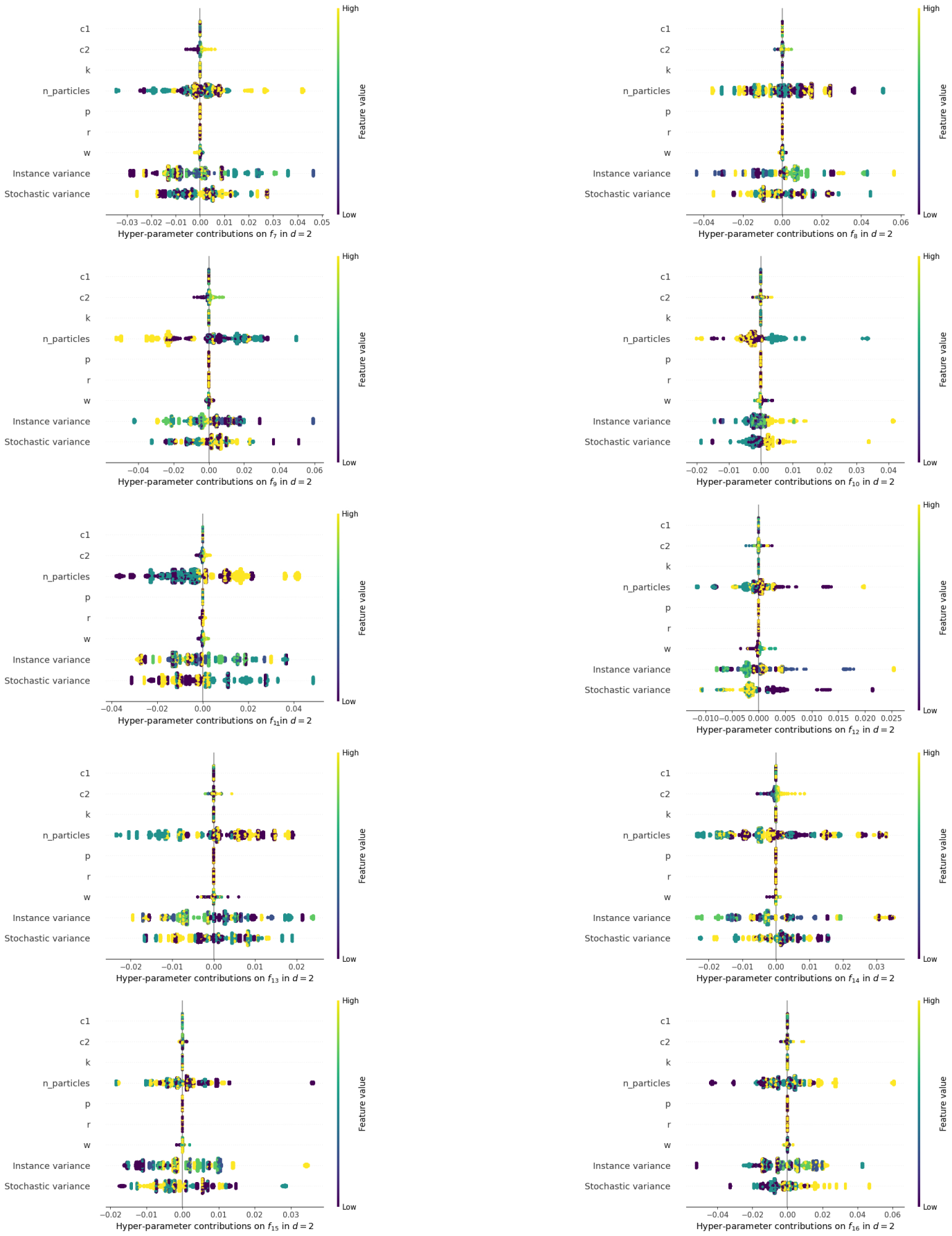


Figure 2: The Impact of Hyperparameters on Performance for Benchmark Function in a 2 d PSO with Star Topology

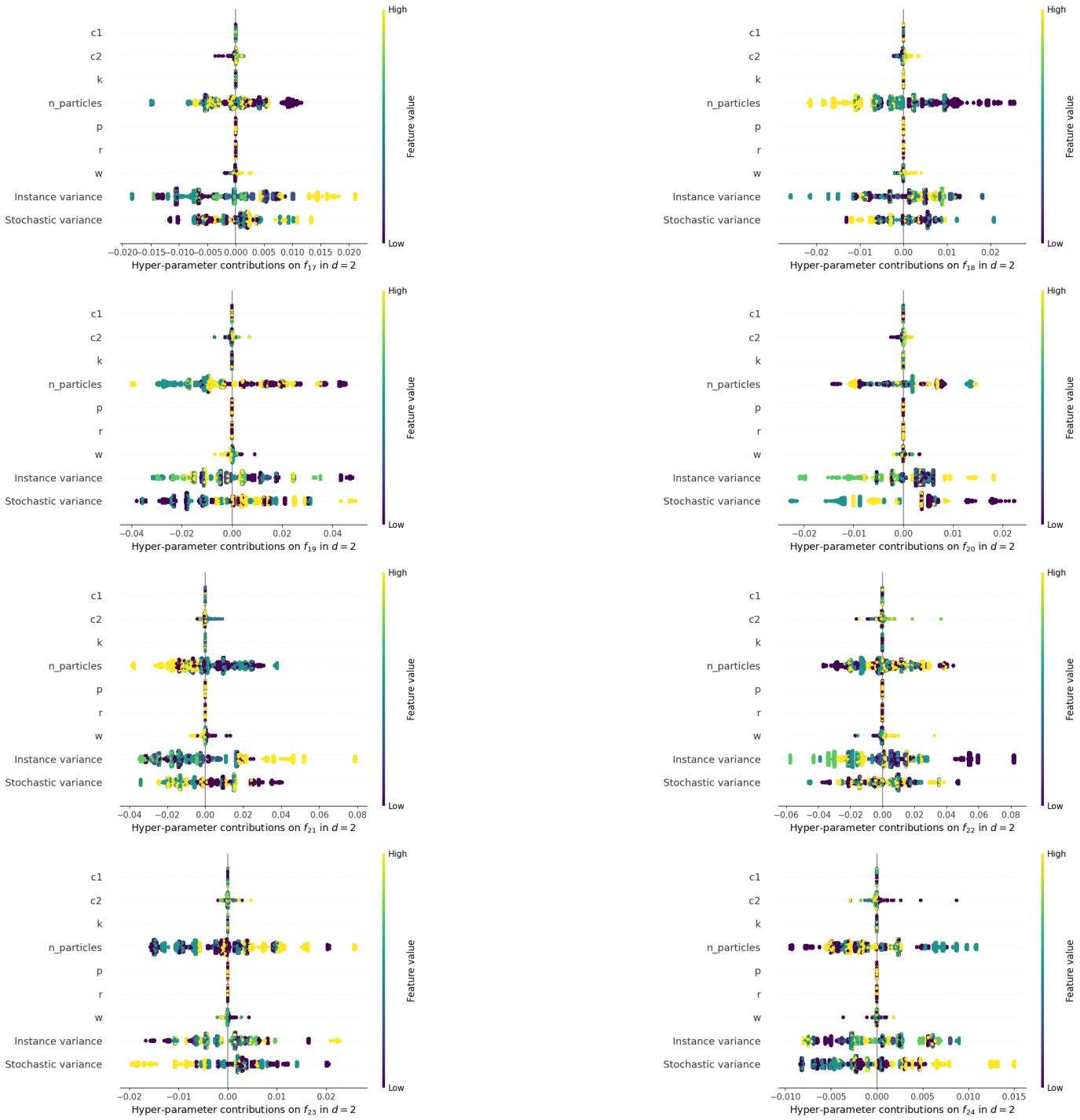


Figure 3: The Impact of Hyperparameters on Performance for Benchmark Function in a 2 d PSO with Star Topology

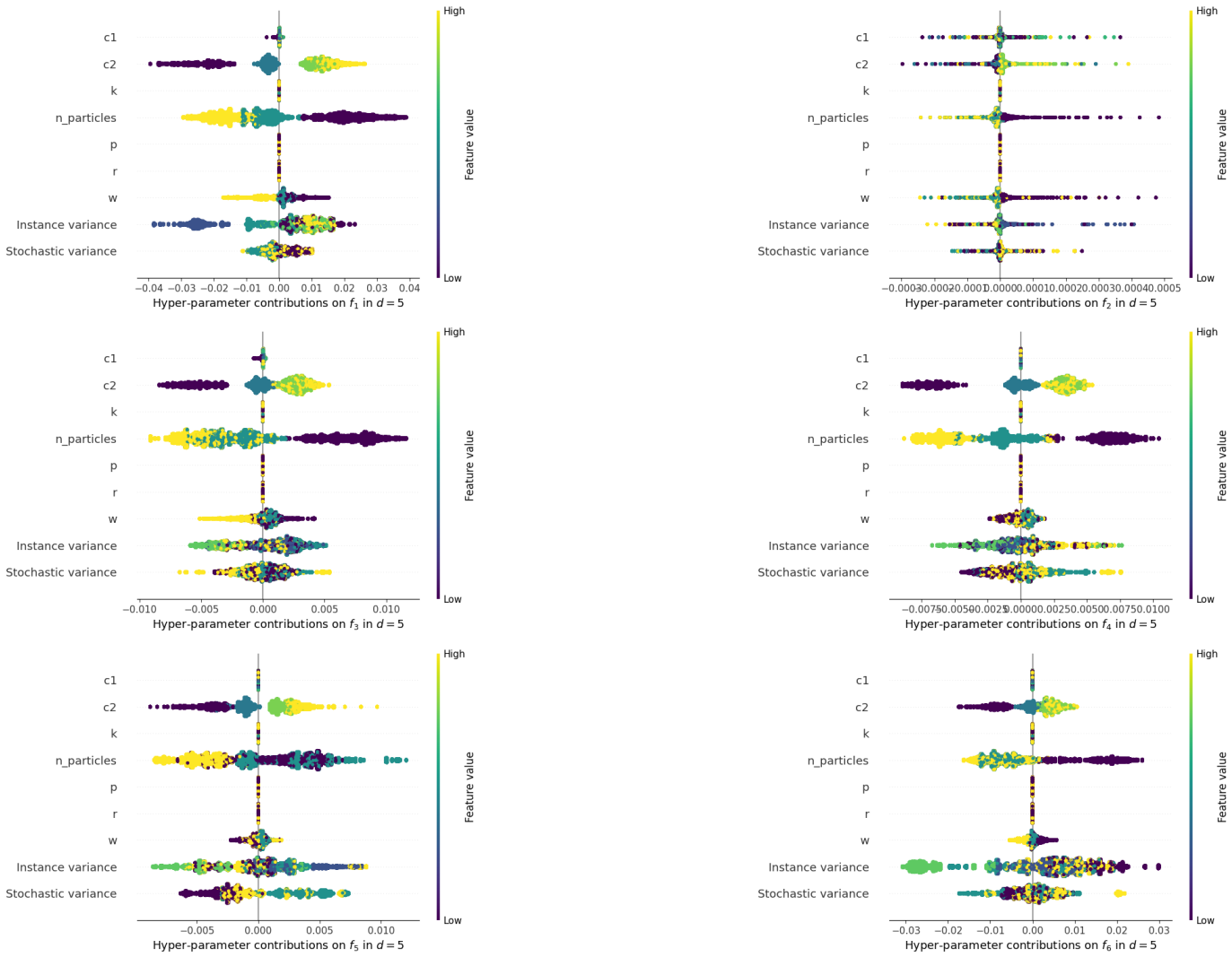


Figure 4: The Impact of Hyperparameters on Performance for Benchmark Function in a 5 d PSO with Star Topology

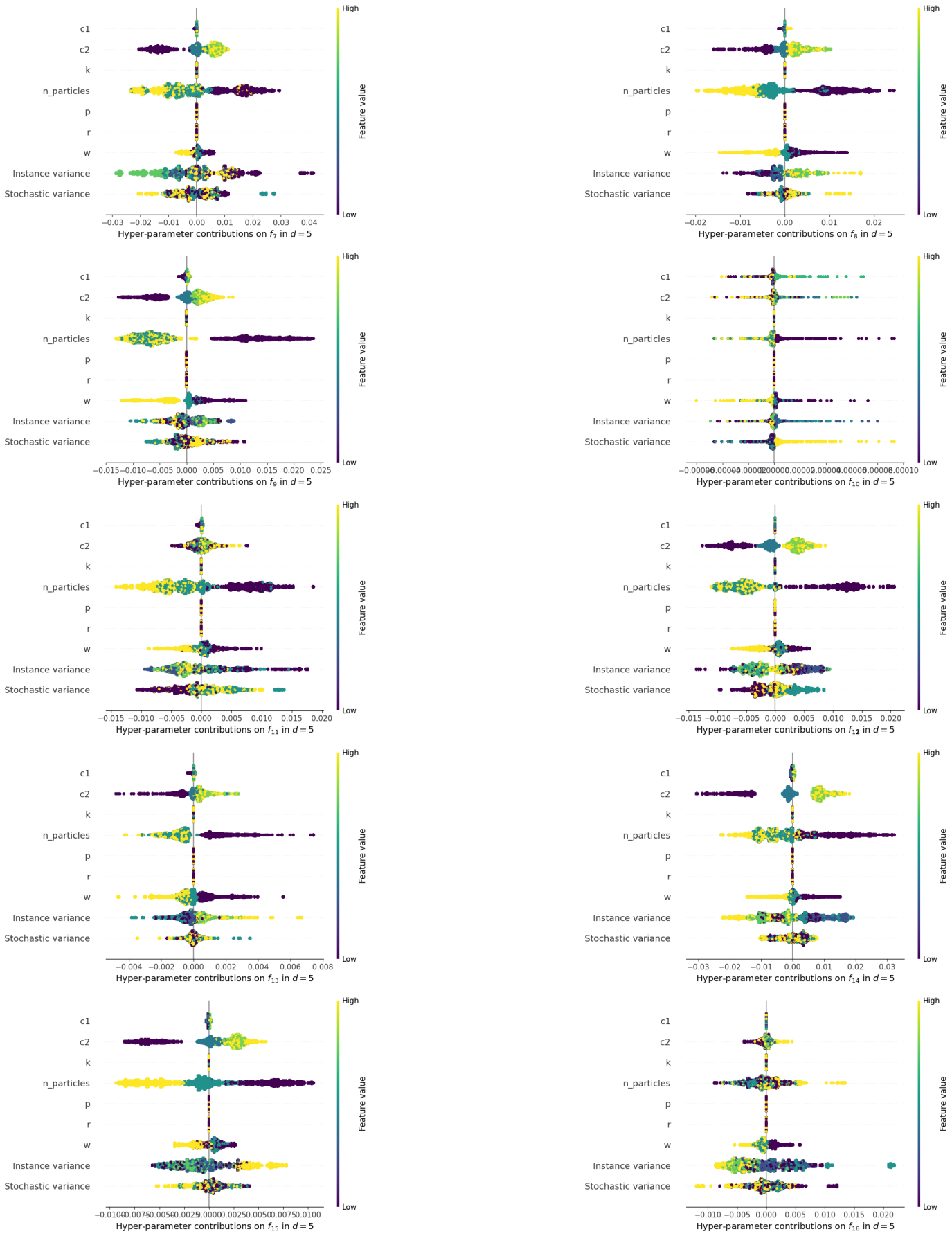


Figure 5: The Impact of Hyperparameters on Performance for Benchmark Function in a 5 d PSO with Star Topology

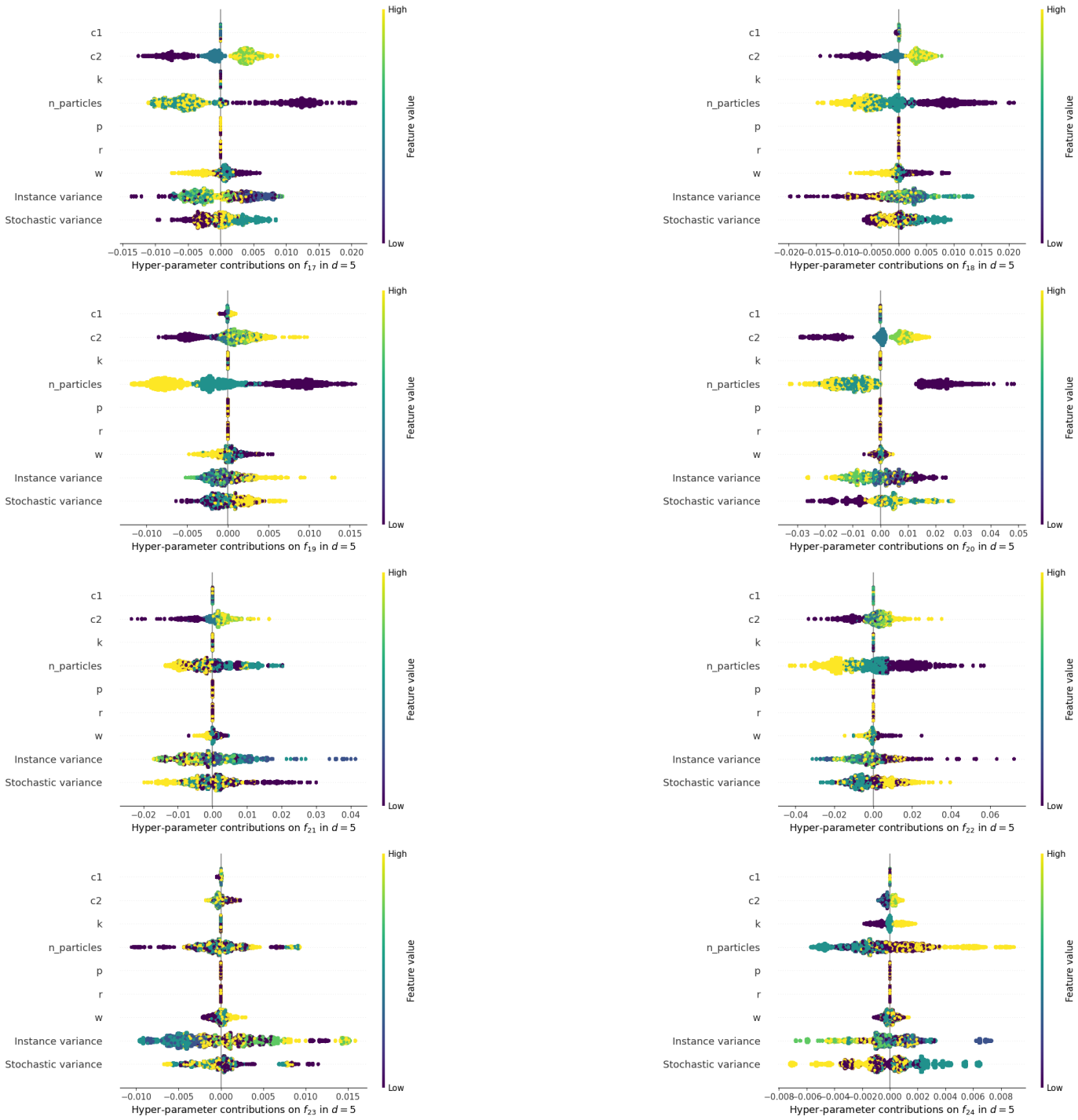


Figure 6: The Impact of Hyperparameters on Performance for Benchmark Function in a 5 d PSO with Star Topology

1.2. *Case 2: Ring Topology*

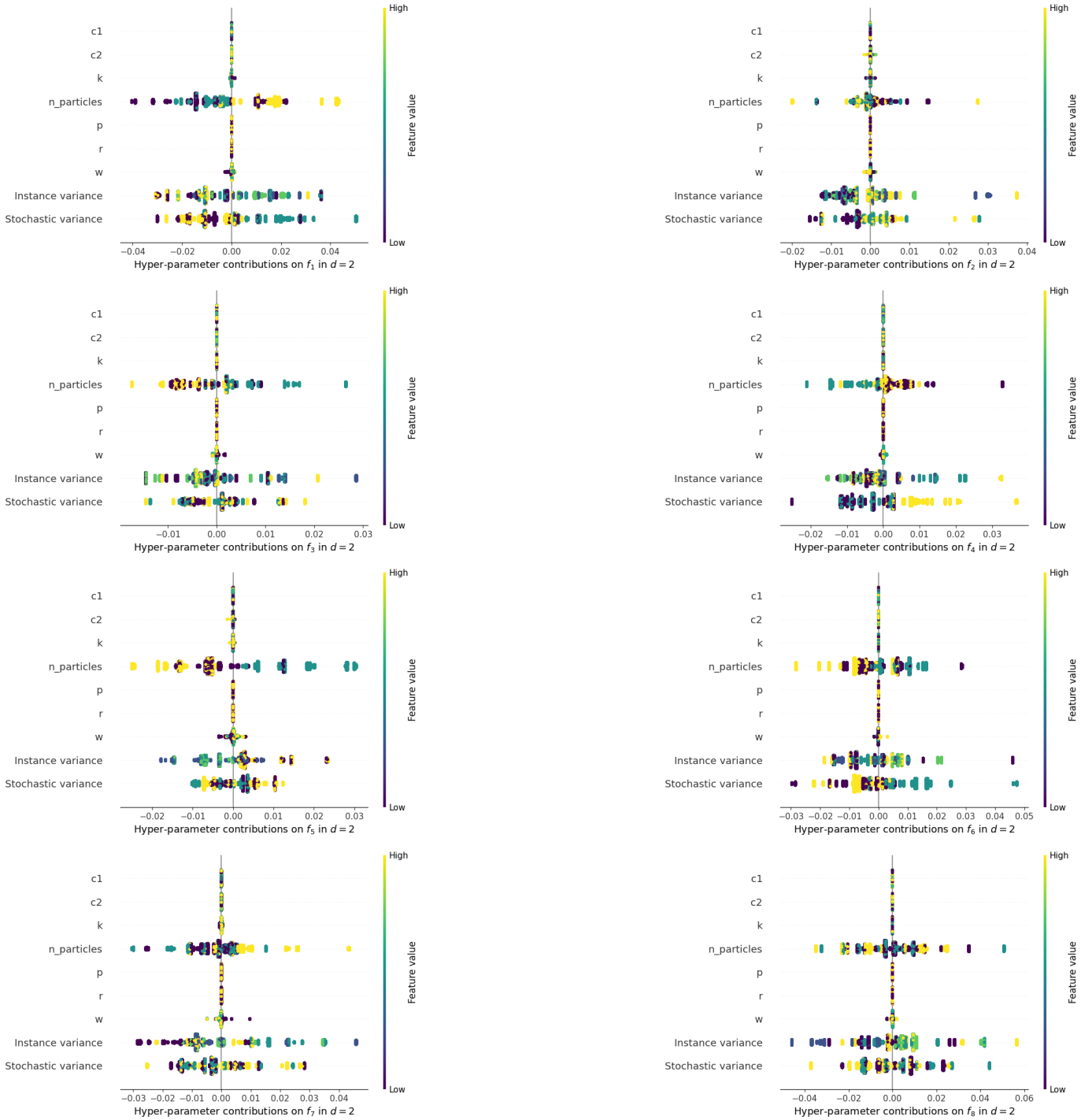


Figure 7: The Impact of Hyperparameters on Performance for Benchmark Function in a 2 d PSO with Ring Topology

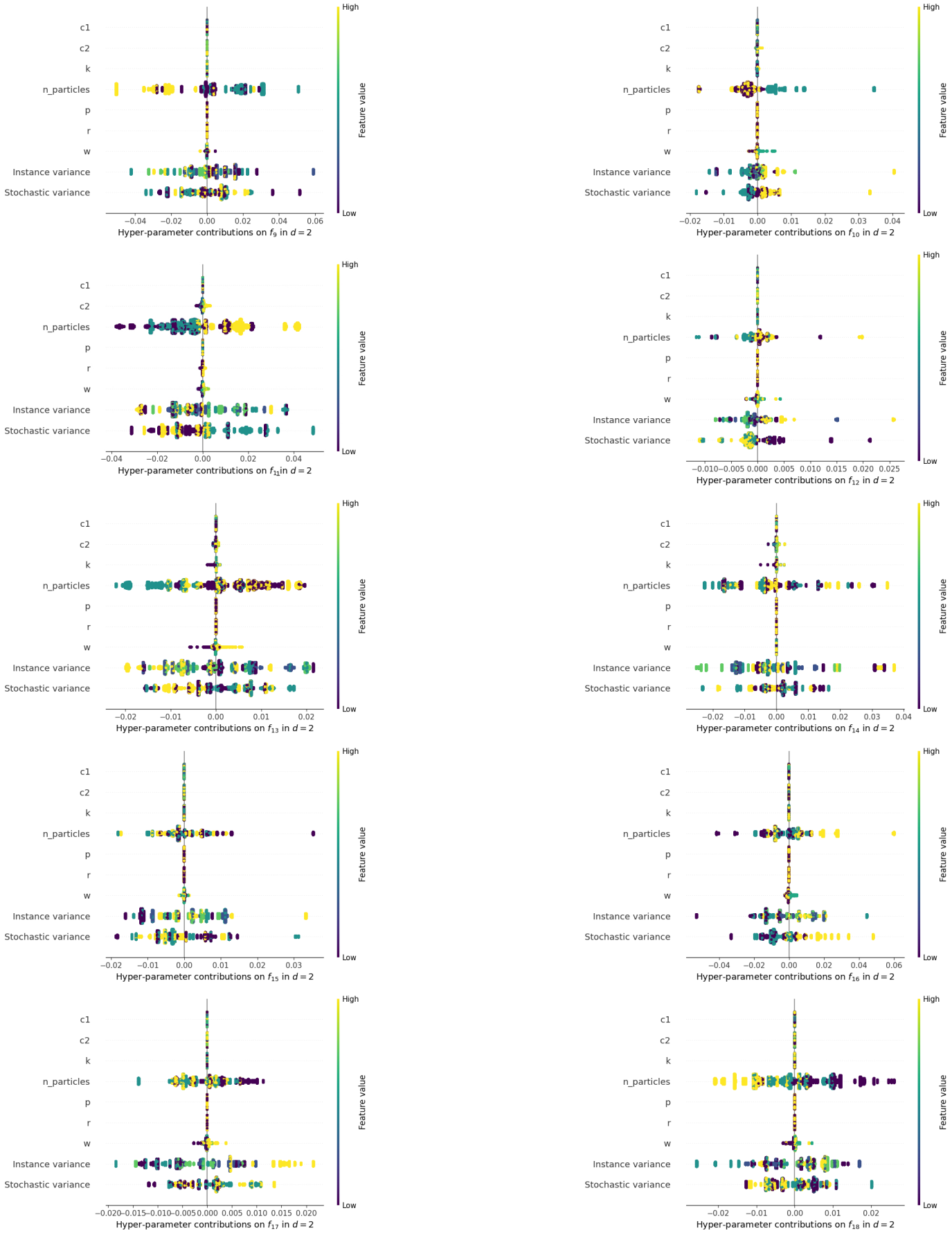


Figure 8: The Impact of Hyperparameters on Performance for Benchmark Function in a 2 d PSO with Ring Topology

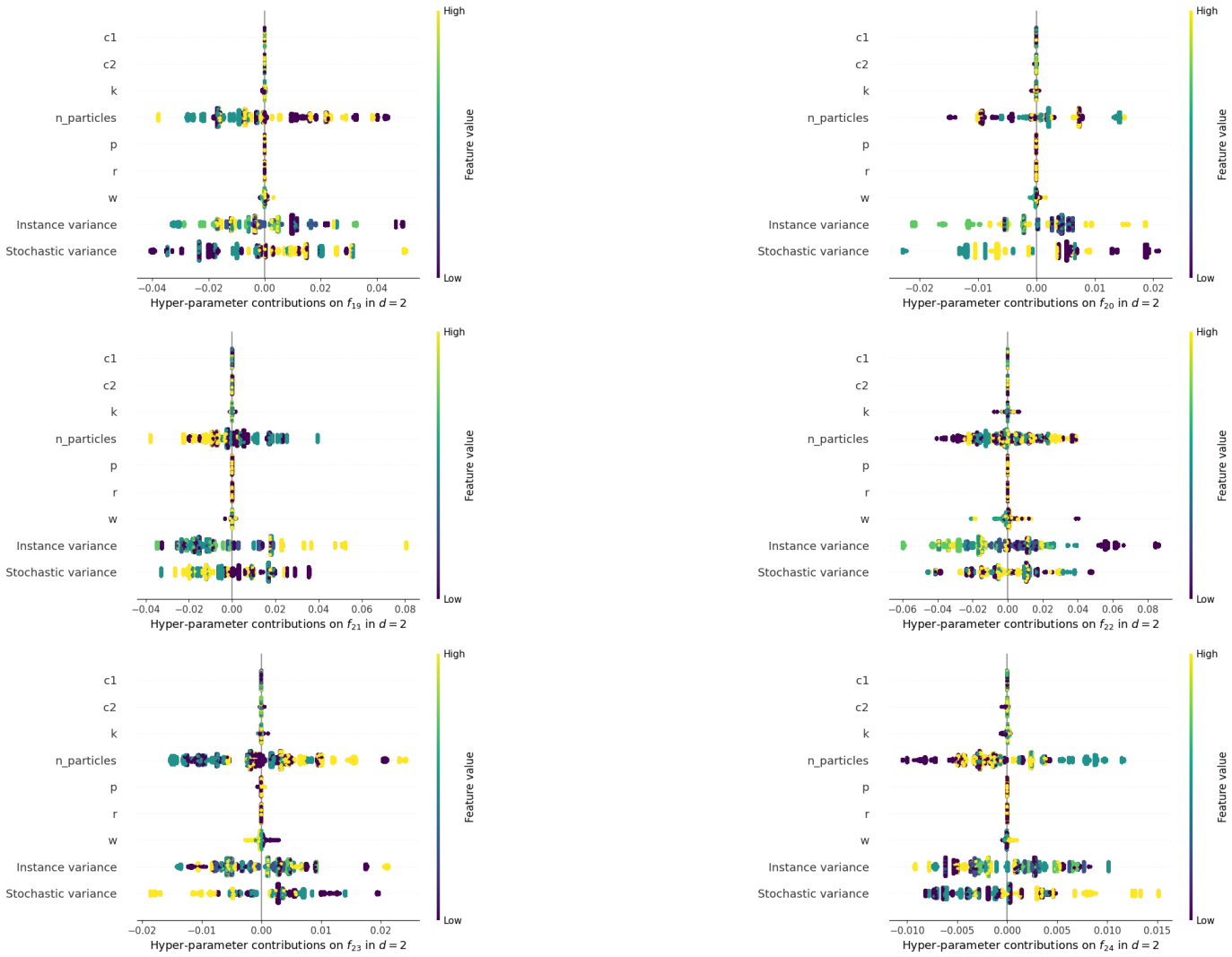


Figure 9: The Impact of Hyperparameters on Performance for Benchmark Function in a 2 d PSO with Ring Topology

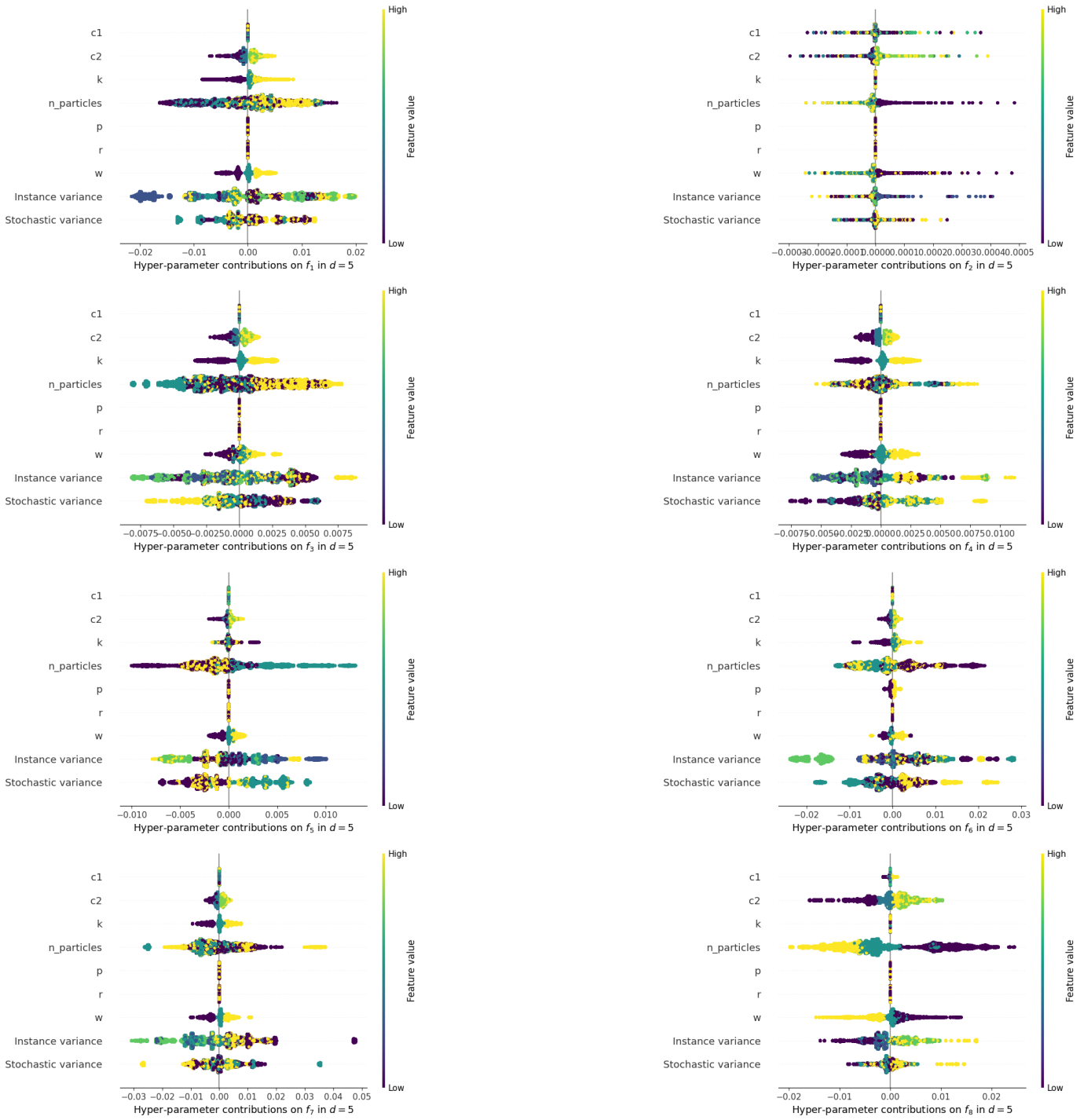


Figure 10: The Impact of Hyperparameters on Performance for Benchmark Function in a 5 d PSO with Ring Topology

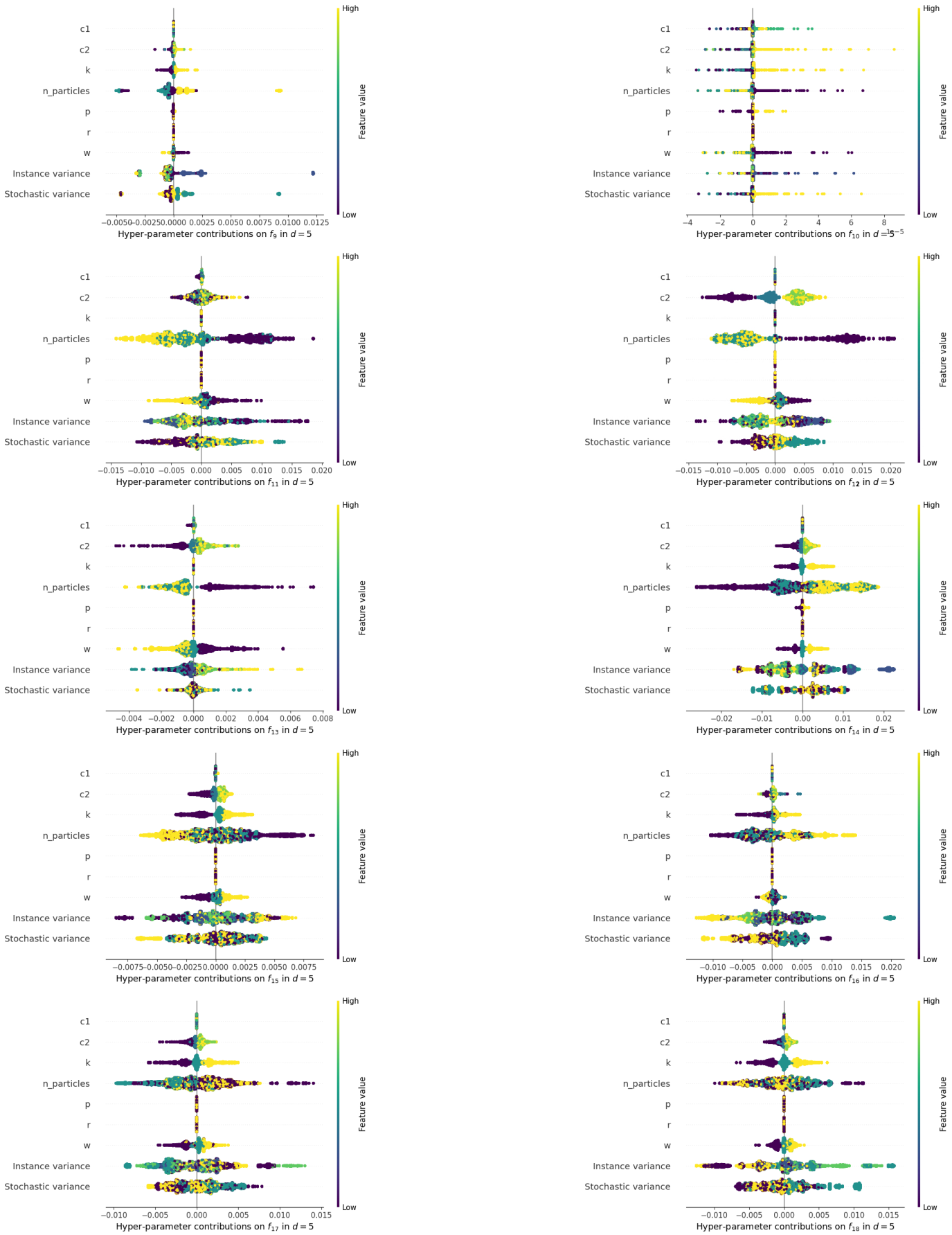


Figure 11: The Impact of Hyperparameters on Performance for Benchmark Function in a 5 d PSO with Ring Topology

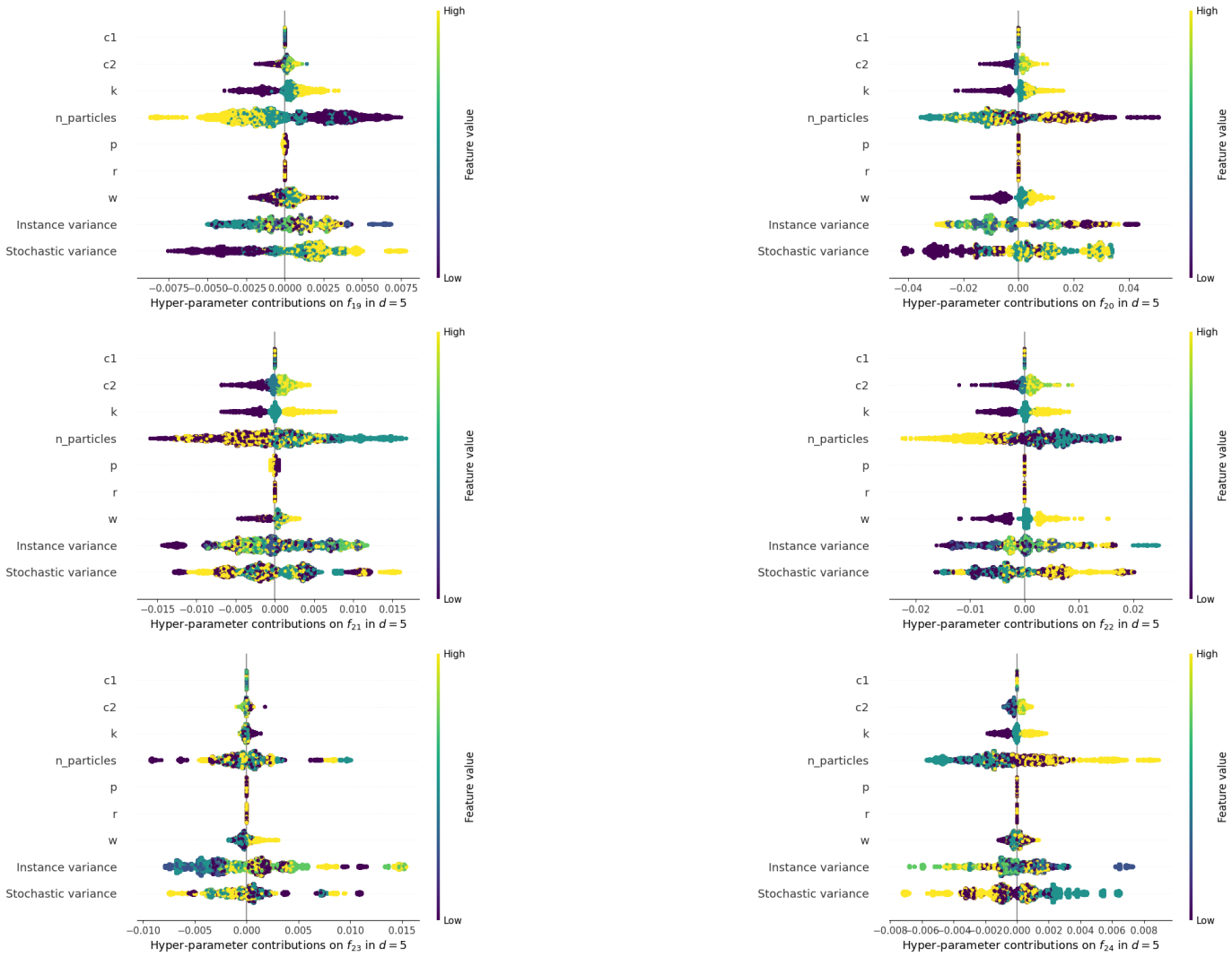


Figure 12: The Impact of Hyperparameters on Performance for Benchmark Function in a 5 d PSO with Ring Topology

1.3. *Case 3: Von Neumann Topology*

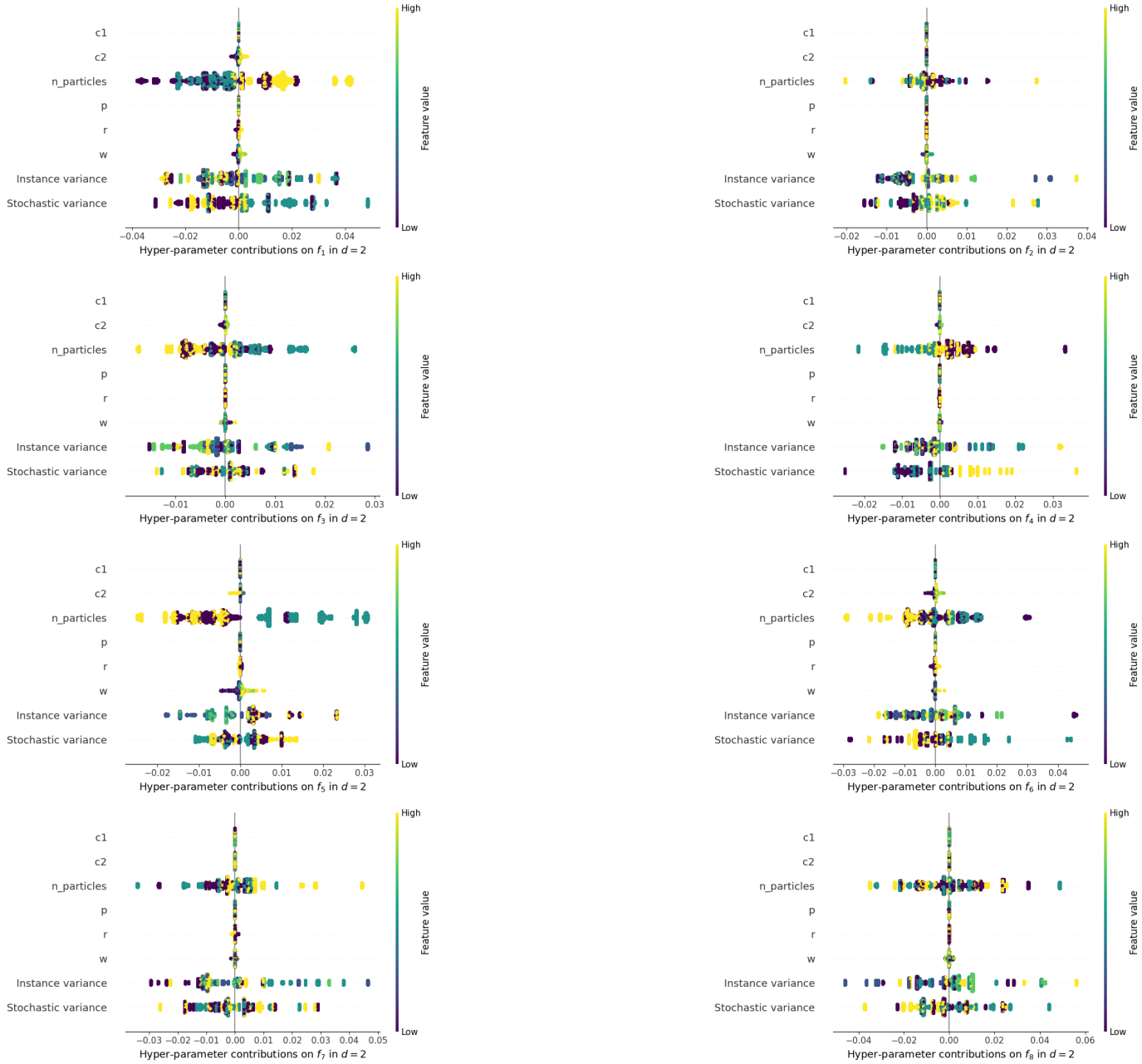


Figure 13: The Impact of Hyperparameters on Performance for Benchmark Function in a 2 d PSO with Von Neumann Topology

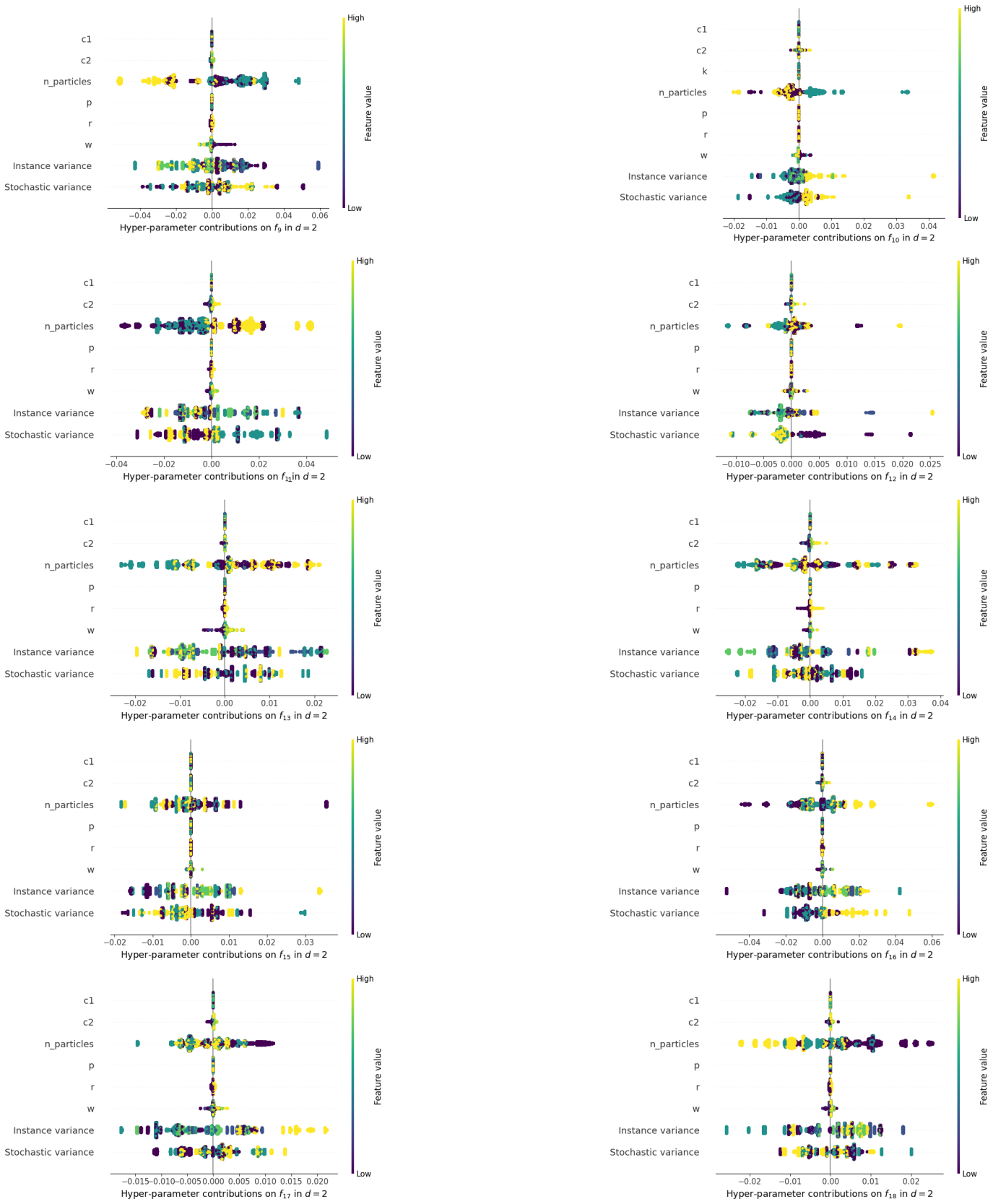


Figure 14: The Impact of Hyperparameters on Performance for Benchmark Function in a 2 d PSO with Von Neumann Topology

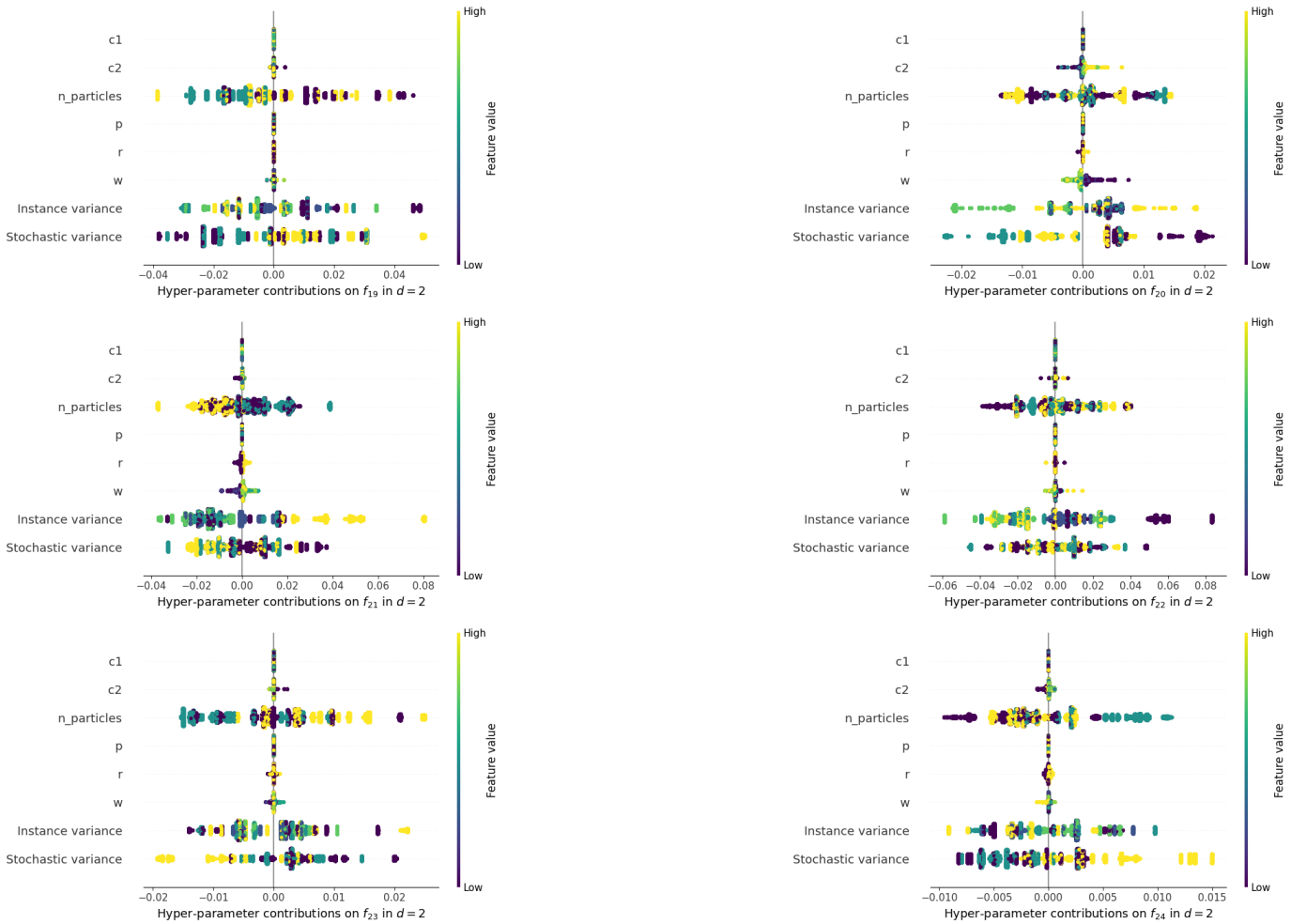


Figure 15: The Impact of Hyperparameters on Performance for Benchmark Function in a 2 d PSO with Von Neumann Topology

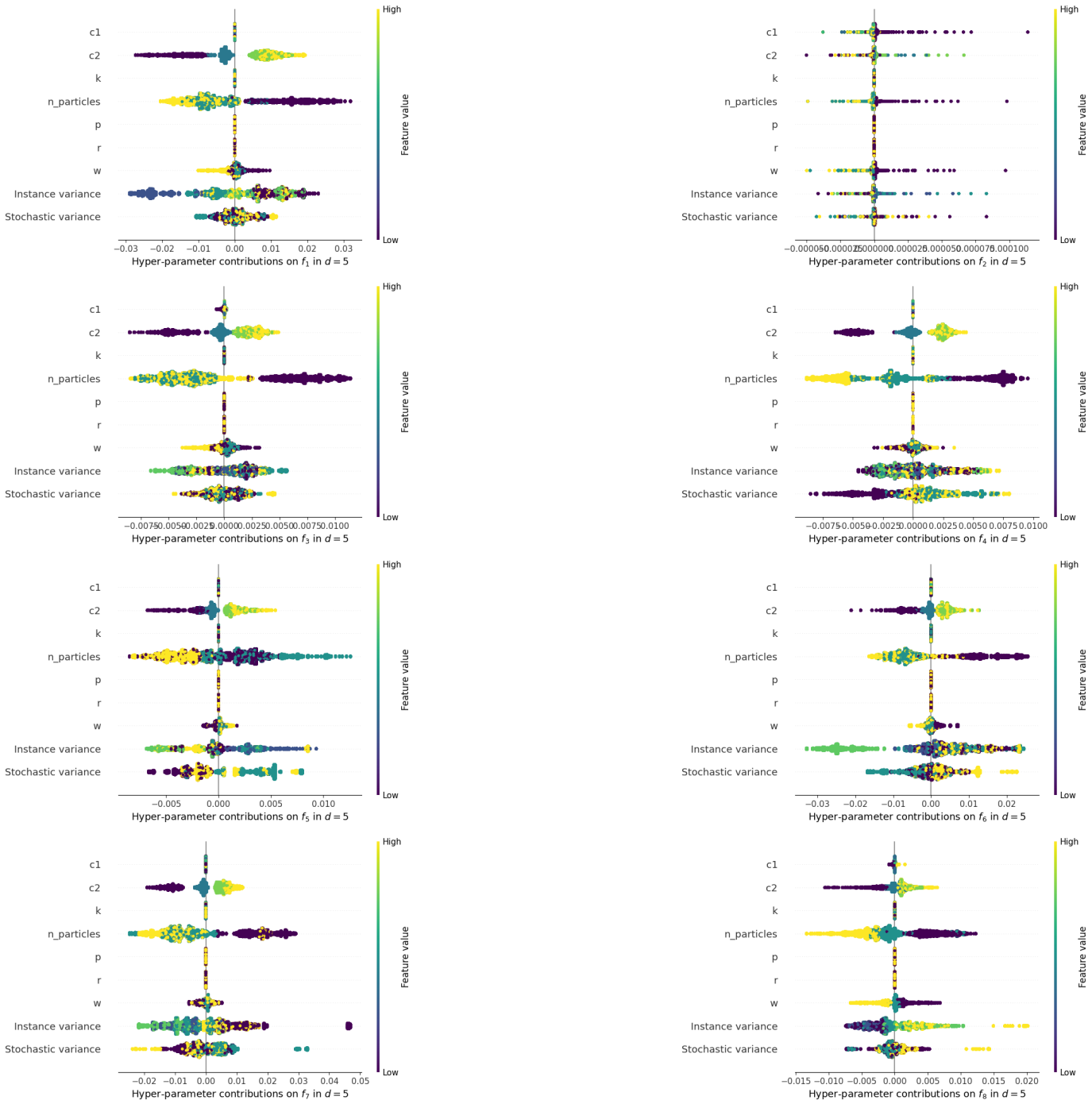


Figure 16: The Impact of Hyperparameters on Performance for Benchmark Function in a 5 d PSO with Von Neumann Topology

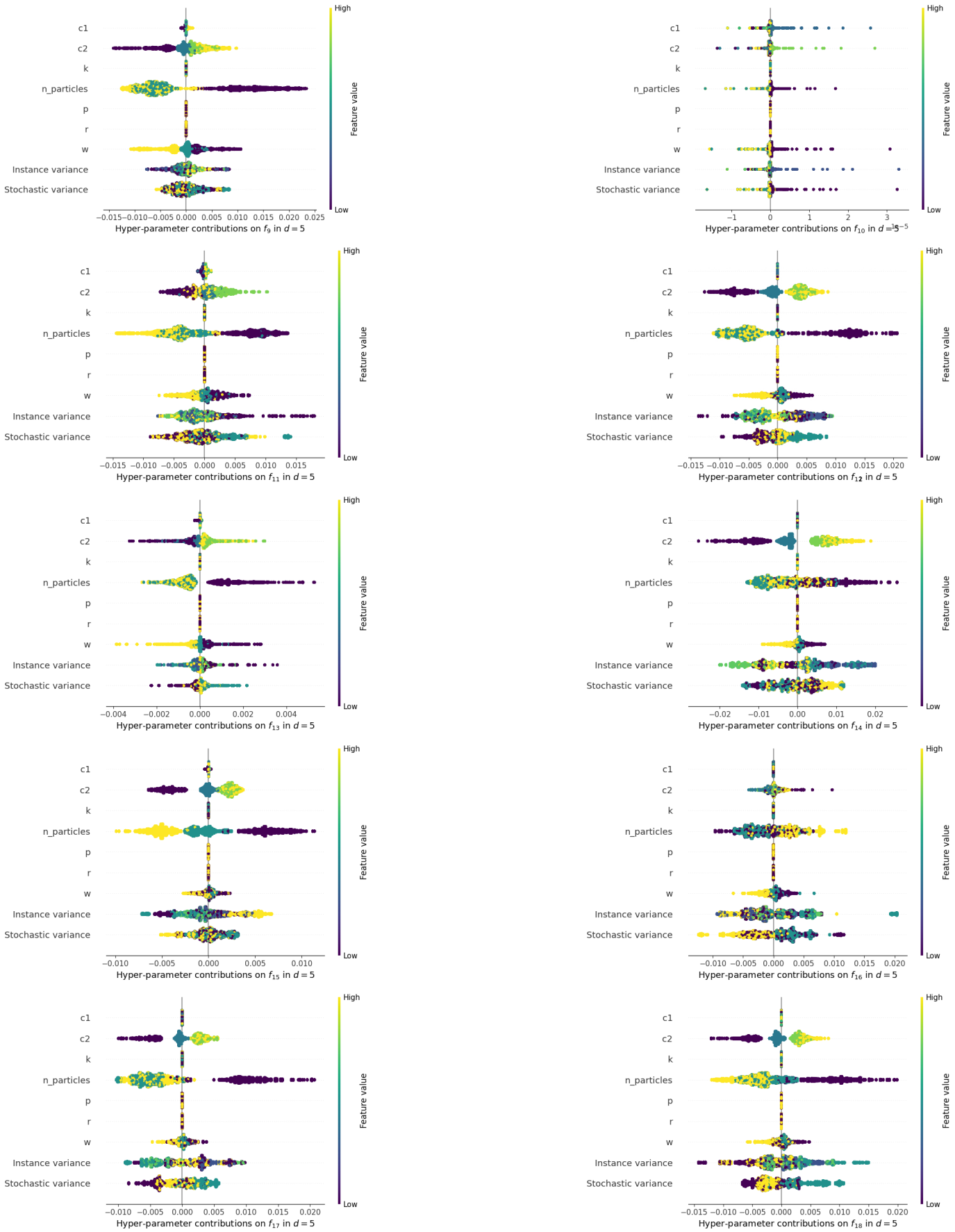


Figure 17: The Impact of Hyperparameters on Performance for Benchmark Function in a 5 d PSO with Von Neumann Topology

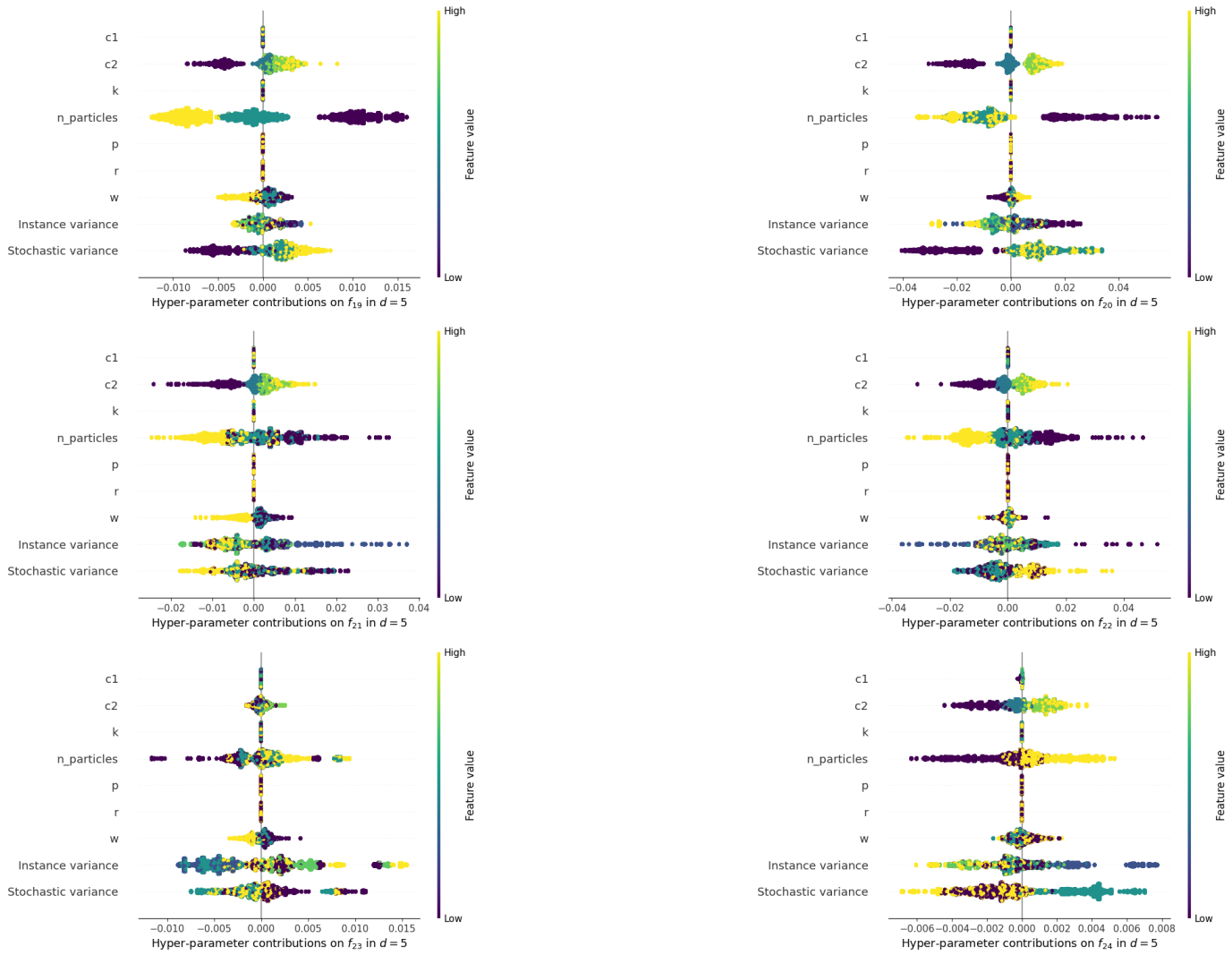


Figure 18: The Impact of Hyperparameters on Performance for Benchmark Function in a 5 d PSO with Von Neumann Topology

2. Decision plots

This plot serves primarily to demonstrate the core concepts, rather than to provide detailed information on its own. The x-axis corresponds to the model's output, measured in log odds. The plot is aligned such that the x-axis is centered at the value of *explainer.expected_value*. All SHAP values are expressed relative to this expected value, similar to how effects in a linear model are interpreted relative to the intercept.

The y-axis displays the model's features, which are arranged by default in order of descending importance. This importance is derived from the specific observations being visualized and may differ from the importance order for the full dataset. Beyond default importance ordering, the decision plot also allows for hierarchical clustering of features or custom ordering defined by the user.

- Each observation's prediction is depicted by a colored line. At the top of the plot, each line intersects the x-axis at the predicted value for that observation. The color of each line corresponds to this predicted value, represented on a color scale.

- Progressing from the bottom to the top of the plot, the cumulative effect of each feature's SHAP value is added to the model's base value (the expected value). This illustrates how each feature contributes to the final prediction. At the bottom of the plot, all observation lines converge at *explainer.expected_value*.

*2.1. **Case 1: Star Topology***

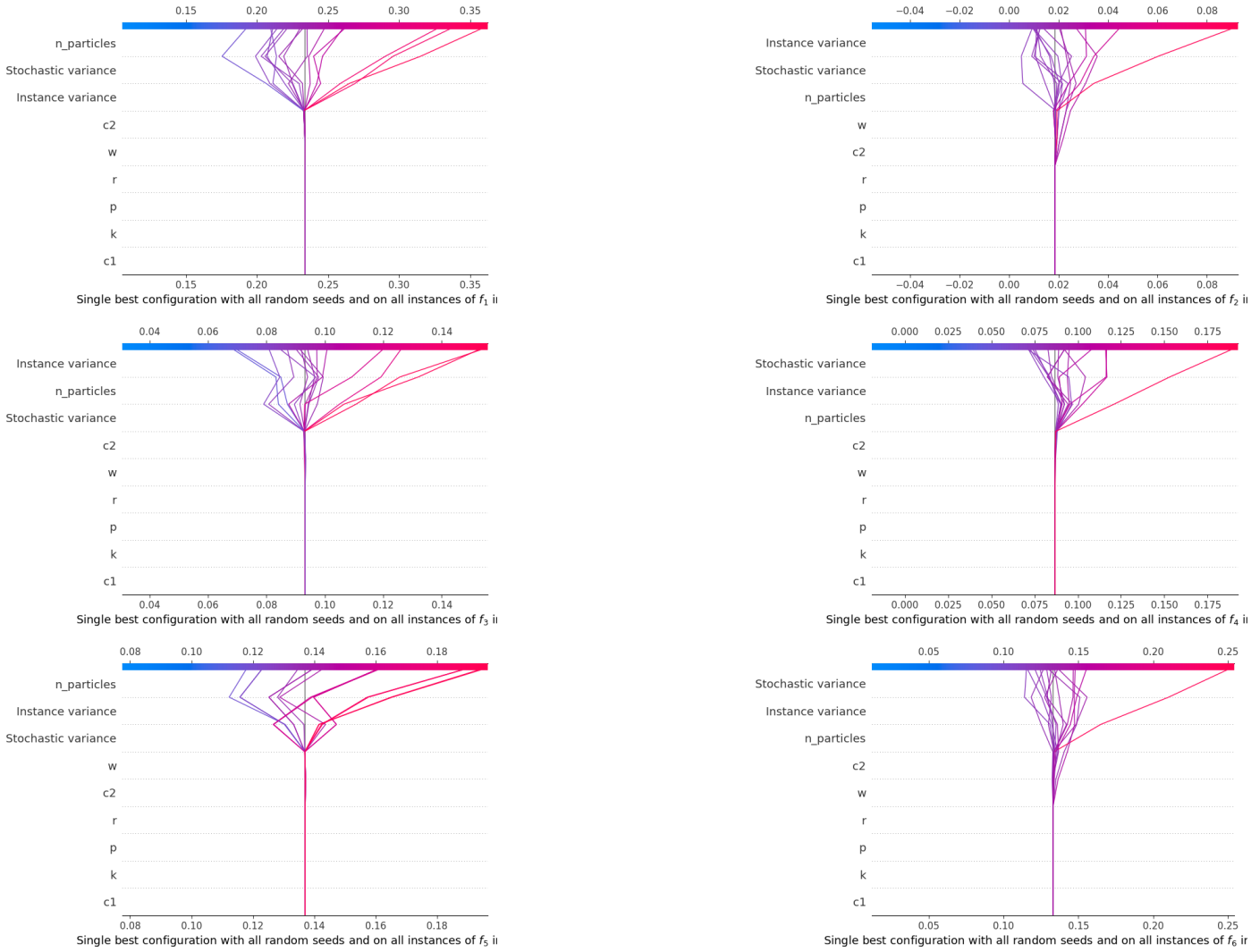


Figure 19: Single best configuration with all random seeds and on all instances in 2 d PSO using Star topology

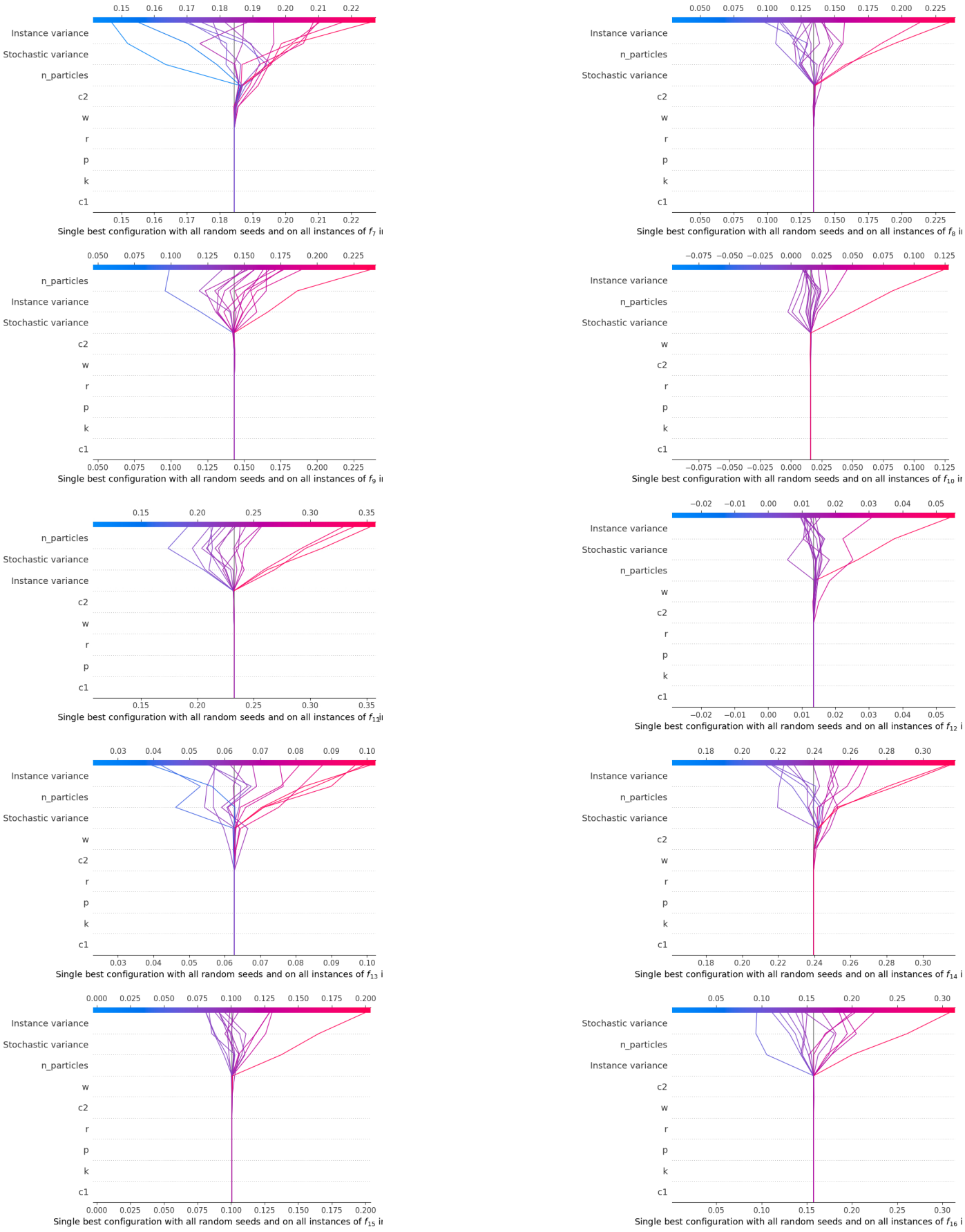


Figure 20: Single best configuration with all random seeds and on all instances in 2 d PSO using Star topology

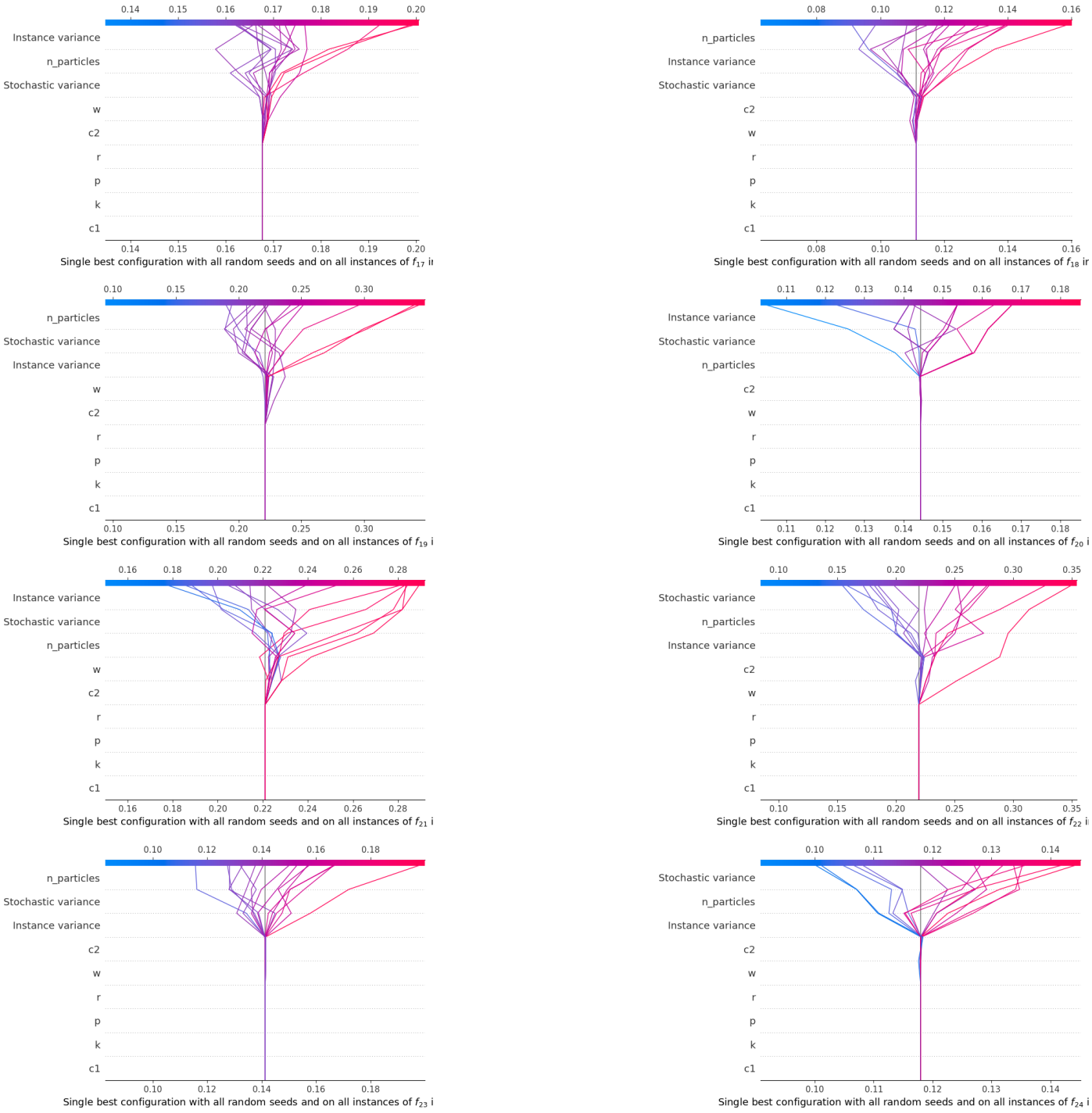


Figure 21: Single best configuration with all random seeds and on all instances in 2 d PSO using Star topology

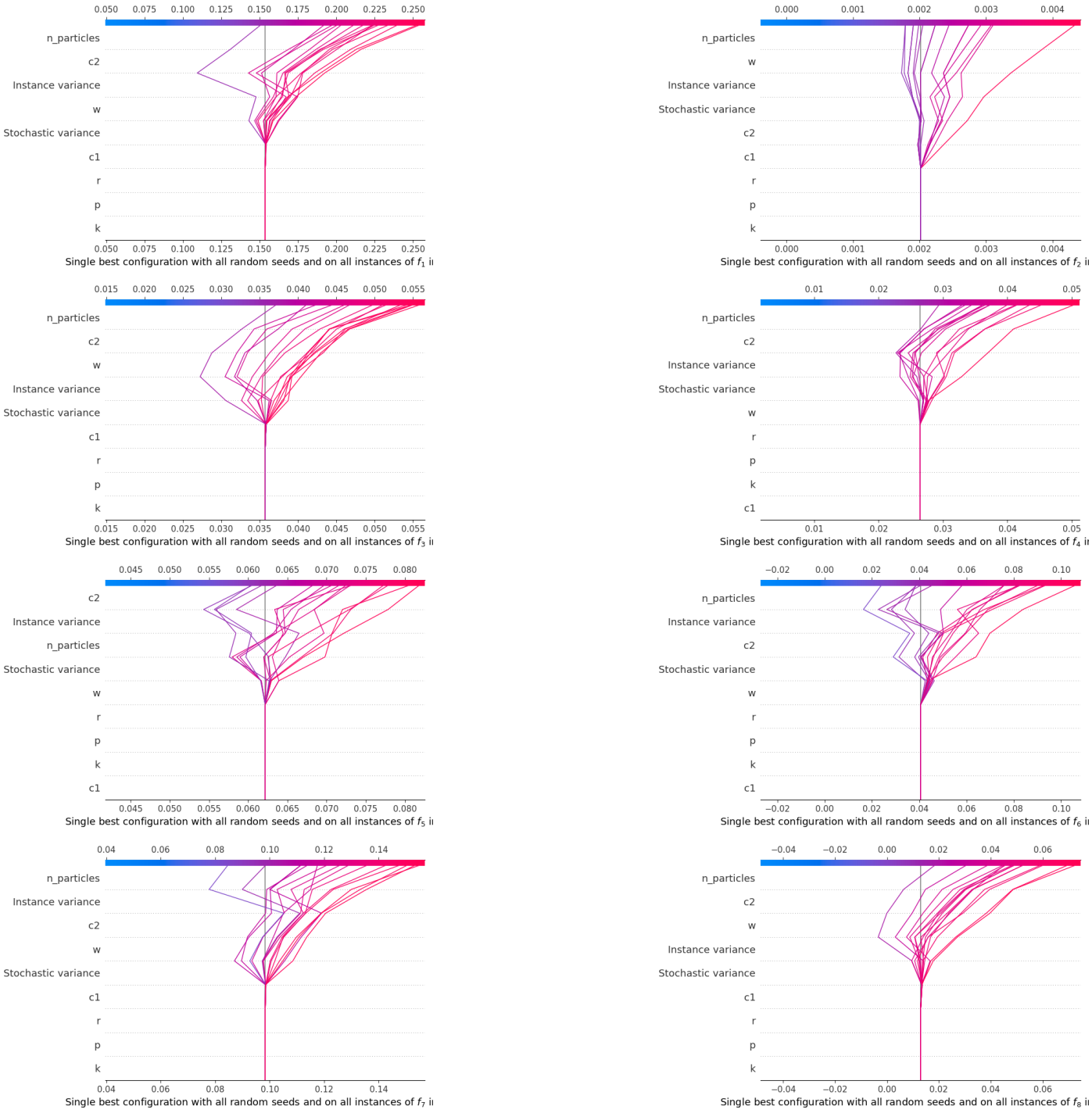


Figure 22: Single best configuration with all random seeds and on all instances in 5 d PSO using Star topology

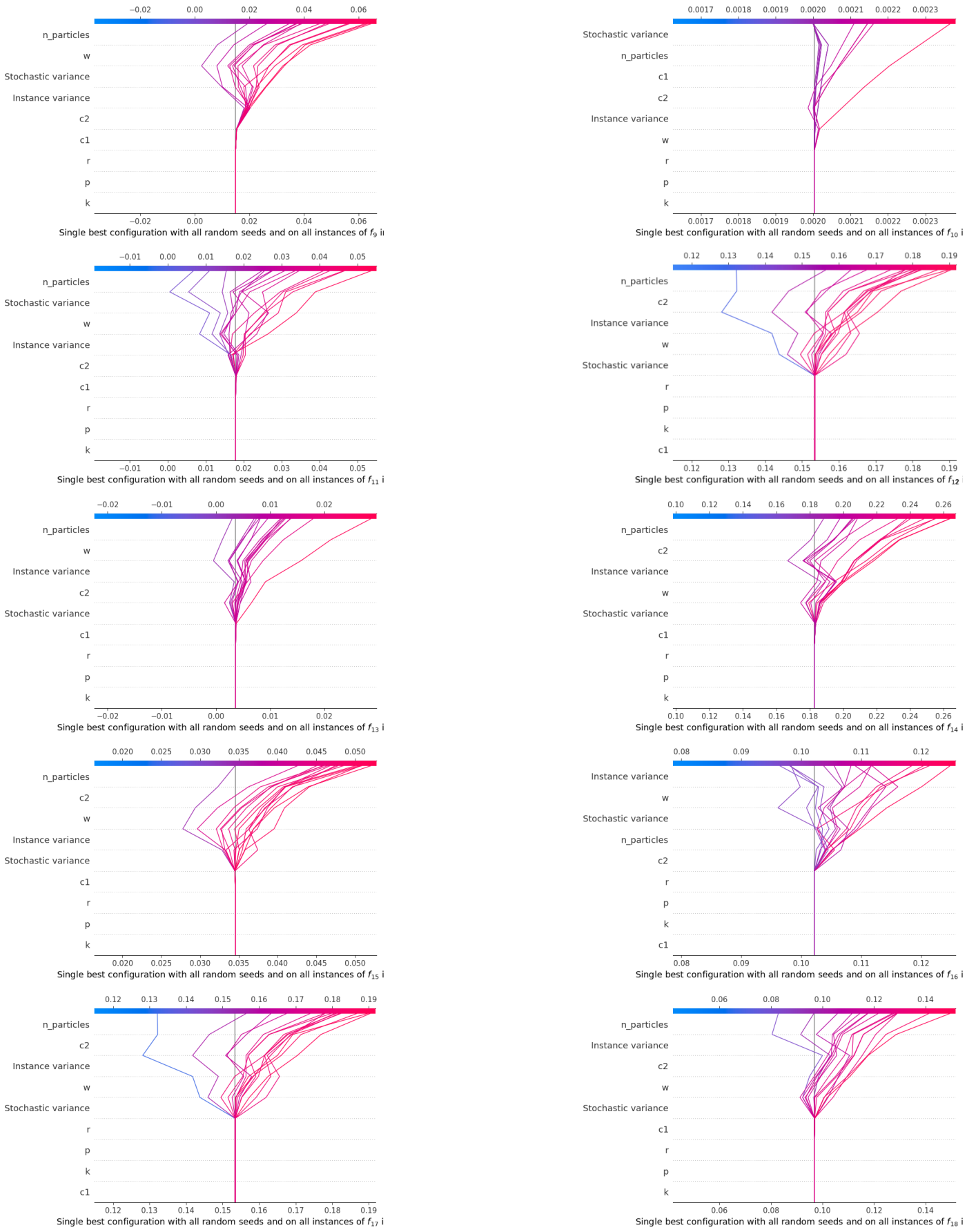


Figure 23: Single best configuration with all random seeds and on all instances in 5 d PSO using Star topology

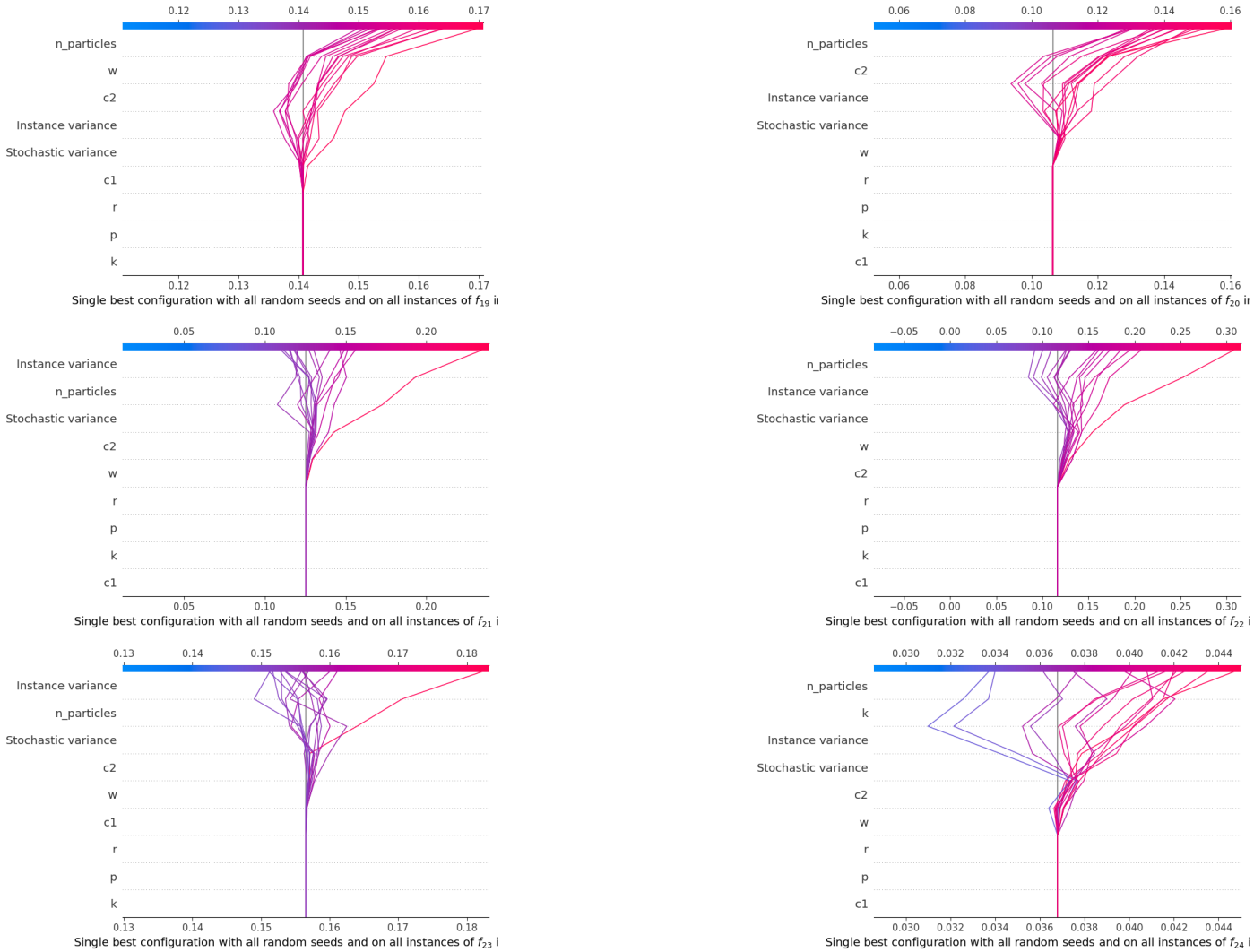


Figure 24: Single best configuration with all random seeds and on all instances in 5 d PSO using Star topology

2.2. *Case 2: Ring Topology*

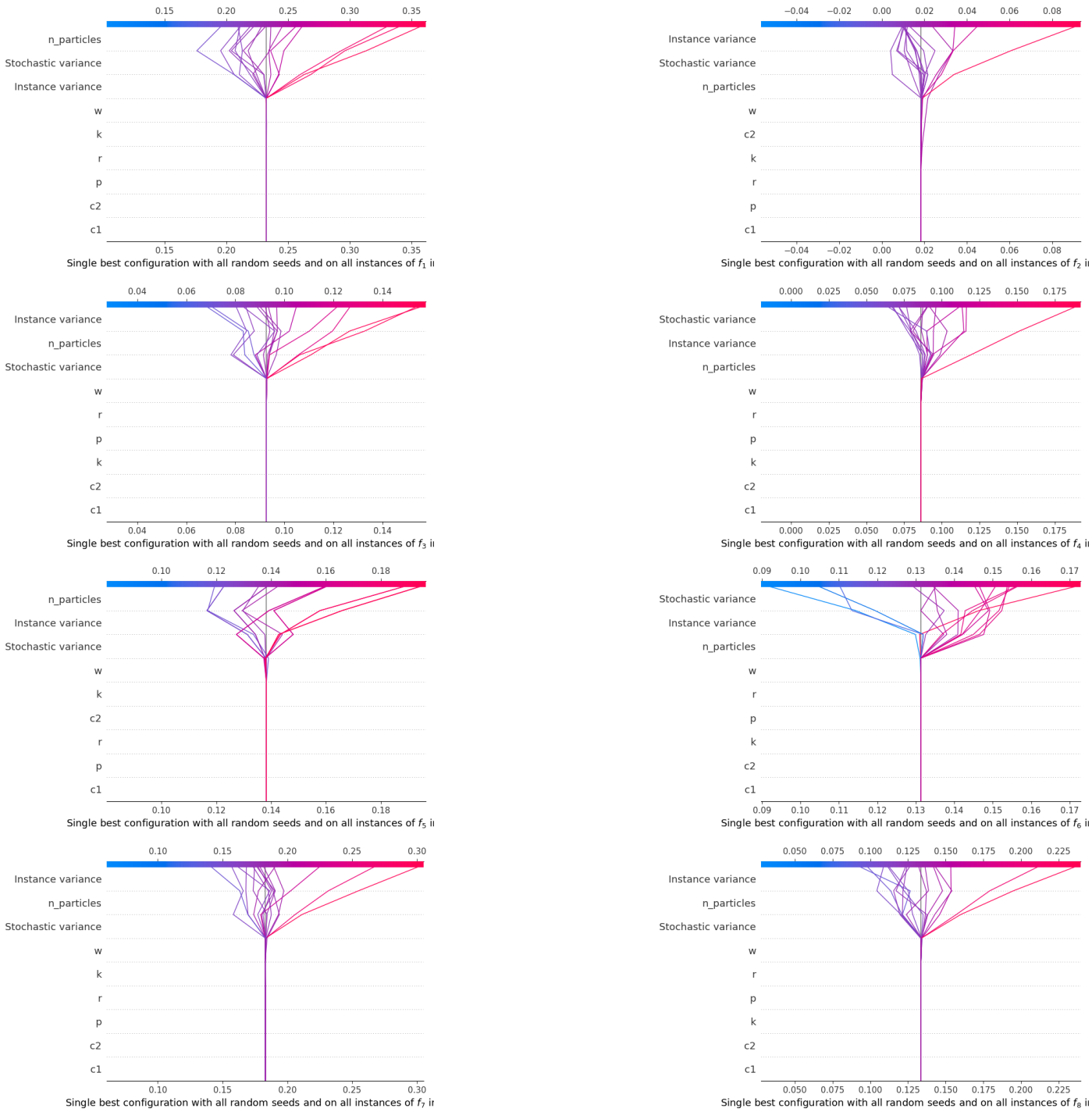


Figure 25: Single best configuration with all random seeds and on all instances in a 2 d PSO with Ring Topology

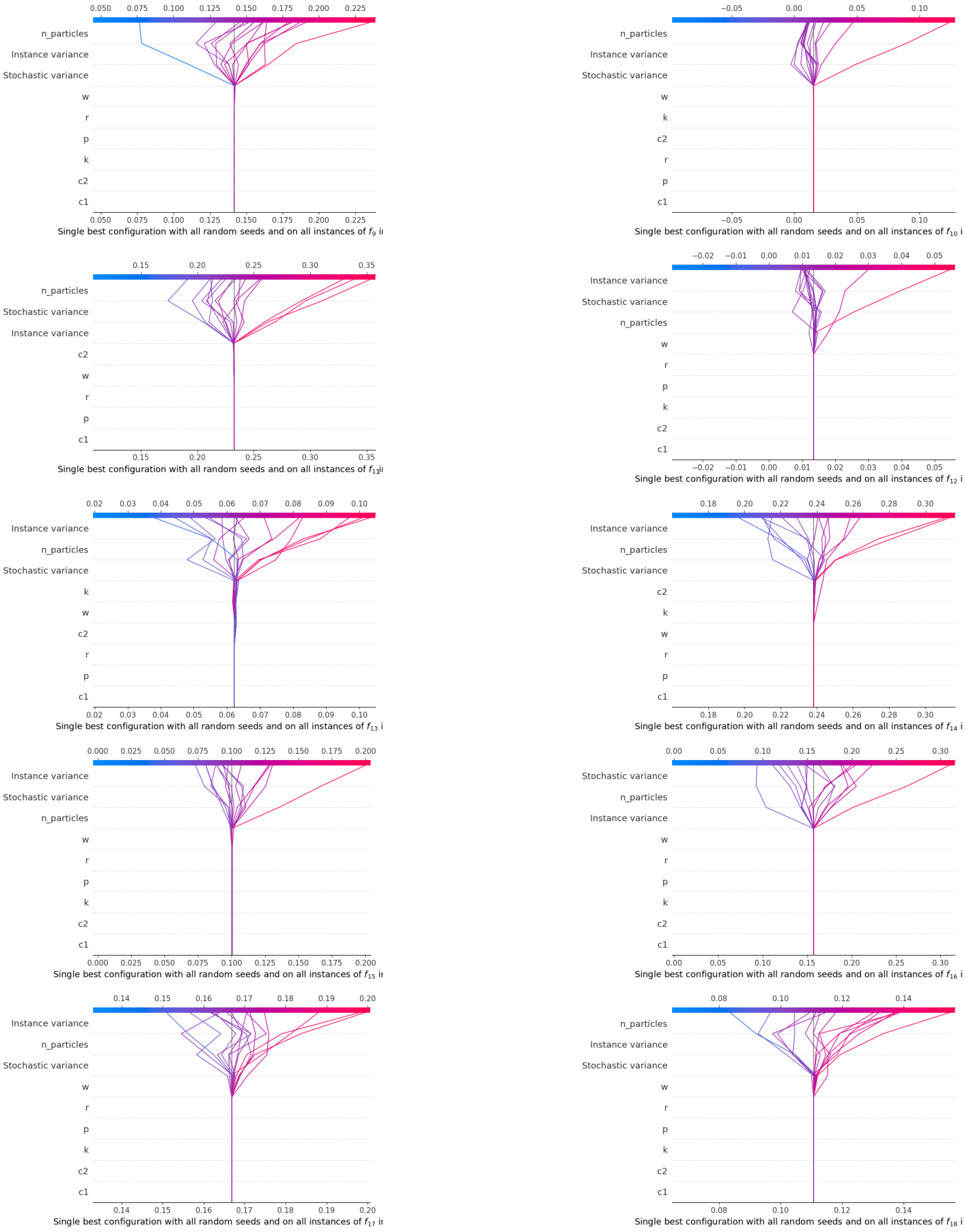
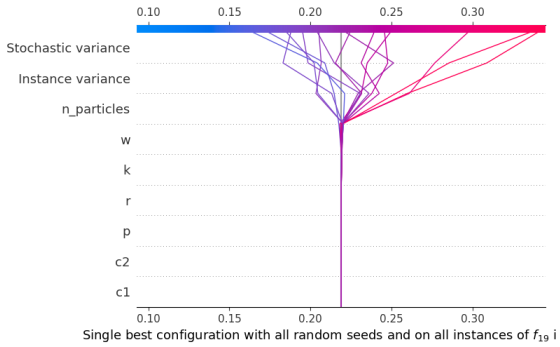
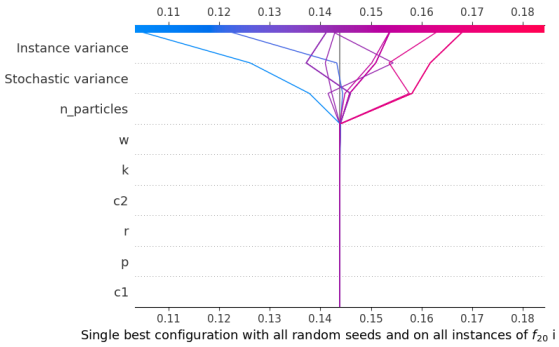
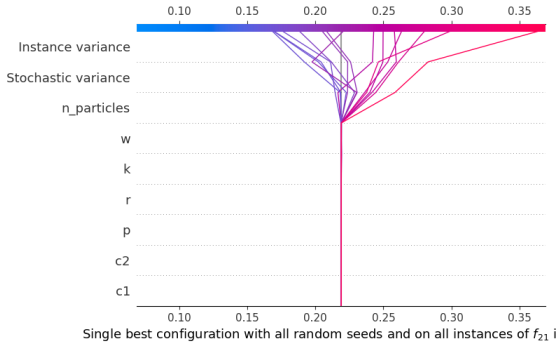
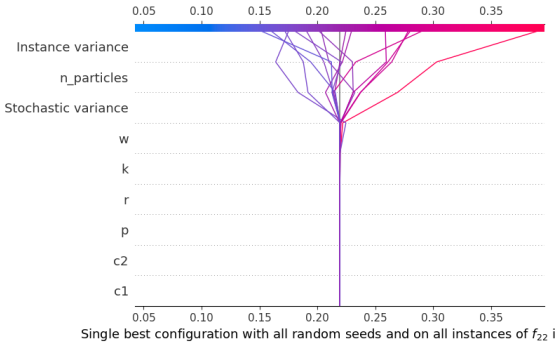


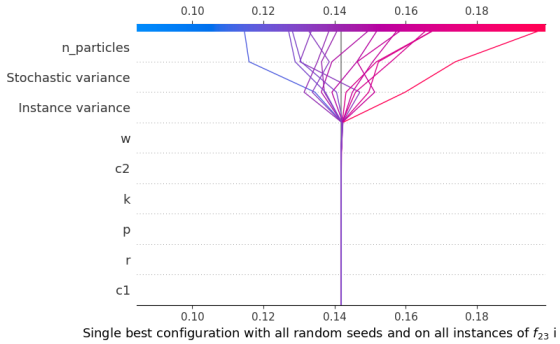
Figure 26: Single best configuration with all random seeds and on all instances in a 2 d PSO with Ring Topology











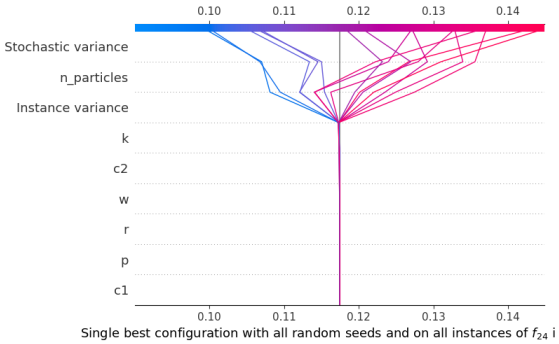


Figure 27: Single best configuration with all random seeds and on all instances in a 2 d PSO with Ring Topology

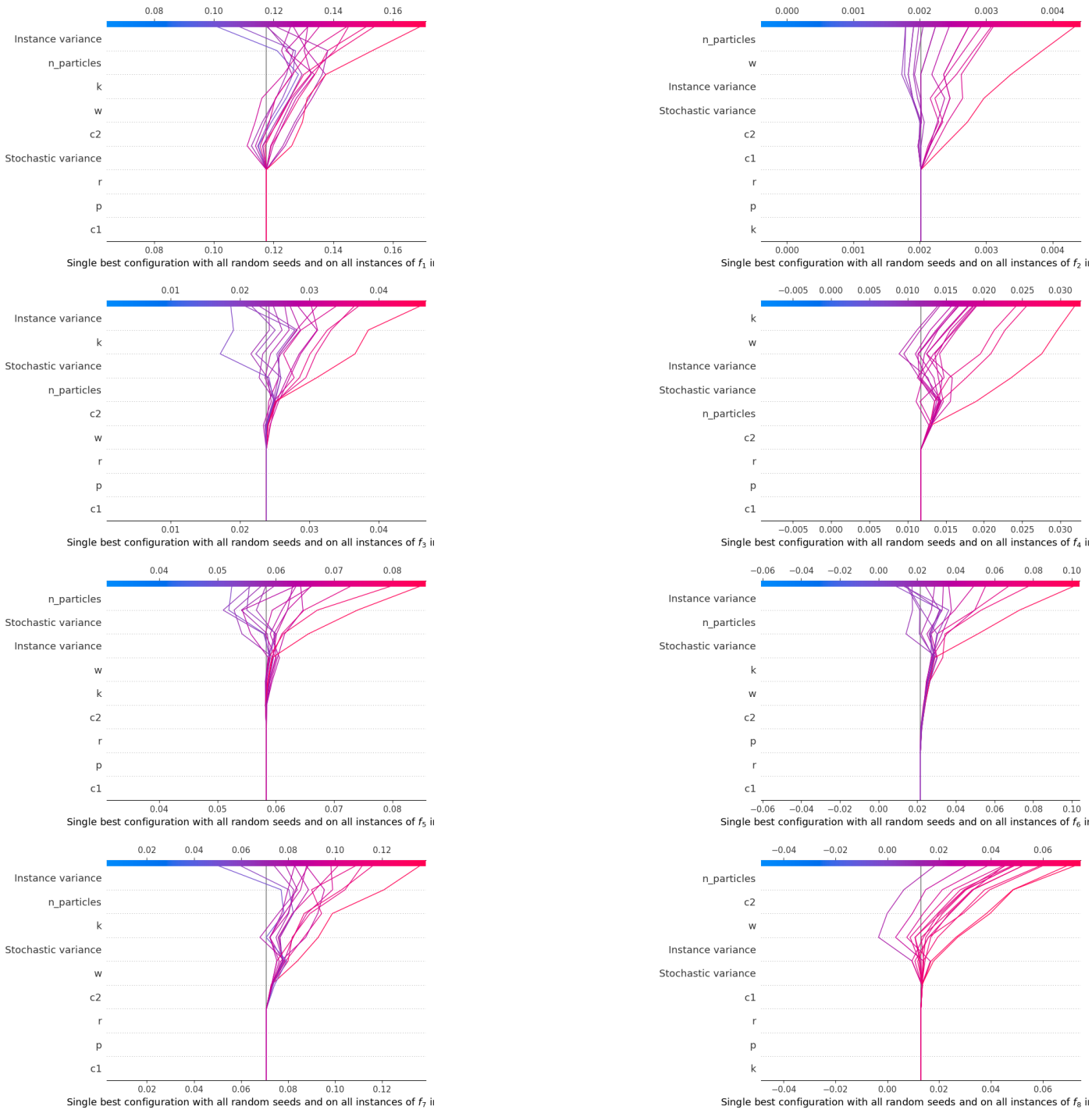


Figure 28: Single best configuration with all random seeds and on all instances in a 5 d PSO using Ring topology

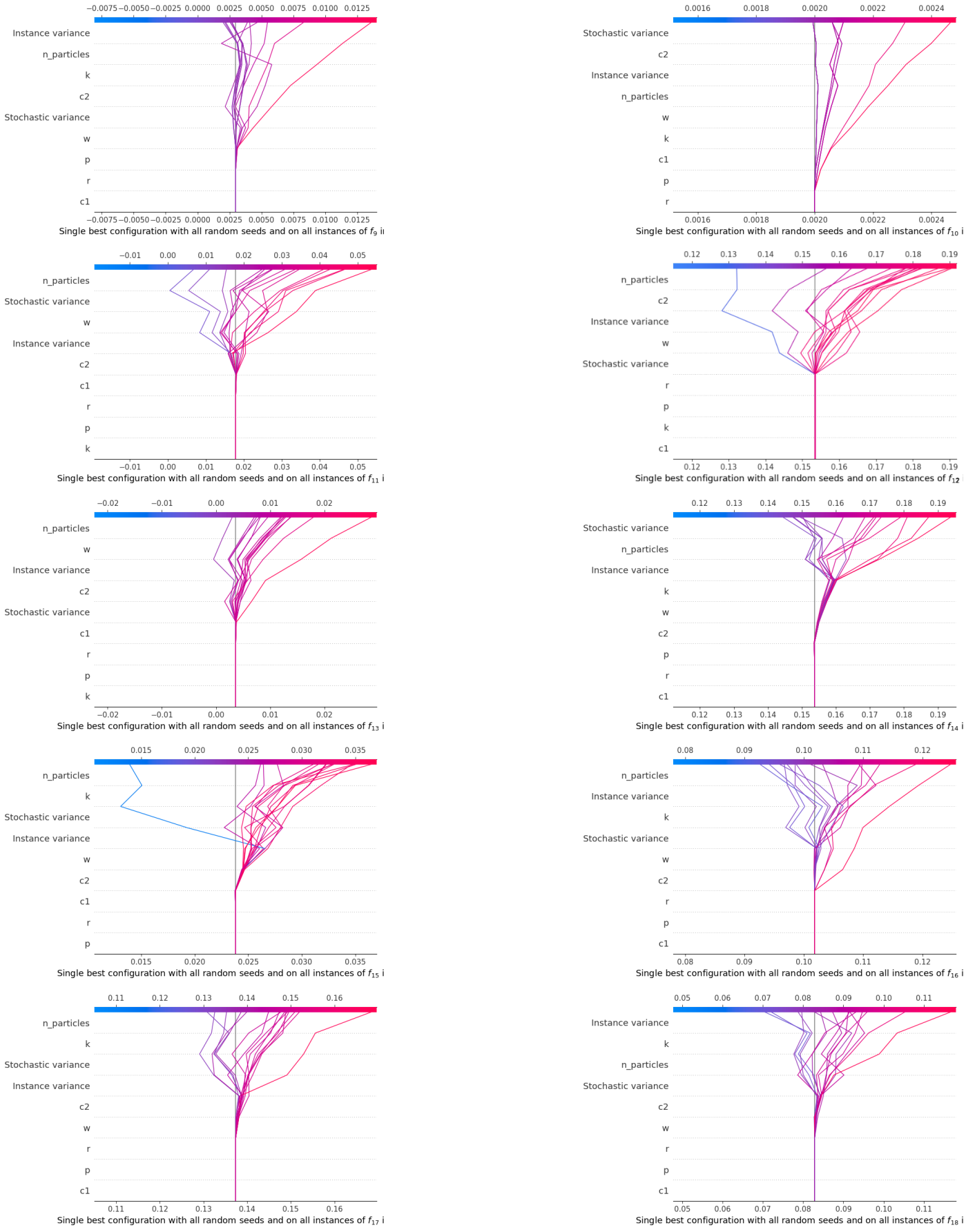


Figure 29: Single best configuration with all random seeds and on all instances in a 5 d PSO using Ring topology

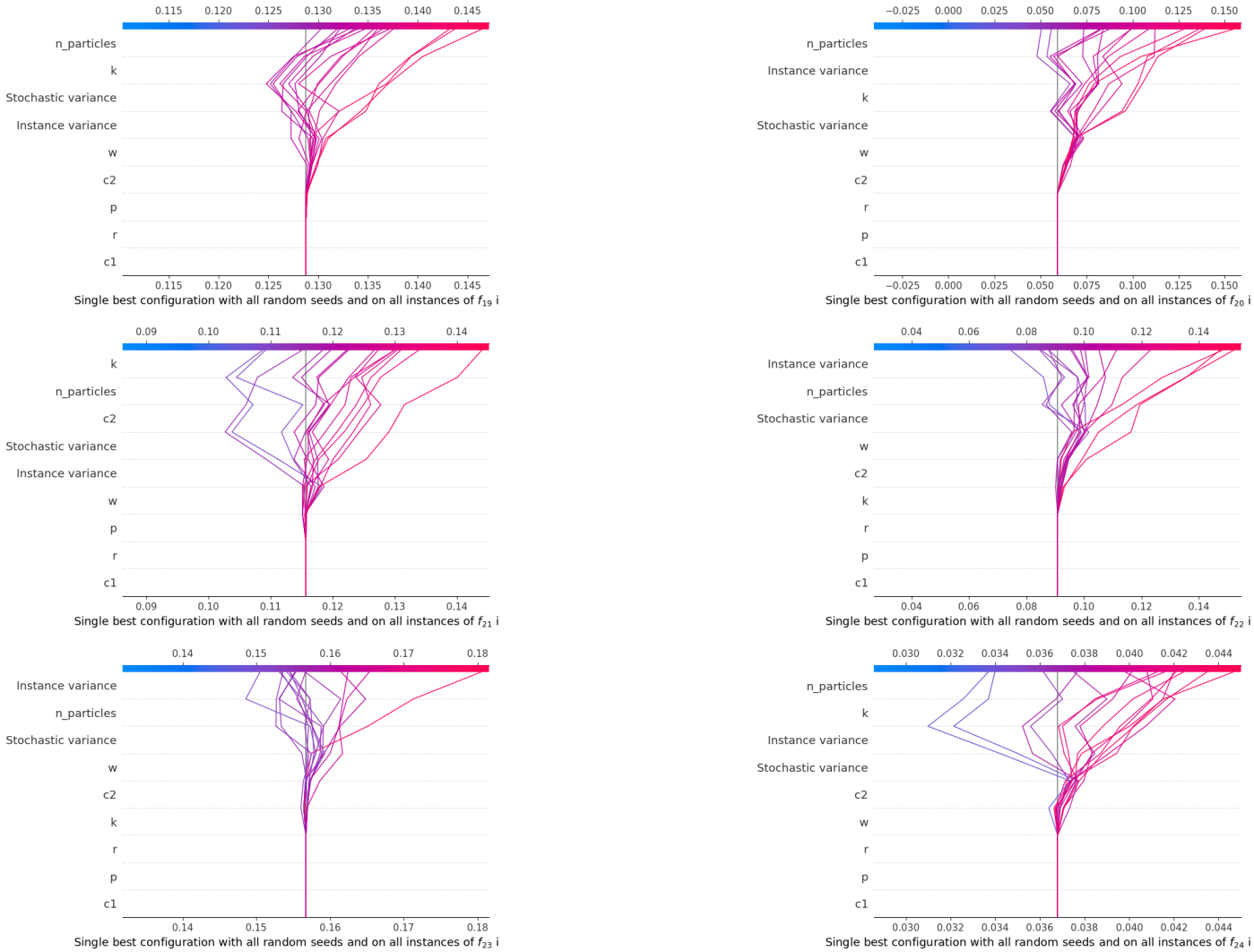


Figure 30: Single best configuration with all random seeds and on all instances in a 5 d PSO using Ring topology

2.3. *Case 3: Von Neumann Topology*

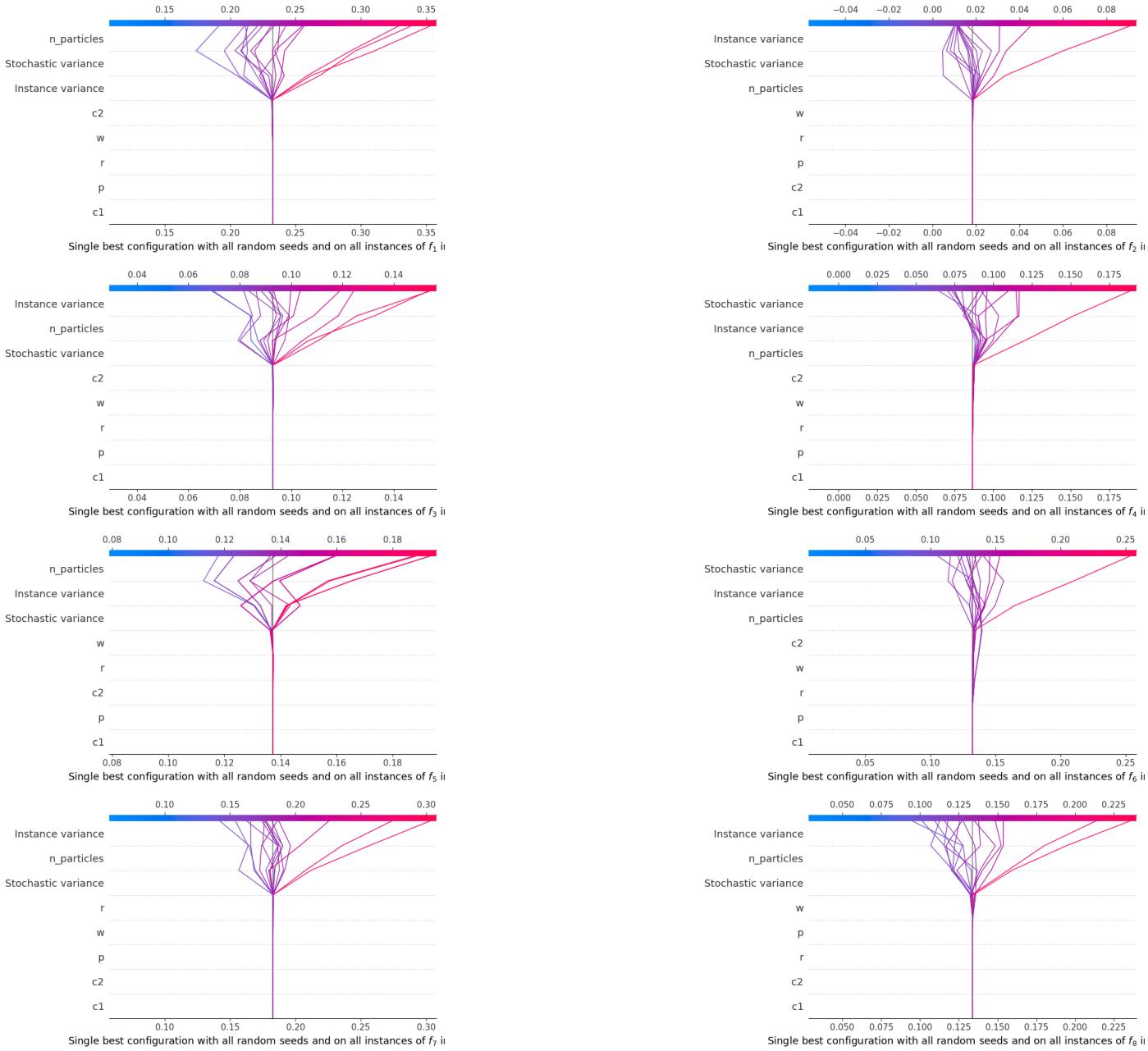


Figure 31: Single best configuration with all random seeds and on all instances in 2 d PSO using Von Neumann topology

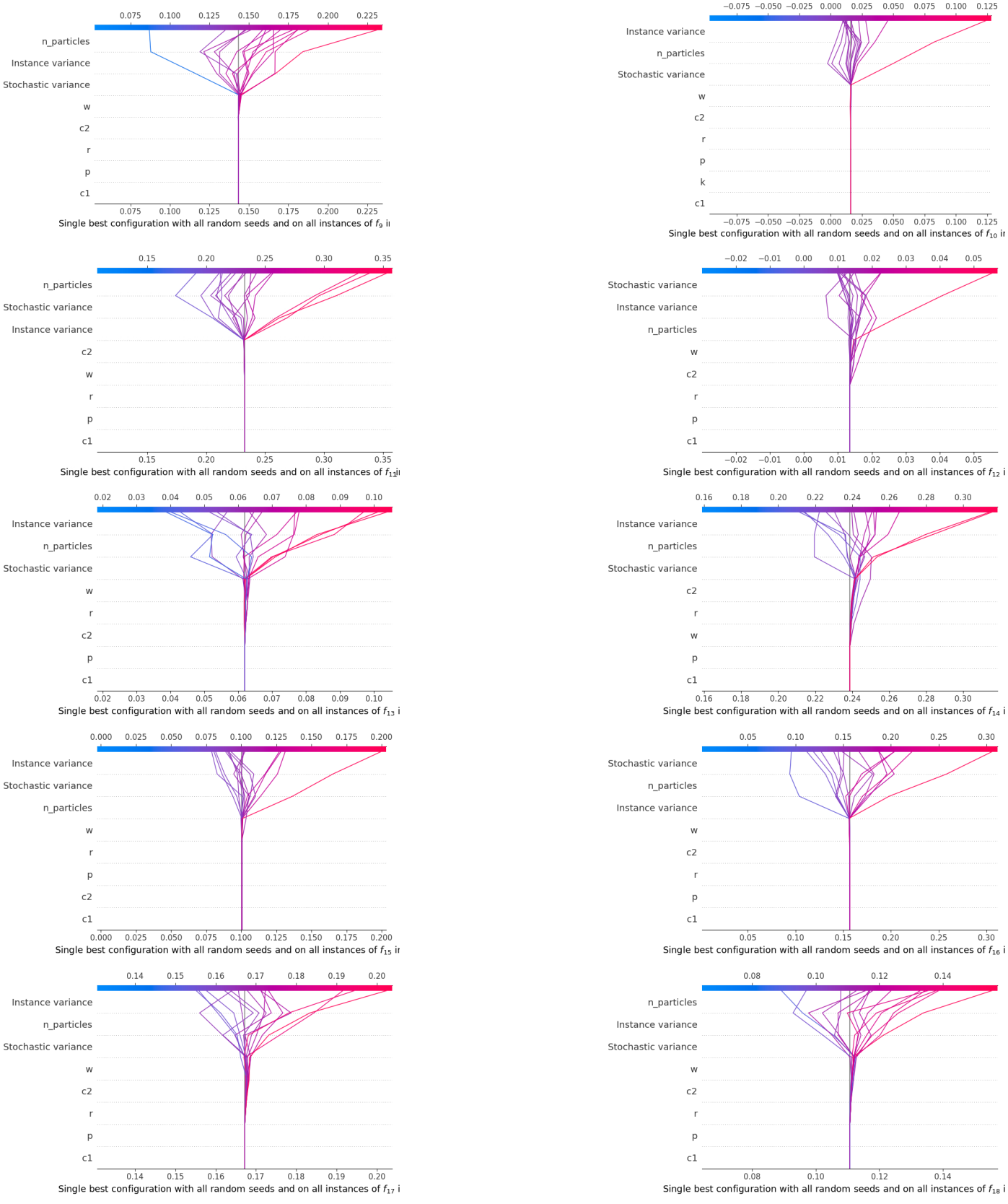


Figure 32: Single best configuration with all random seeds and on all instances in 2 d PSO using Von Neumann topology

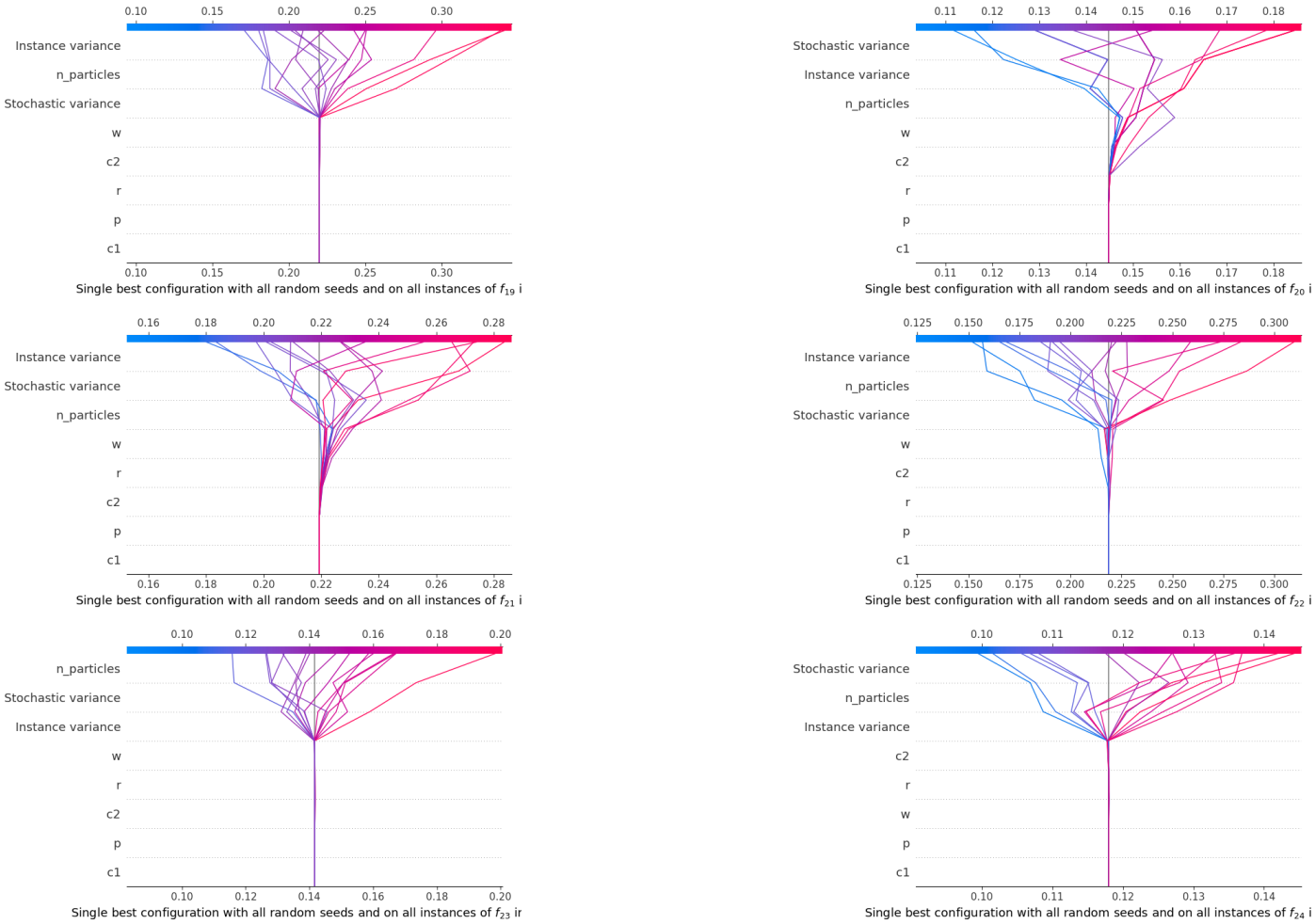


Figure 33: Single best configuration with all random seeds and on all instances in 2 d PSO using Von Neumann topology

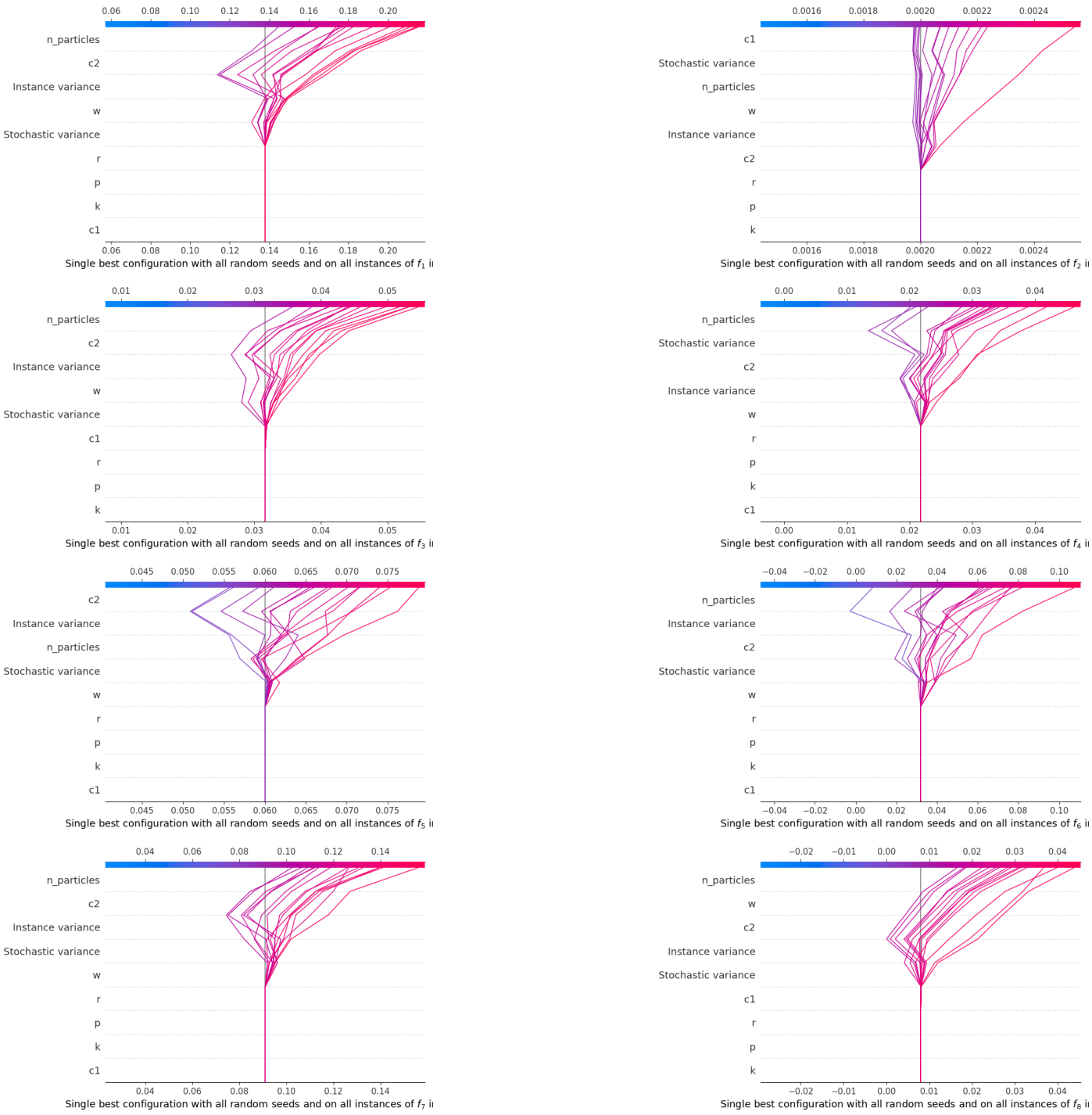


Figure 34: Single best configuration with all random seeds and on all instances in a 5 d PSO using Von Neumann topology

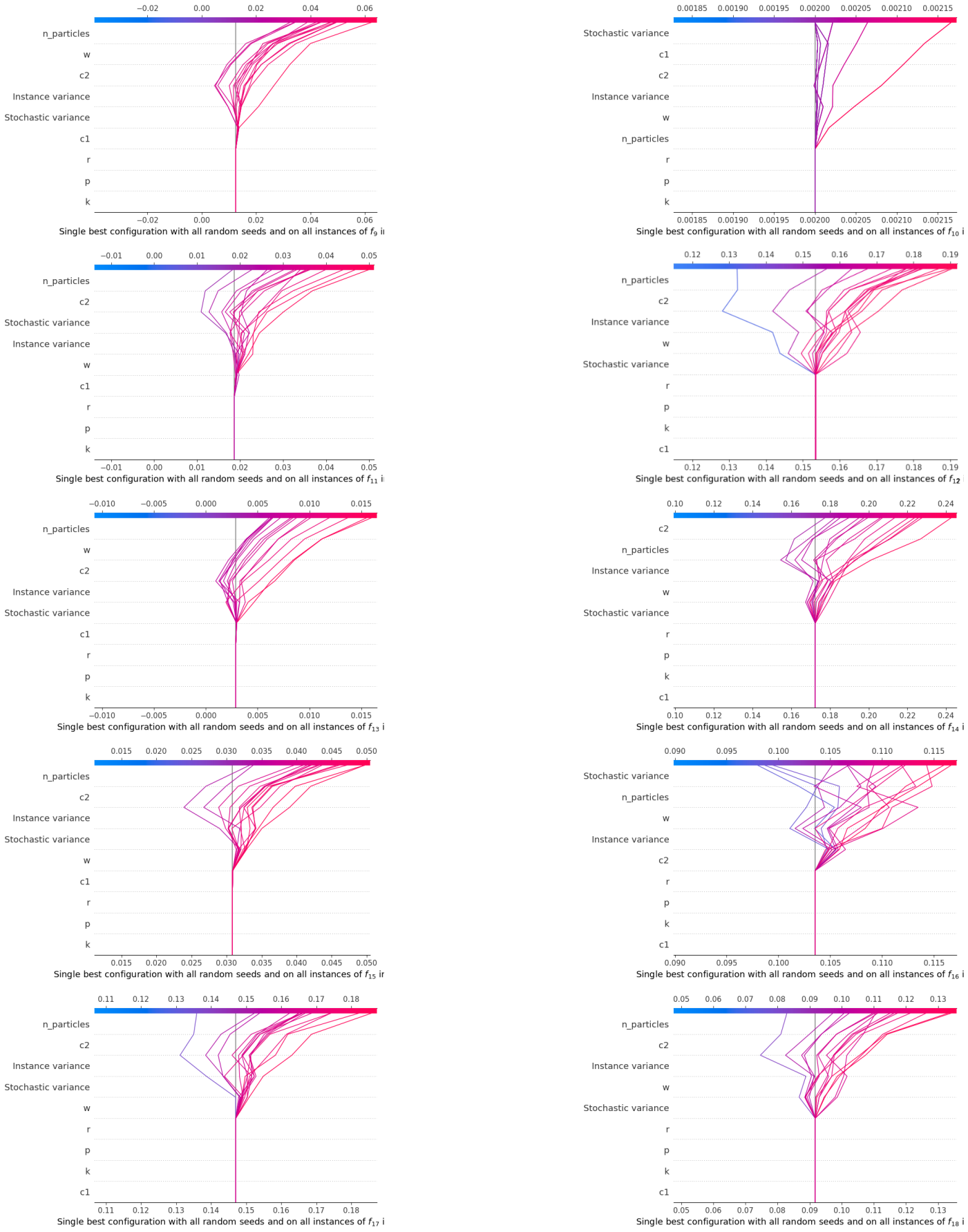


Figure 35: Single best configuration with all random seeds and on all instances in 5 d PSO using Von Neumann topology

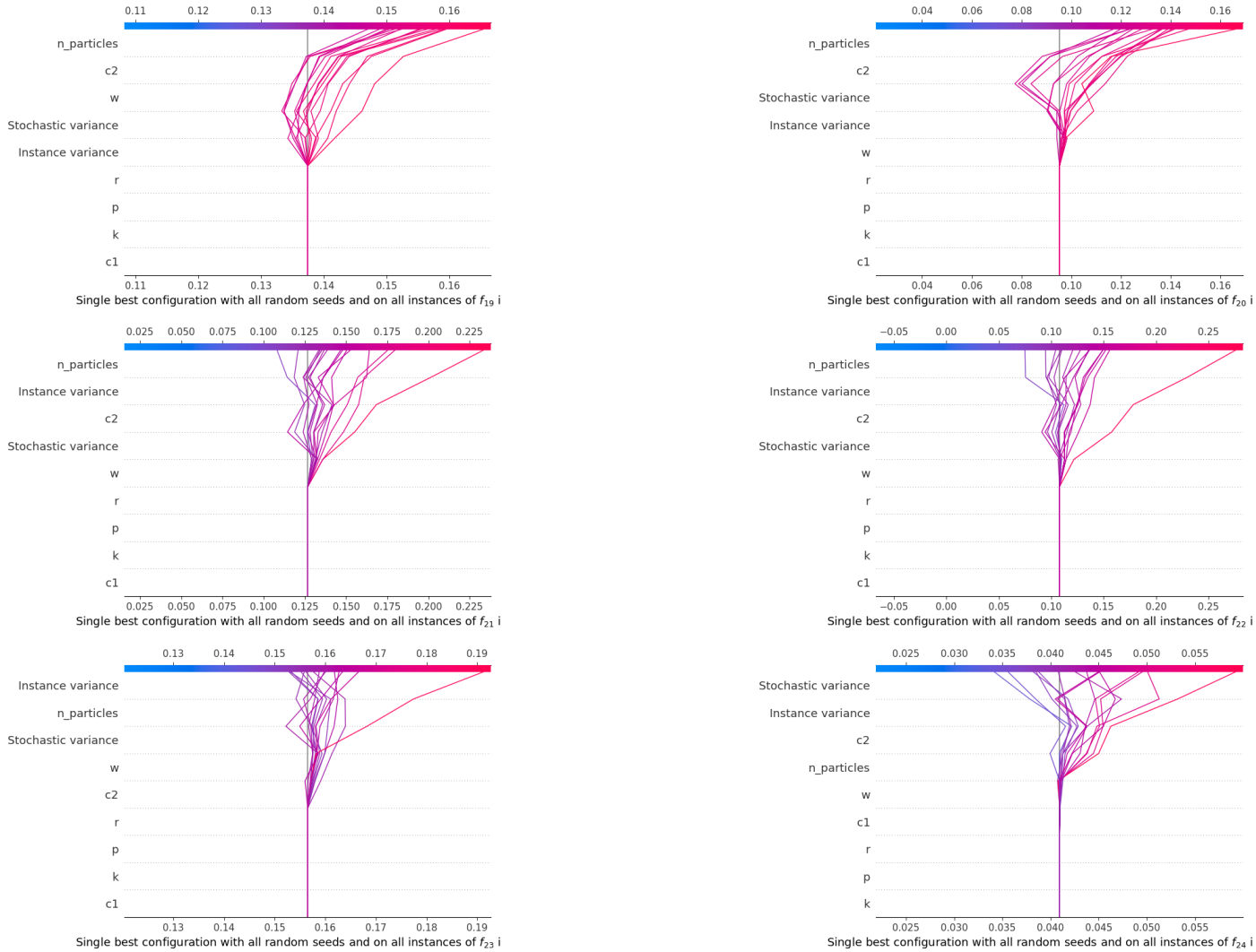


Figure 36: Single best configuration with all random seeds and on all instances in S d PSO using Von Neumann topology

3. Force Plots

A SHAP force plot provides a detailed, visual explanation for an individual model prediction by deconstructing how each feature contributed to the final output. The plot starts from a baseline value, which is the average prediction across the entire dataset, and then illustrates the additive impact of each feature value for that specific instance. Positive contributions that push the prediction above the baseline are shown as red arrows pushing to the right, while negative contributions that pull the prediction below the baseline are shown as blue arrows pushing to the left. The width of each arrow corresponds to the magnitude of that feature's SHAP value, or its contribution strength. Ultimately, the sum of all these forces—the collective push of all the feature contributions—visually explains the journey from the average expectation to the model's final prediction for that single case.

3.1. *Case 1: Star Topology*

Figure 37: Force plots in 2 d PSO using Star topology

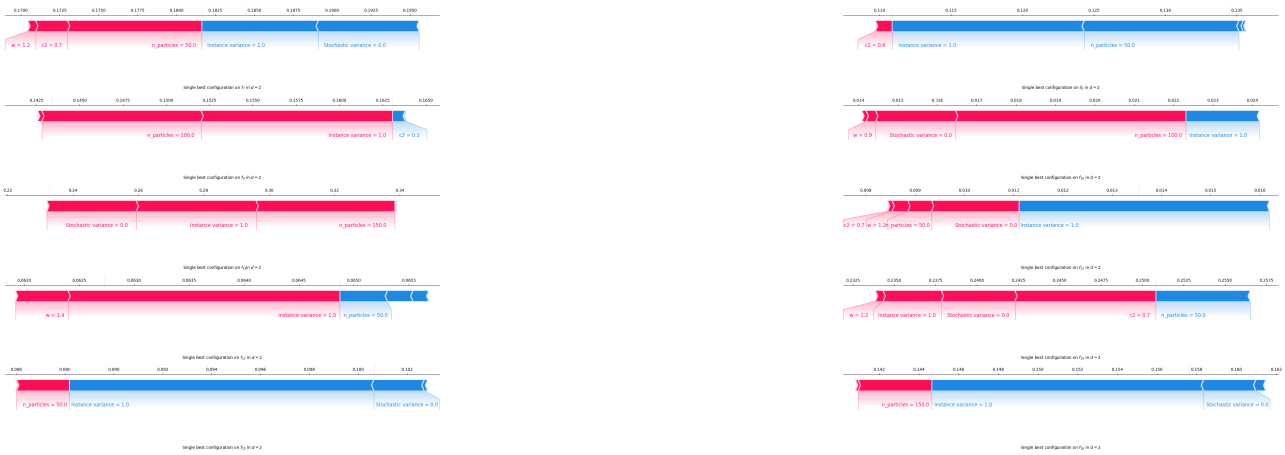


Figure 38: Force plots in 2 d PSO using Star topology

Figure 39: Force plots in 2 d PSO using Star topology

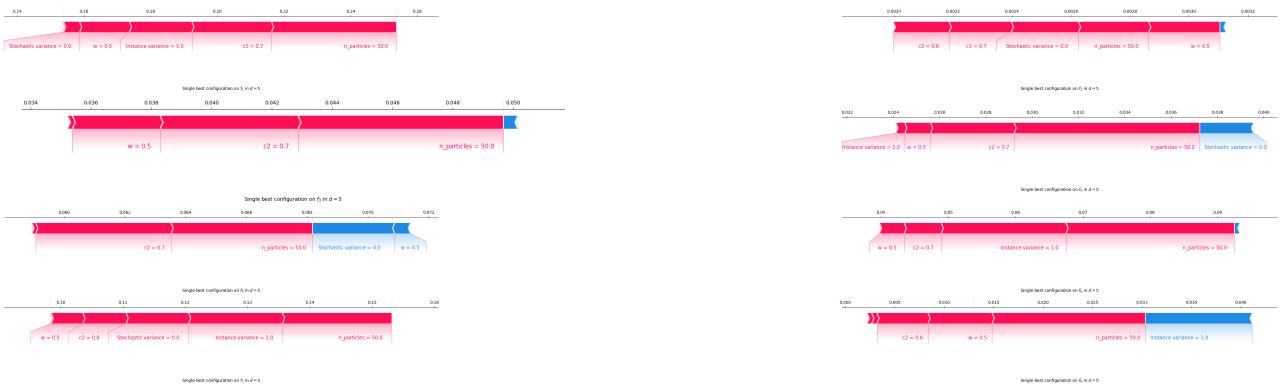


Figure 40: Force plots in 5 d PSO using Star topology

Figure 41: Force plots in 5 d PSO using Star topology

3.2. *Case 2: Ring Topology*

Figure 42: Force plots in 2 d PSO using Ring topology

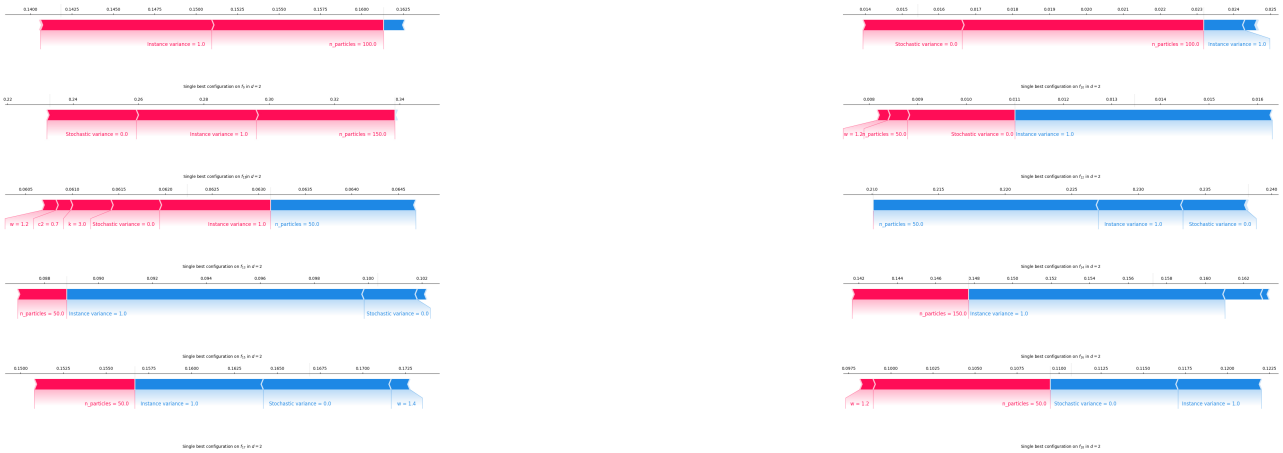


Figure 43: Force plots in 2 d PSO using Ring topology

Figure 44: Force plots in 2 d PSO using Ring topology

Figure 45: Force plots in 5 d PSO using Ring topology

Figure 46: Force plots in 5 d PSO using Ring topology

3.3. *Case 3: Von Neumann Topology*

Figure 47: Force plots in 2 d PSO using Von Neumann topology

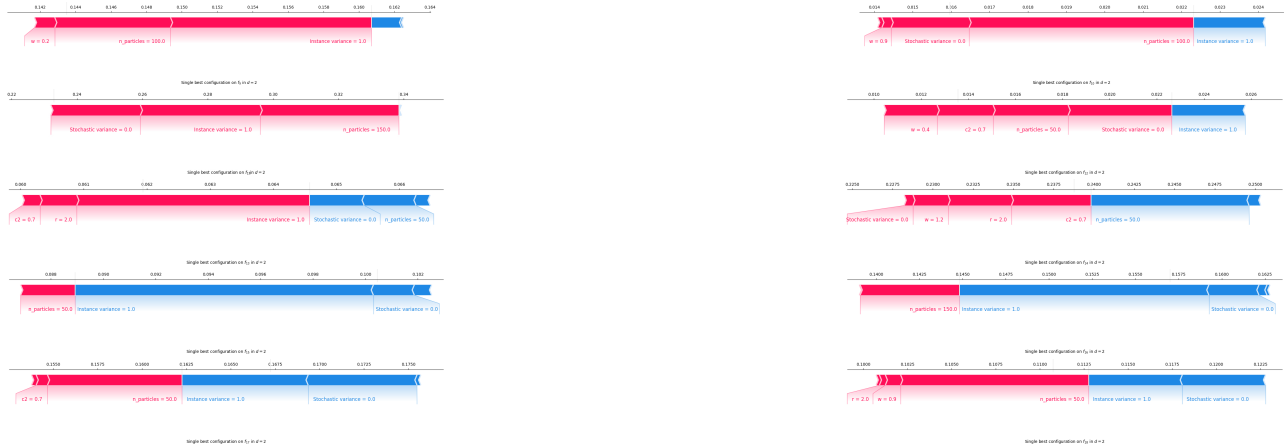


Figure 48: Force plots in 2 d PSO using Von Neumann topology

Figure 49: Force plots in 2 d PSO using Von Neumann topology

Figure 50: Force plots in 5 d PSO using Von Neumann topology

Figure 51: Force plots in 5 d PSO using Von Neumann topology

4. Decision Trees Plots

Figure 52: Decision tree (depth=7) for cognitive component (c_1) module in PSO using Star Topology ($d = 5$). Nodes show feature splits with value distributions — yellow: false, green: true. The black arrow marks the split threshold.

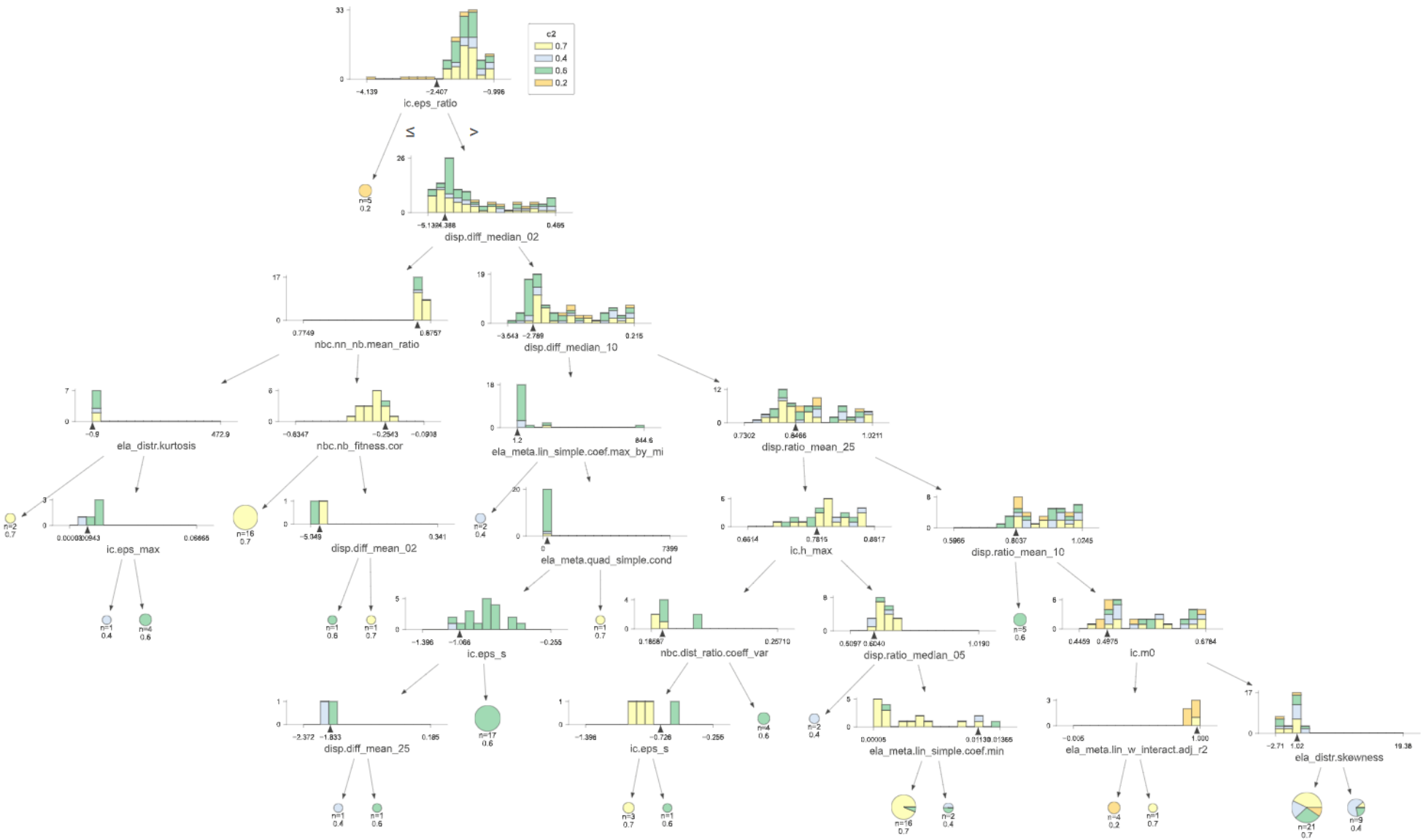


Figure 53: Decision tree (depth=7) for social component (c_2) module in PSO using Star Topology ($d = 5$). Nodes show feature splits with value distributions — yellow: false, green: true. The black arrow marks the split threshold.

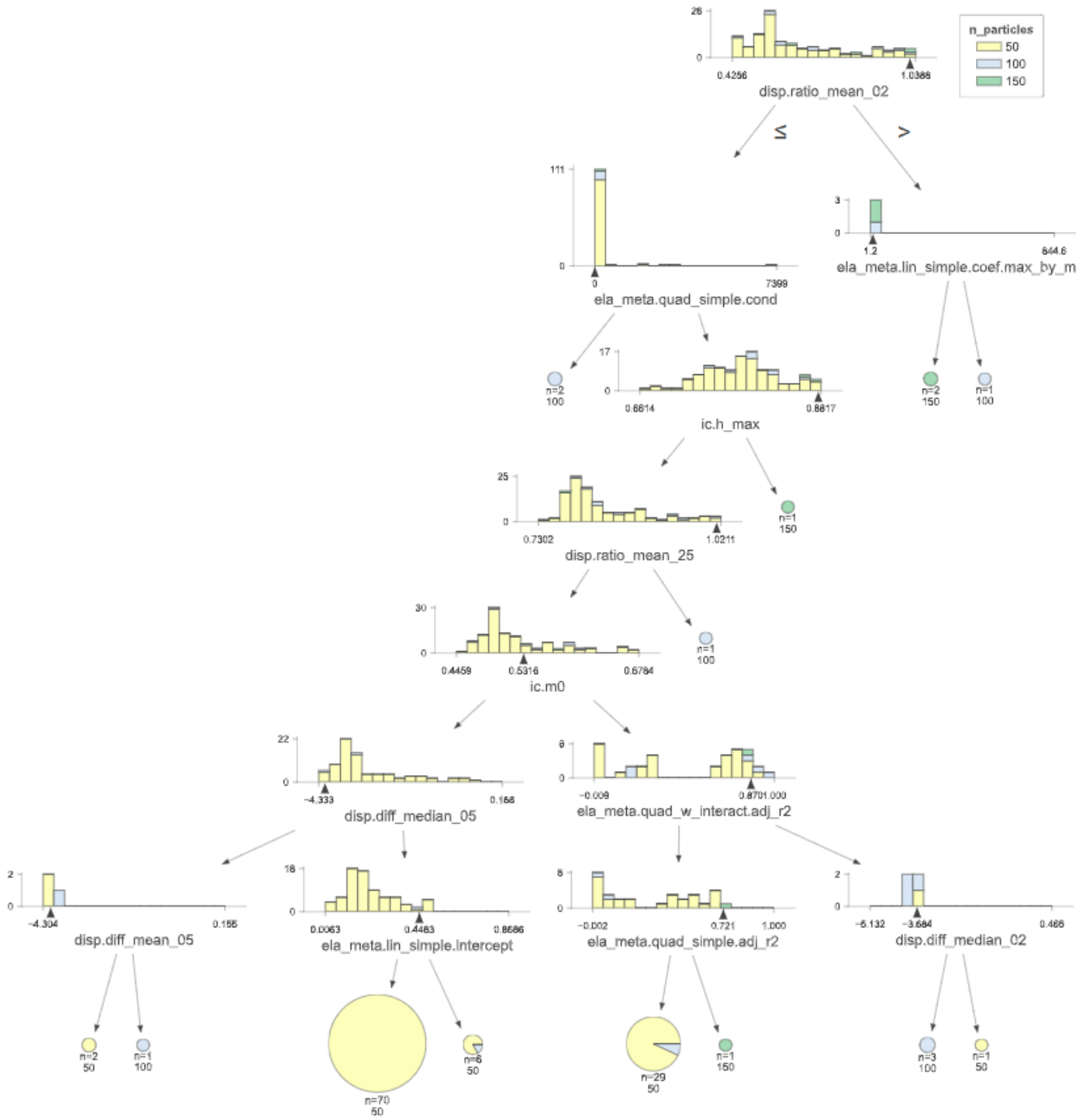


Figure 54: Decision tree (depth=7) for n_particle module in PSO using Star Topology ($d = 5$). Nodes show feature splits with value distributions — yellow: false, green: true. The black arrow marks the split threshold.

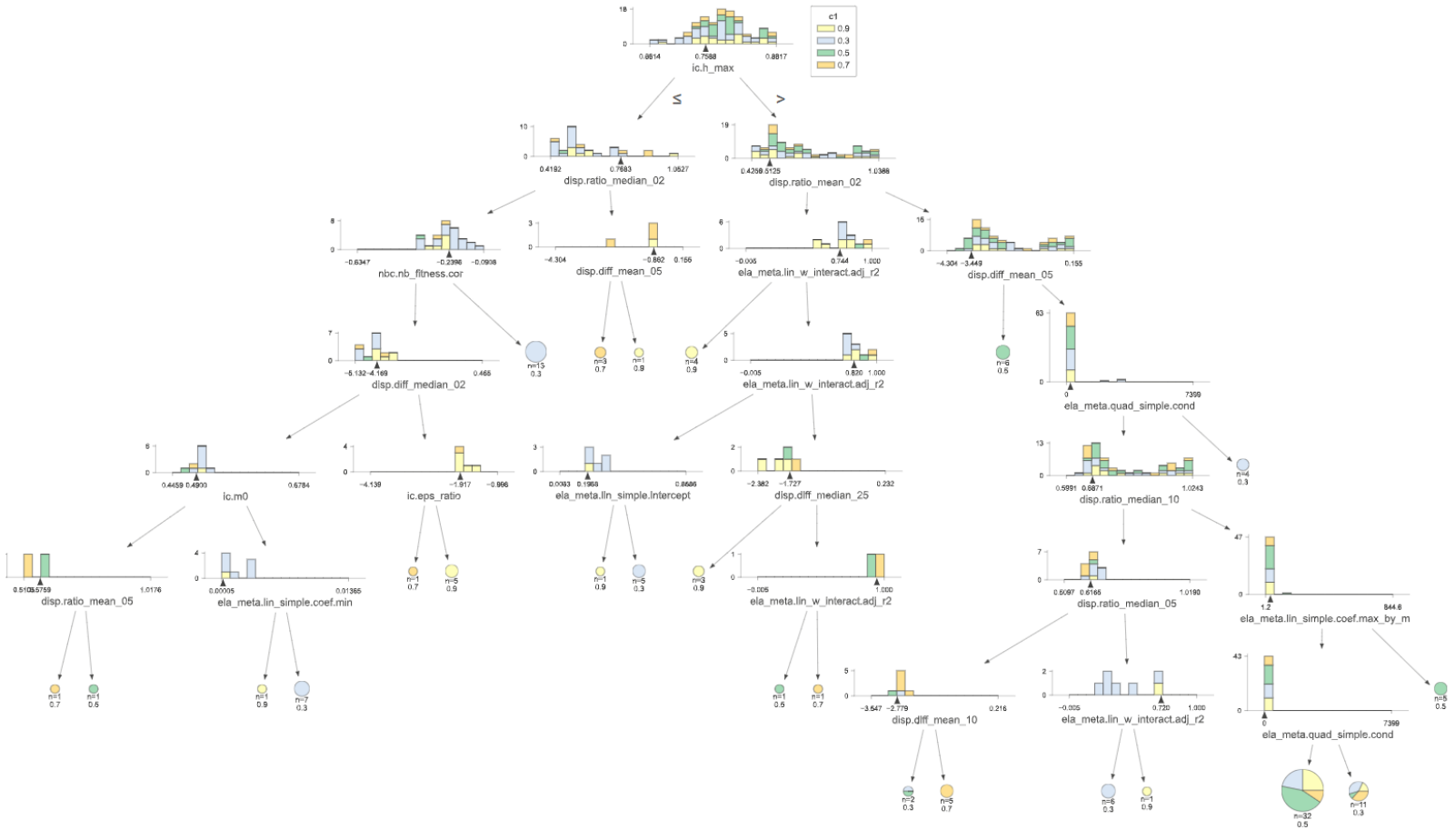


Figure 55: Decision tree (depth=7) for cognitive component (c_1) module in PSO using Ring Topology ($d = 5$). Nodes show feature splits with value distributions — yellow: false, green: true. The black arrow marks the split threshold.

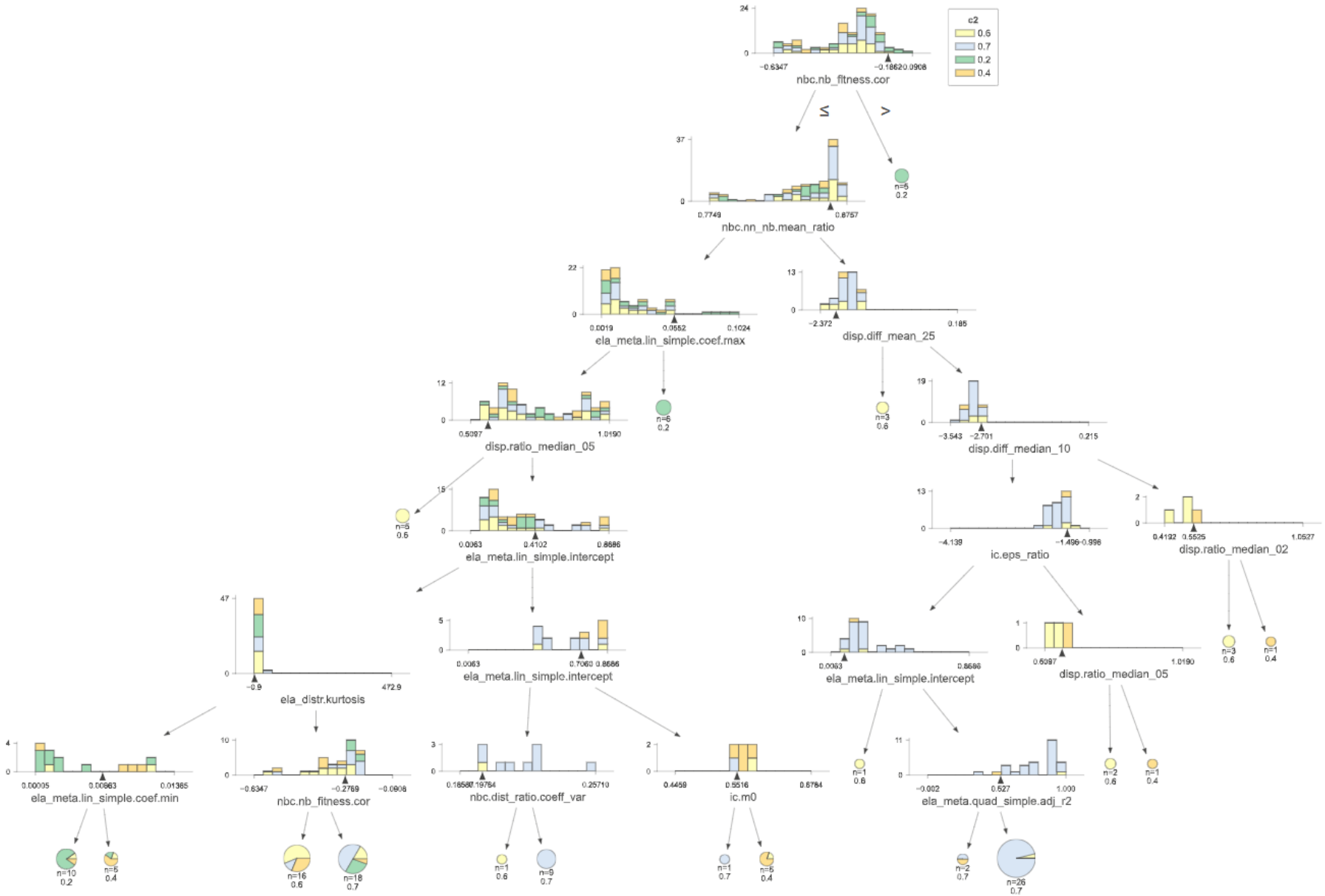


Figure 56: Decision tree (depth=7) for social component (c_2) module in PSO using Ring Topology ($d = 5$). Nodes show feature splits with value distributions — yellow: false, green: true. The black arrow marks the split threshold.

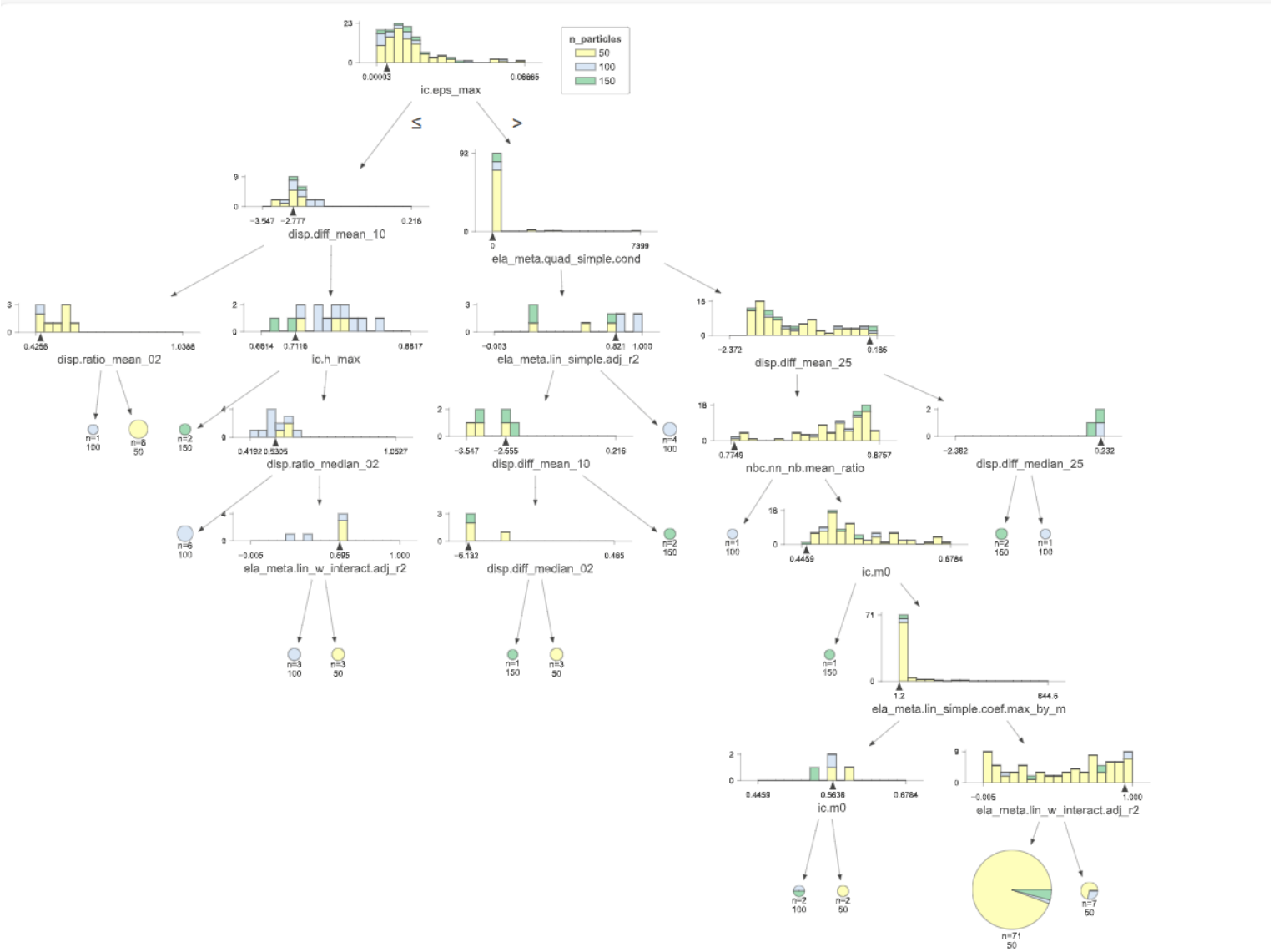


Figure 57: Decision tree (depth=7) for n_particle module in PSO using Ring Topology ($d = 5$). Nodes show feature splits with value distributions — yellow: false, green: true. The black arrow marks the split threshold.

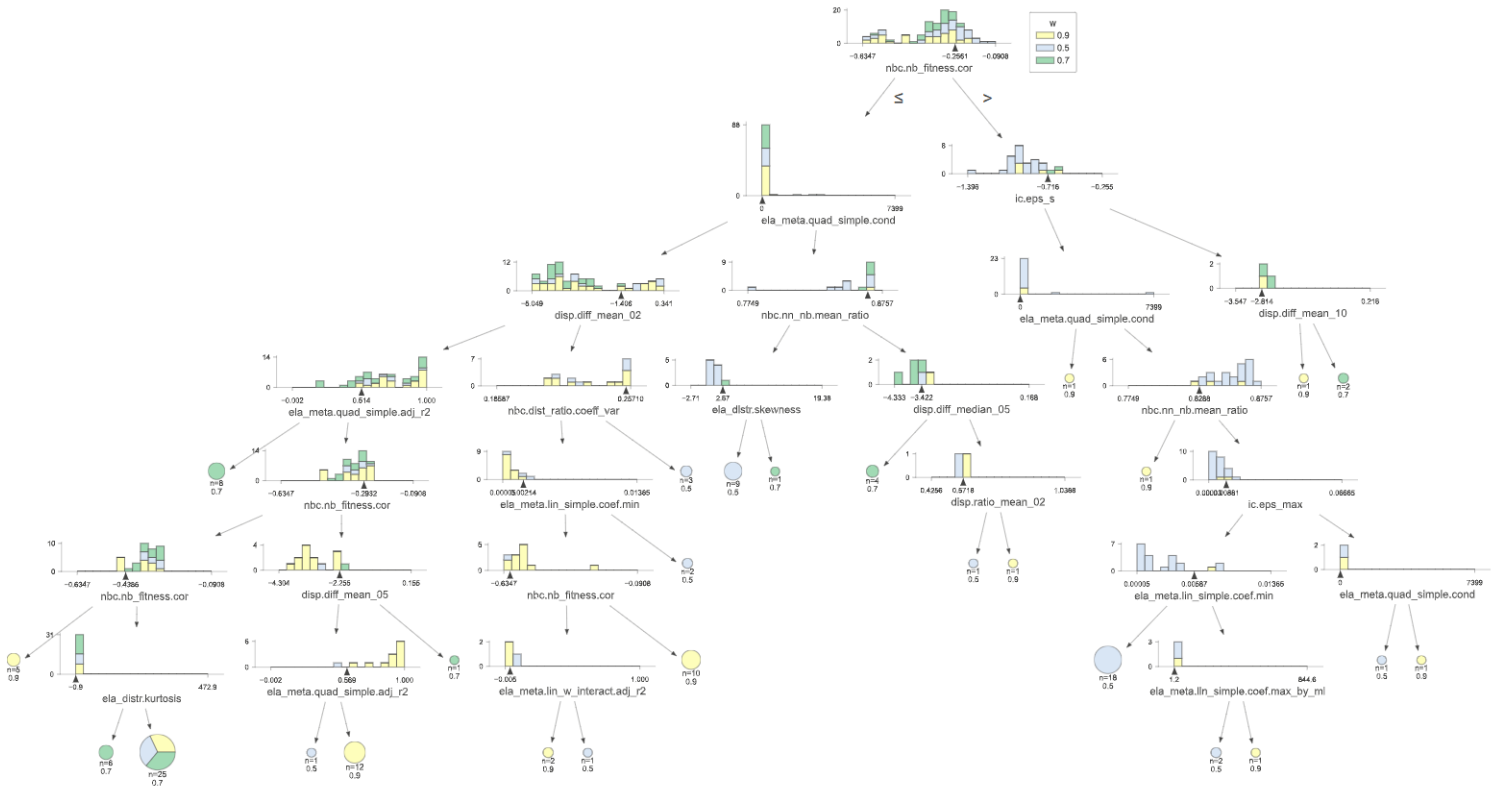


Figure 58: Decision tree (depth=7) for inertia weights (w) module in PSO using Ring Topology ($d = 5$). Nodes show feature splits with value distributions — yellow: false, green: true. The black arrow marks the split threshold.

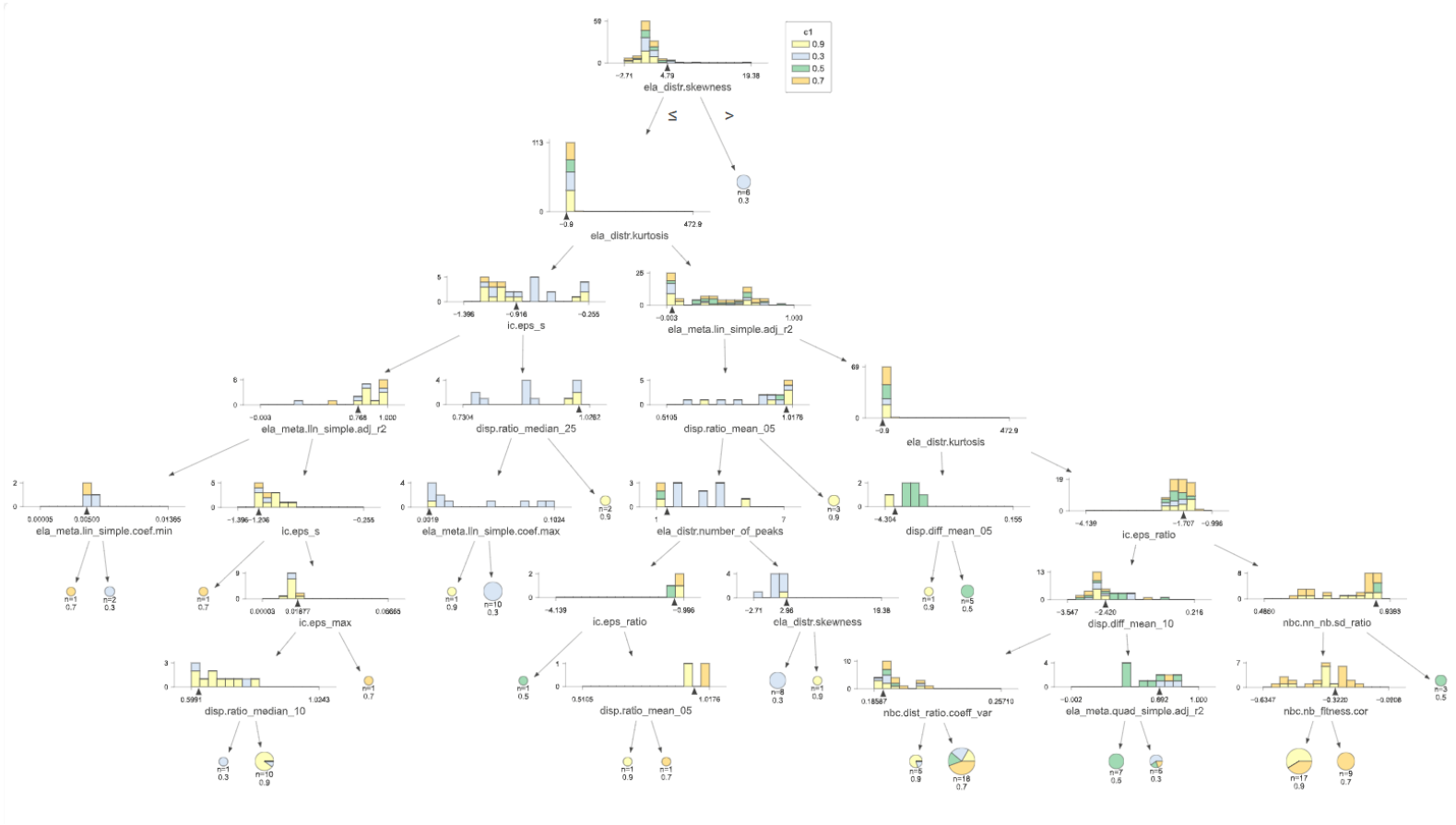


Figure 59: Decision tree (depth=7) for cognitive component (c_1) module in PSO using Von Neumann Topology ($d = 5$). Nodes show feature splits with value distributions — yellow: false, green: true. The black arrow marks the split threshold.

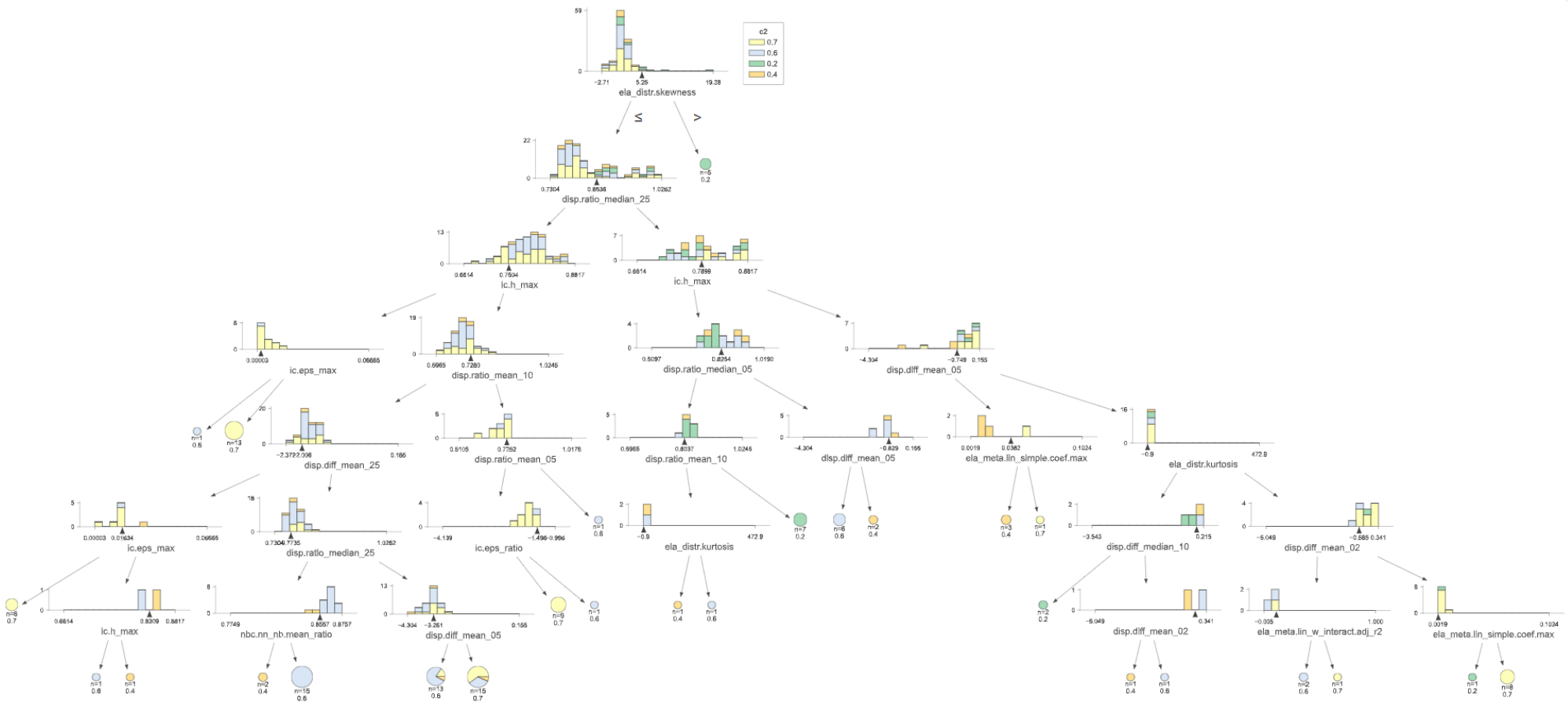


Figure 60: Decision tree (depth=7) for social component (c_2) module in PSO using Von Neumann Topology ($d = 5$). Nodes show feature splits with value distributions — yellow: false, green: true. The black arrow marks the split threshold.

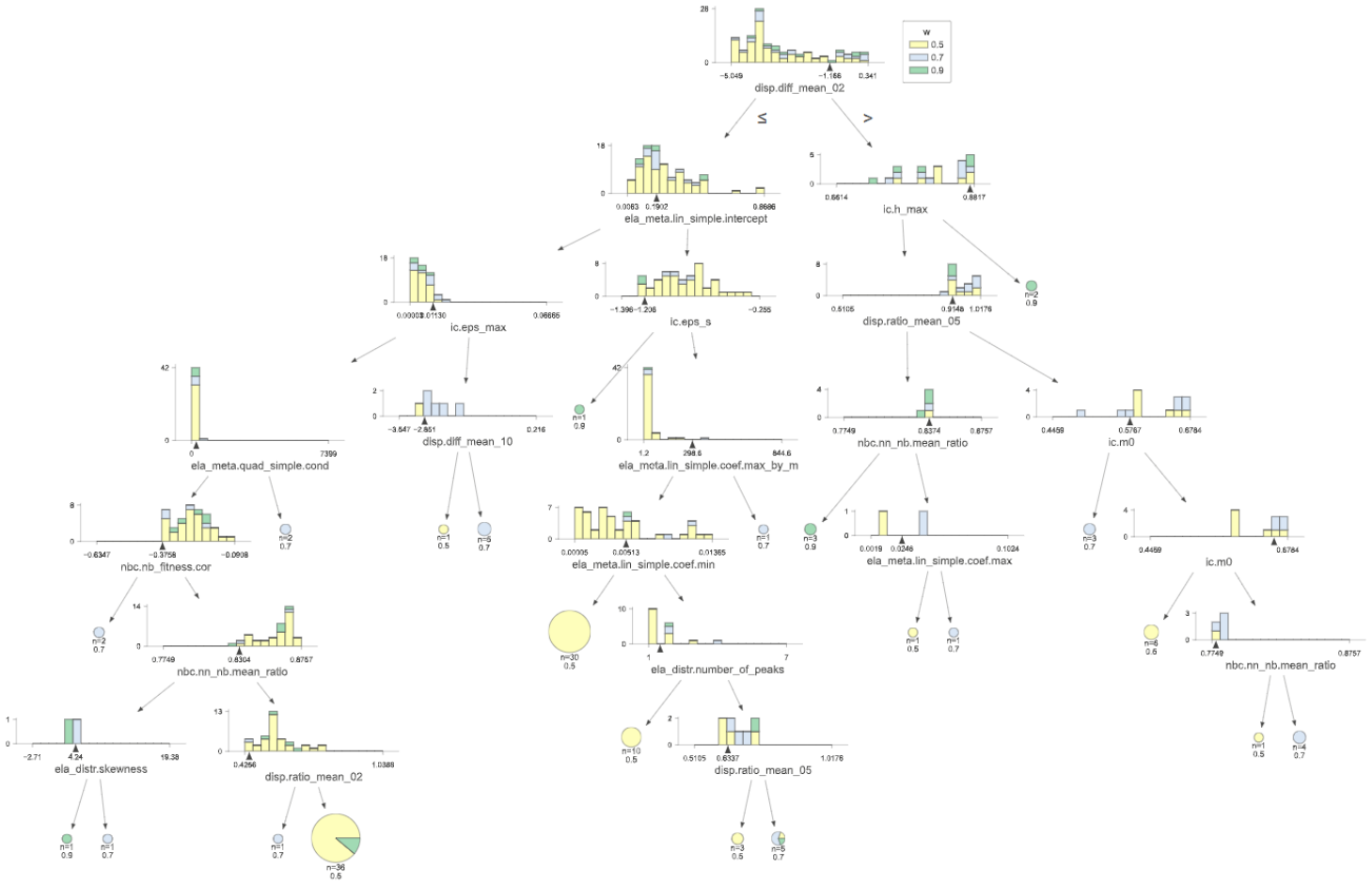


Figure 61: Decision tree (depth=7) for inertia weights (w) module in PSO using Von Neumann Topology ($d = 5$). Nodes show feature splits with value distributions — yellow: false, green: true. The black arrow marks the split threshold.