



# Empirical applications of discrete choice dynamic programming models

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## ABSTRACT

The development over the past 25 years of methods for the estimation of discrete choice dynamic programming (DCDP) models opened up new frontiers for empirical research in a host of areas, including labor economics, industrial organization, economic demography, health economics, development economics, political economy and marketing. In this paper, we first describe the development of the DCDP framework, showing how it was a natural extension of static discrete choice modeling. We then summarize six papers that adopt the DCDP paradigm that address substantively important social and economic questions. Finally, we consider the issue of the credibility of empirical findings based on the structural estimation of DCDP models.

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## 1. Introduction<sup>2</sup>

The development of methods for the estimation of discrete choice dynamic programming (DCDP) models, that began over 20 years ago, opened up new frontiers for empirical research in a host of areas, including labor economics, industrial organization, economic demography, health economics, development economics and political economy, and has spread to areas outside of traditional economics, such as marketing.<sup>3</sup> There are a number of survey papers that describe the methodology and provide examples of applications found in the literature up to the mid-1990s (Eckstein and Wolpin, 1989a; Miller, 1997; Rust, 1993, 1994), and a recent survey that describes the methodological work that has been ongoing since that time (Aguirregabiria and Mira, in press). Another conventional survey would thus have limited value. The purpose of this essay is, instead, to provide evidence about whether the methodology's promise has borne fruit as a tool for empirical research. The success of what has come to be called, for better or worse, the "structural" approach to microeconomic empirical research should be judged according to the value of the empirical work that the approach has made possible.<sup>4</sup>

To that end, we describe how the DCDP paradigm has been used to address quantitatively six diverse, substantively important and challenging questions. The six papers that we summarize span the fields of economic demography, economic development, labor economics, health economics and political economy. The papers fall into two categories in terms of their goals. One of the papers attempts to explain a set of historical phenomena. Papers of this kind, to the extent that

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<sup>2</sup> This essay derives from the plenary talk by Wolpin at the June 2007 SED conference in Prague.

<sup>3</sup> Indeed, the DCDP approach is now arguably the predominant one in marketing.

<sup>4</sup> The structural approach encompasses continuous as well as discrete choice models and static as well as dynamic models. Explicit modeling of dynamical considerations does not alter the basic rationale for the imposition of structure as contained in Marschak (1953).

they are successful, provide models that improve our ability to forecast the future course of related events. The five other papers perform *ex ante* policy evaluations that attempt to assess the impact of policies outside of the historical experience. Papers of this kind, to the extent that they are successful, provide policy makers with the ability to compare the efficacy of alternative prospective policies.

The questions these six papers address are:

1. What are the economy-wide changes in the US since the mid 1960s that have been responsible for the increase in wage inequality, the increase in the college premium, the closing of the male–female wage gap, the increase in the labor force participation of women and the growth of the service sector?
2. To what extent can monetary incentives reduce racial differences in school attainment and wages?
3. What government policies would be most effective in increasing educational attainment in developing countries?
4. How will the new expansion of Medicare to incorporate prescription drug coverage affect the health and life expectancy of the elderly?
5. How would the career decisions of politicians be influenced by such policies as term limits, changes in Congressional salaries, and changes in post-Congressional career options?
6. What would be the impact of employer sanctions and increased border protection on the flow of illegal Mexican immigrants to the US?

We do not provide a critical assessment of the individual papers, but rather offer an overall picture of the strengths and weakness of the DCDP approach. As even the casual reader will recognize, the modeling assumptions in the individual papers used to address these questions are many and there is little doubt that other researchers would have chosen differently. One should not then, as we do not, think of these studies as in any way definitive. There is no such thing in empirical work. What we hope is that the reader will be convinced that these exercises comprise serious attempts to answer exceedingly difficult questions, that they make progress in doing so, and that their results should be taken at least as seriously as those derived from other empirical approaches. Although it goes without saying, these are not the only papers that tackle important questions using the DCDP approach, and many other papers would have equally well served our purpose.

We proceed first by describing the development of the DCDP framework. We show that it was a natural extension of the latent variable formulation of static discrete choice modeling. We begin, in Section 2, with the binary choice setting in order to fix ideas, using a simple labor force participation model as the prime motivating example. The DCDP framework is shown to have the same empirical structure as the static framework and, in that sense, raises no new conceptual estimation problems. Similarly, the computational issues that arise in the estimation of static multinomial choice models carry over to the dynamic case, but with the added complexity of having to numerically solve a dynamic programming problem. Section 3 summarizes the model structure and empirical results of the six papers that tackle the questions raised above. The value of the empirical work depends on the credibility that is attached to the findings. The next section addresses that issue, examining alternative methods of model validation. We include this section because practitioners of the DCDP approach themselves have been notably sensitive to it and because it is probably the most fundamental and vexing problem faced by empirical researchers of all stripes. The last section attempts to draw general lessons from the papers we review.

## 2. The common empirical structure of static and dynamic discrete choice models

The development of the DCDP empirical framework was a straightforward and natural extension of the static discrete choice empirical framework. The common structure they share is based on the latent variable specification, the building block for all economic models of discrete choice. To illustrate the general features of the latent variable specification, consider a binary choice model in which an economic agent, denoted by  $i$ , makes a choice at each discrete period  $t$ , from  $t = 1$  to  $T$ , between two alternatives  $d_{it} \in \{0, 1\}$ . Examples might be the choice of whether to work or not, whether (to try) to have a child or not, or whether to attend college or not. The outcome is determined by whether a latent variable,  $v_{it}^*$ , reflecting the difference in the payoff between choosing  $d_{it} = 1$  and  $d_{it} = 0$ , crosses a scalar threshold value, which, without loss of generality, is taken to be zero. The preferred alternative is the one with the largest payoff, i.e., where  $d_{it} = 1$  if  $v_{it}^* \geq 0$  and zero otherwise.

In its most general form, the latent variable may be a function of three types of variables:  $\tilde{D}_{it}$  is a vector of the history of all past choices ( $d_{i\tau}$ :  $\tau = 1, \dots, t - 1$ ),  $\tilde{X}_{it}$  is a vector of contemporaneous and lagged values of  $J$  additional variables ( $X_{ij\tau}$ :  $j = 1, \dots, J$ ;  $\tau = 1, \dots, t$ ) that enter the decision problem, and  $\tilde{\epsilon}_{it}$  ( $\epsilon_{i\tau}$ :  $\tau = 1, \dots, t$ ) is a vector of contemporaneous and lagged unobservables that also enter the decision problem.<sup>5</sup> The agent's decision rule at each age is given by

$$d_{it} = \begin{cases} 1 & \text{if } v_{it}^*(\tilde{D}_{it}, \tilde{X}_{it}, \tilde{\epsilon}_{it}) \geq 0, \\ 0 & \text{if } v_{it}^*(\tilde{D}_{it}, \tilde{X}_{it}, \tilde{\epsilon}_{it}) < 0. \end{cases} \quad (1)$$

All empirical binary choice models are special cases of this formulation. Static models are distinguished from dynamic models by whether past choices affect the latent variable and, thus, the current choice. The goal of researchers

<sup>5</sup> As will be seen in the empirical applications we consider, there are a wide range of types of variables that would be included in  $X$ . Their common feature is that they are not directly choices of the agent, although they may be affected by prior choices or correlated with choices without being directly affected by them.

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