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Technical Efficiency, Production Functions and Conservation Supply Curves

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Abstract

In a recent paper Huntington (1994) lays some of the groundwork for more meaningful discussions between economists and technologists on the apparent underinvestment in energy efficiency. In a discussion illustrated by a production function, he points out that the technical efficiency of economic actors should be treated as an empirical question. Huntington's groundwork can be further extended by observing that there is a close relationship between production functions and conservation supply curves, an analytical tool routinely used by technologists. Here we show that a conservation supply curve can be obtained from a production function by a simple transformation.

Technical Efficiency, Production Functions and Conservation Supply Curves

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In a recent paper in this journal Huntington discusses the concept of technical efficiency and its possible relationship to the efficient use of energy (Huntington, 1994). The paper lays some of the groundwork for more meaningful discussions between economists and technologists on the apparent underinvestment in energy efficiency. Huntington (an economist) illustrates his discussion with a production function, a standard item in the economist's tool kit. While very useful, Huntington's groundwork can be further developed by observing that there is a close relationship between production functions and conservation supply curves (CSCs), an analytical tool routinely used by technologists.

CSCs were introduced by A H Rosenfeld and his students (Meier, Wright and Rosenfeld, 1983).[1] Subsequent work by Rosenfeld and a number of other investigators is summarized in Rosenfeld et al., 1993. A noteworthy application of the CSC approach, in which the technique is used to describe conservation potential at the national level, can be found in the work of the Mitigation Panel of the National Academy of Sciences study on the policy implications of greenhouse warming (Rubin et al., 1992).

Originally, an impetus for the development of CSCs was a reaction to the perception that energy conservation necessarily required sacrifice by consumers. According to Meier, Wright and Rosenfeld, "One approach to energy conservation is to accept lower levels of service ([e.g.,] turning down the thermostat). Our approach, however, favors simple, economic measures that improve efficiency and save large amounts of energy *without changing the level of service.* (Meier, Wright and Rosenfeld, 1983, p 15, emphasis added)" They created CSCs to illustrate their approach. As they described it, "[A conservation] supply curve consists of a series of steps, each of which represents a conservation measure. The width of each step is the annual energy that could be saved . . . by the implementation of the measure within the time horizon specified. . . . To decide which conservation measures are economic, one must compare their costs of conserved energy to the price of new energy supplies during the time horizon. (Meier, Wright and Rosenfeld, 1983, p 34)" One of the CSCs that they published is shown in Figure 1. Since they wanted to compare the cost of conservation with the cost of new supply, the formal similarity between CSCs and traditional supply curves made it easy for them to explain their views. However, as is shown below, CSCs are much more closely related to production functions like the one used by Huntington in his discussion of technical inefficiency.

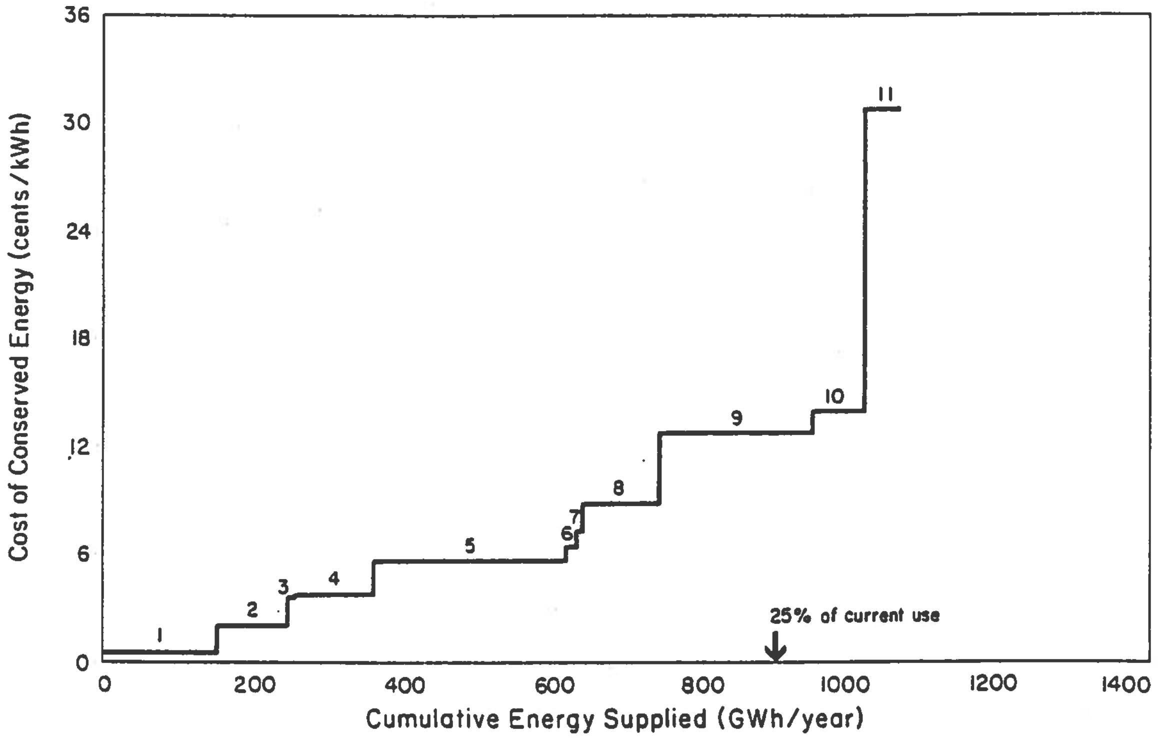

Figure 1. An example of a conservation supply curve. This example is for residential electric space heating in California. The numbers on the curve refer to conservation measures. For example, measure 1 is night setback of the thermostat and measure 5 is addition of storm windows (Meier, Wright and Rosenfeld, 1983, p 40).

From production functions to conservation supply curves

Generally an energy service is produced by using several inputs besides energy and so must be described by a production function such as $Q(E,x_1,\ldots,x_n)$, where $x_1,\ldots,x_n$ are the non-energy inputs.[2] Because we are interested in the cost of conserving E, wesummarize the non-energy inputs by a single cost, C, which is the minimum possible cost of non-energy inputs for a given level of output. This leads us to a production function of the form $Q(E,C)$, which gives the maximum possible output from input, E, when cost, C, is spent optimally on all other inputs. Since our concern is with energy conservation that doesn't change the level of service, plotting an isoquant of output from this production function proves illuminating. In this case we wish to plot the isoquant that corresponds to the level of energy service, say Q_0, produced before the conservation measures being analyzed are implemented. Such an isoquant is shown in Figure 2. Following Huntington, we will refer to this isoquant as the "best practice (BP) frontier." To the left and below the BP frontier the production of Q_0 is not feasible. To the right and above the BP frontier the production of Q_0 is feasible but "technically inefficient." By technically inefficient we mean that it is possible to reduce one input and produce the same output without increasing any other inputs. Technical efficiency is a necessary, but not sufficient, condition for economic efficiency.

The base case, shown in Figure 2, must be chosen before proceeding to the construction of the total cost of conserved energy curve (TCC). The base case (E_b, C_b) is just a reference case that produces the same output, Q_0, that defines the BP frontier. In Figure 2 the base case is technically inefficient. The point (E_b, C_b) is analogous to the technically inefficient point, A, on the graph of a production isoquant that illustrates Huntington's discussion (Huntington's Figure 1). Conservation can only be defined relative to some reference case, so the choice of the base case is essential.

The base-case point serves as the origin on the TCC graph, which is defined by the left-right reflection of the isoquant in the vertical line through that point, as shown in Figure 3. The horizontal axis on the graph measures the amount of energy conserved ($\mathcal{E}$) relative to the base, and the vertical axis measures the total cost ($\mathcal{C}$) of conserving that energy if the optimal mix of other inputs is used. That is, $\mathcal{E} = -(E - E_b)$ and $\mathcal{C} = C - C_b$.

Going from the TCC to the CSC is straightforward. The TCC is defined by the total cost of conserving energy and the CSC is defined by the *marginal* cost of conserving energy, which is simply the derivative of the TCC, $\mathcal{C}'(\mathcal{E})$. An example is shown in Figure 4. Since the TCC is defined for both positive and negative values of conservation, so is the CSC.

Note that when the base case is technically inefficient, the TCC passes below the origin. This is because when the base case is technically inefficient, it is possible to produce the same output (of energy services) using the base level of energy but a less

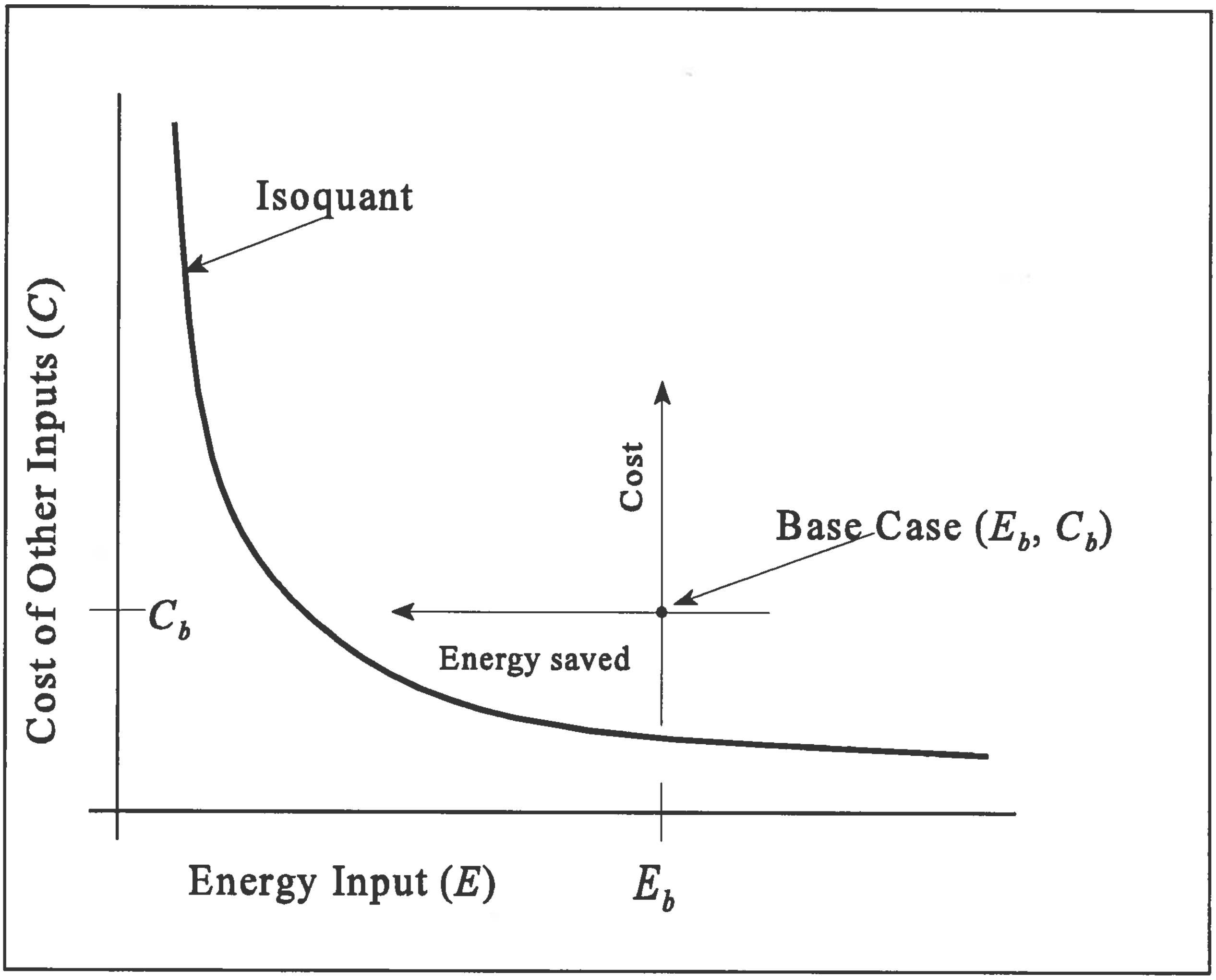

Figure 2. A production function. The isoquant shows technically efficient production of a fixed level of energy service.

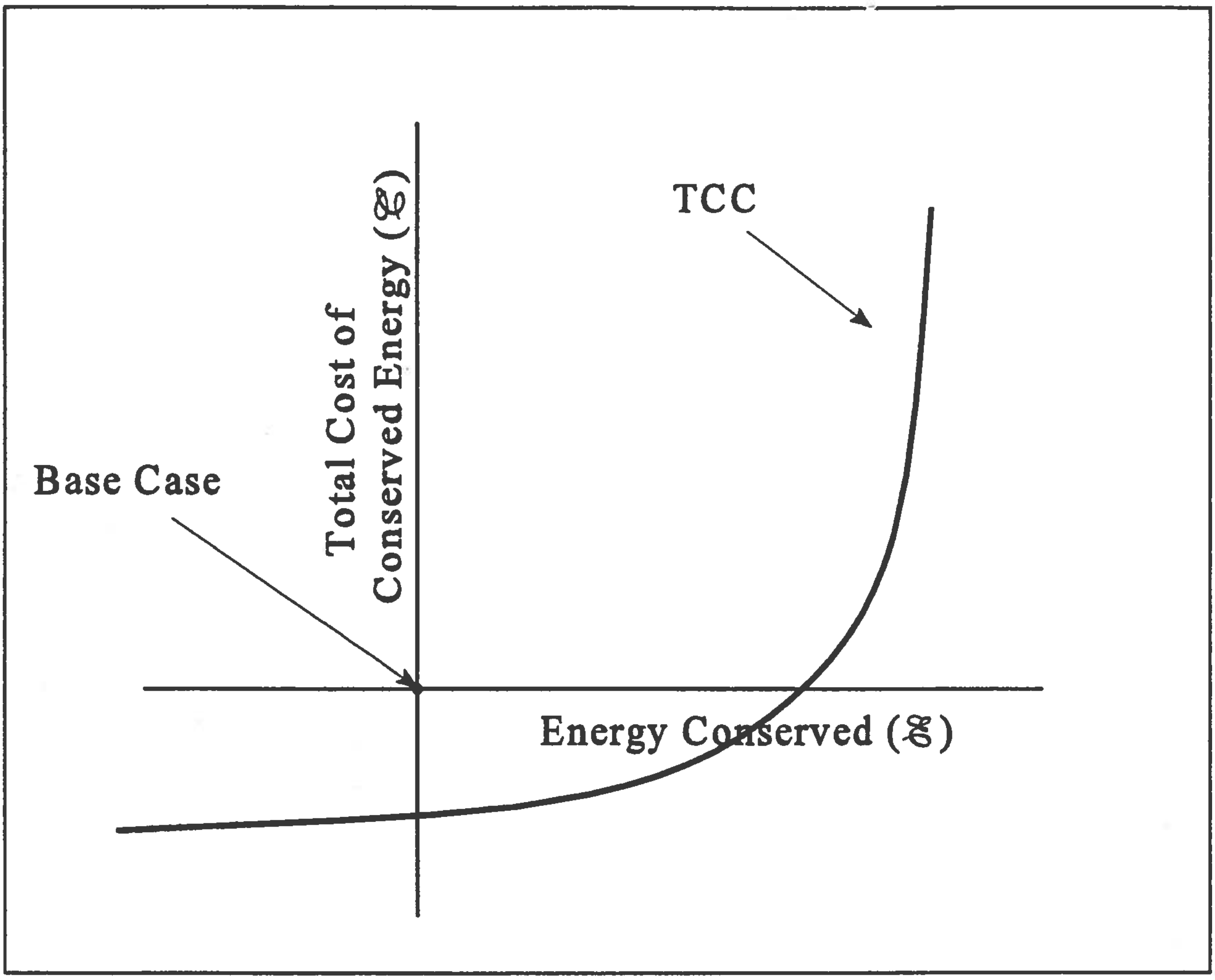

Figure 3. A total cost of conserved energy curve (TCC). The TCC is obtained from a simple transformation of the isoquant in Figure 2.

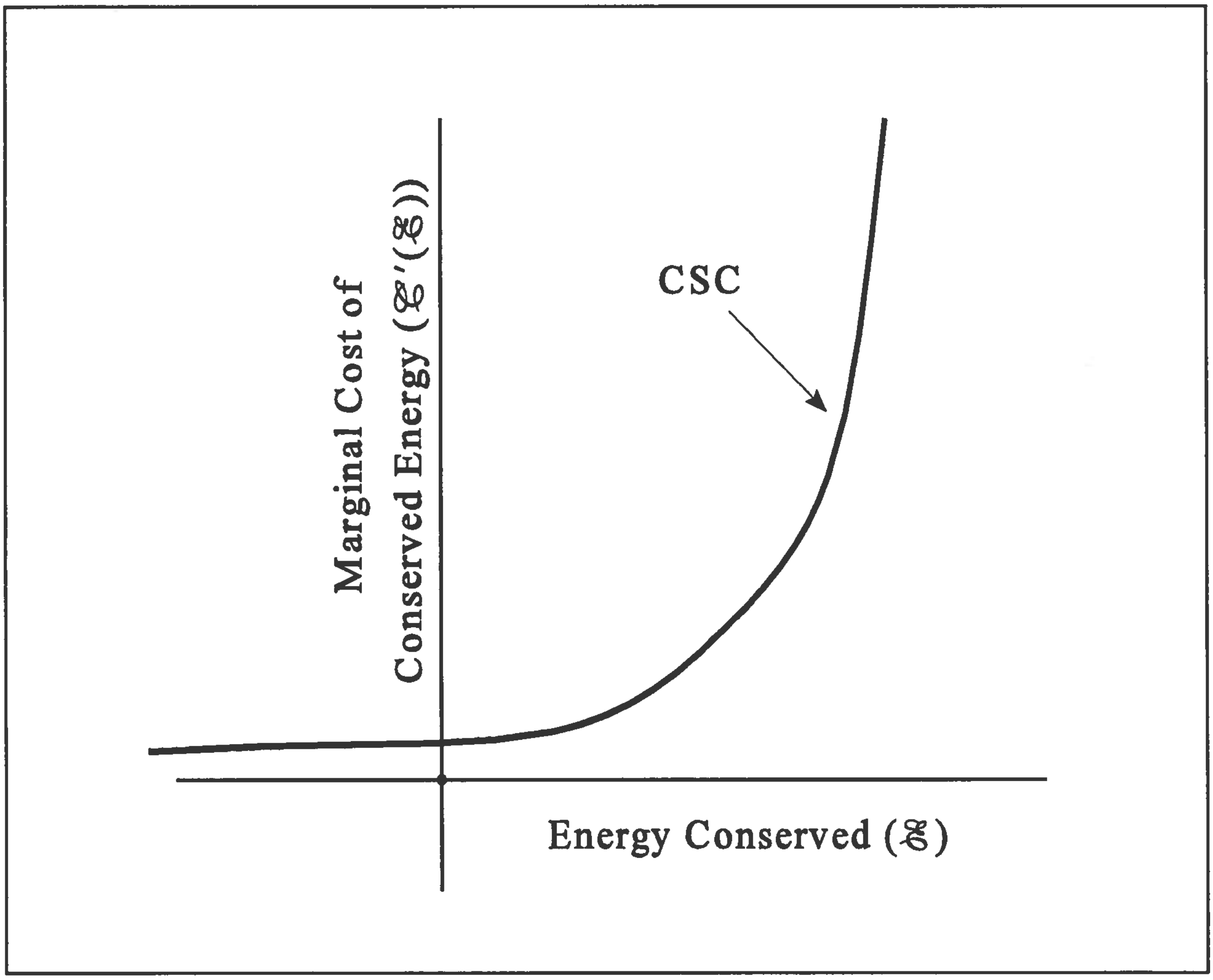

Figure 4. A conservation supply curve (CSC). The CSC is the derivative of the TCC in Figure 3.

costly combination of other inputs. However, under the usual assumption that E is a monotonically decreasing function of C, the CSC will be non-negative everywhere and it will be zero only when for some $\mathcal{E} > 0$ there is a value of $\mathcal{C}$ on the TCC that cannot be further reduced by the substitution of energy for other inputs. This follows from our definition of the CSC as the derivative of the TCC. When the TCC passes below the origin, it is obviously possible to save energy and other costs at the same time. In this circumstance, one might say (and it has been said (Fickett, Gellings and Lovins, 1990)) that the cost of conserved energy is negative. But this confounds the effect of moving from the origin to the BP frontier and the effect of moving along the BP frontier. This compound cost should not be confused with the marginal cost of energy conservation defined above. Note also that the net savings from correcting technical inefficiency cannot be discovered from the CSC because the CSC only reports the slope of the TCC and not how far below the origin it passes. However, the CSC does allow the computation of the net savings that are attributable to energy conservation. To find these savings for any particular level of energy saved, $\mathcal{E}_i$, simply integrate the CSC from 0 to $\mathcal{E}_i$ and subtract this from $\mathcal{E}_i$ times the price of energy.

Although we have used an inefficient base case in our illustrations, nothing in the foregoing requires inefficiency. If the base case is efficient then it must lie on the BP frontier, otherwise there would be technical inefficiency. It also must be located at the point on the BP frontier where motion along the frontier decreases the cost of the energy at the same rate that it increases the cost of other inputs, otherwise money can be saved by moving one way or the other. At this point, the slope of the BP frontier is minus the marginal cost of energy. So, with an efficient base case, the height of the CSC at the origin will be exactly the marginal cost of energy. This provides us with the prescription for correcting inefficiency. That is, move from an inefficient point to the point on the CSC where the marginal cost of conserving energy equals the marginal cost of consuming energy. This point satisfies the same conditions as the point C in Huntington's Figure 1.

Furthering the dialogue

Huntington observes that many economic enquiries begin with the presumption of economically efficient actors. He notes, as an example, that researchers frequently estimate a cost function under the assumption that all firms are price takers rather than price setters and are minimizing their costs (Huntington, 1994, p 837). One of Huntington's contributions in laying the groundwork for discussions between economists and technologists is to recognize that, for the dialogue to be fruitful, the efficiency of economic actors cannot be presumed and must be treated as an empirical question.

Huntington also observes that simply finding inefficiency will not tell us what, if any, policy interventions are appropriate. We need to know something about the causes of inefficiency before appropriate policy responses can be devised.[3] This too raises empirical questions. As demonstrated by the issue of this journal in which Huntington's paper appears, these questions can be addressed productively by a variety of disciplines.

The technologist makes a contribution here by proposing (at least apparently) more efficient methods to try. There is much to learn from the evaluation of technical trials conducted, for example, on the scale of a utility service territory (Levine and Sonnenblick, 1994). Empirical investigations by anthropologists and sociologists also provide useful insights (Kempton and Layne, 1994; Lutzenhiser, 1994).

Huntington concludes his paper with several questions. One of these is, "Can significant departures from best practice technology (ie technical inefficiency) be identified and measured meaningfully?" The close relationship between CSCs and production functions demonstrated above makes it clear that what technologists are doing when they create CSCs is, in effect, constructing a production function from engineering data. In doing this technologists are, in spite of a vocabulary and perspective that are very different from the economist, attempting to answer Huntington's question.

The authors would like to thank Severin Borenstein for very helpful advice and comments.

Notes

1. Rosenfeld reports that work on conservation supply curves was initially stimulated by a suggestion from Roger Sant *ca.* 1978 (personal communication).

2. Many of the ideas presented here concerning the relationship of CSCs to production functions are also presented by Stoft (1995) in the context of an analysis of a number of theoretical and practical issues related to CSCs.

3. For an early attempt to address this issue see Blumstein et al. (1980).

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