ROBUST CONTROL OF CONTACT-RICH ROBOTS VIA NEURAL BAYESIAN INFERENCE

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Expectation of the performance index

Proof of Lemma **??**. Substituting the solution (**??**) of the SDE (**??**) expression into the performance measure (**??**) yields

$$
\begin{aligned}
\mathcal{J} = &-\frac{1}{4}\frac{q+r\theta^2}{p+\theta}\left(1+e^{2T(p+\theta)}\right) + (q+r\theta^2)\theta\sigma\int_0^T e^{(p+\theta)t}\int_0^t e^{(p+\theta)(t-s)}dW_s dt + \\
&\frac{1}{2}(q+r\theta^2)\theta^2\sigma^2\int_0^T\left(\int_0^t e^{(p+\theta)(t-s)}dW_s\right)^2 dt
\end{aligned}
$$

The conditional expectation of this quantity given the system parameter p under the distribution induced by the Wiener process may be computed in closed-form using Itô calculus:

$$
\begin{aligned}
\mathbb{E}_W\left[\mathcal{J}\mid p\right] = &-\frac{1}{4}\frac{q+r\theta^2}{p+\theta}\left(1-e^{2T(p+\theta)}\right) + (q+r\theta^2)\theta\sigma\int_0^T e^{(p+\theta)t}\cancelto{0}{\mathbb{E}_W\left[\int_0^t e^{(p+\theta)(t-s)}dW_s\,\middle|p\right]}dt + \\
&\frac{1}{2}(q+r\theta)^2\theta^2\sigma^2\int_0^T\mathbb{E}_W\left[\left(\int_0^t e^{(p+\theta)(t-s)}dW_s\right)^2\,\middle|p\right]dt \\
= &-\frac{1}{4}\frac{q+r\theta^2}{p+\theta}\left(1-e^{2T(p+\theta)}\right) + \frac{1}{2}(q+r\theta^2)\theta^2\sigma^2\int_0^T\left(\int_0^t e^{2(p+\theta)(t-s)}ds\right)dt \\
= &-\frac{1}{4}\frac{q+r\theta^2}{p+\theta}\left(1-e^{2T(p+\theta)}\right) + \frac{1}{2}(q+r\theta^2)\theta^2\sigma^2\int_0^T -\frac{1}{2(p+\theta)}\left(1-e^{2T(p+\theta)}\right)dt \\
= &-\frac{1}{4}\frac{q+r\theta^2}{p+\theta}\left[\theta^2\sigma^2T + \left(1-e^{2T(p+\theta)}\right)\left(1+\frac{1}{2}\frac{\theta^2\sigma^2}{p+\theta}\right)\right].
\end{aligned}
$$

□