

For  $n = 1, 2, \dots$  let

$$S_n = \log \left( \sqrt[n^2]{1^1 \cdot 2^2 \cdot \dots \cdot n^n} \right) - \log(\sqrt{n}),$$

where  $\log$  denotes the natural logarithm. Find  $\lim_{n \rightarrow \infty} S_n$ .