INTERTEMPORAL PREFERENCES AND TIME-INCONSISTENCY: THE CASE OF FARMLAND VALUES AND RURAL-URBAN LAND CONVERSION

By

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To my close friends, my dear family, and my lovely fiancée.

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LIST OF ABBREVIATIONS

BP	Breusch-Pagan
BL	Box-Ljung
CBD	Central business district
CES	Constant elasticity of substitution
CPI	Consumer price index
CRP	Conservation Reserve Program
CRRA	Coefficient of relative risk aversion
DVT	Development value tax
ERS	Economic Research Service
GIS	Graphical information system
GMM	Generalized method of moments
IRR	Internal rate of return
LVT	Land value tax
NLSY	National Longitudinal Survey of Youth
NPV	Net present value
NRI	National Resources Inventory
PCE	Personal consumption expenditure
PPI	Producer price index
PV	Present value
PDV	Present discounted value
USDA	United States Department of Agriculture

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Many studies have rejected the standard present value model under rational expectations as a viable model for explaining farmland values in both domestic and international data. Current models of farmland values inadequately explain why land prices rise and fall faster than land rents, particularly in the short-run. Previous inquiries into the nature of farmland values assume a time-consistent discount factor and do not seriously investigate the role of intertemporal preferences. This dissertation introduces time-inconsistent preferences into a model of farmland values by including a quasi-hyperbolic discount parameter in the asset equation of nine agricultural regions in the United States.

Strong evidence is found in favor of quasi-hyperbolic discounting as a more appropriate way of describing the discount structure in models of farmland values. By introducing quasi-hyperbolic discounting to the present-value model of farmland values, the discount factor can be broken down into two time-specific rates, the short-run discount rate and the long-run discount rate. Using a time-inconsistent discount factor, like a quasi-hyperbolic one, allows time preferences in the short-run to be different than in the long-run . Thus, the model offers an explanation as to why short-run and long-run land values do not follow the same path.

The theoretical formulation in this paper generalizes time preferences in the asset equation and allows values of the exponential and quasi-hyperbolic discount parameters to be obtained. A hypothesis test is constructed, permitting for a direct test on the discount parameters. Using the linear panel Generalized Method of Moments estimator, problems of heteroskedasticity and serial correlation are reduced. The results of the hypothesis tests imply a formal rejection that short-run discount rates are equal to long-run discount rates, and that the short-run discount rates are substantially larger than the long-run discount rates, a new result in the literature on farmland values.

The results presented in this dissertation are not only important because of their unique insights into intertemporal preferences, but also because of the implications generated by the results. First, the results imply that land-use decisions may be made with a greater interest in short-run gains than long-run returns. Second, the results offer an appealing explanation as to why land values and rents do not follow the same path in the short-run. Finally, the results also suggest that farmland serves as a golden egg to farmers, landowners, or developers who may demand commitment devices to constrain themselves from hasty land investment decisions.

The results have importance policy and extension relevance. Knowing that land-use decisions may be dominated by short-run thinking, extension efforts should address this tendency to insure that future consequences of present choices are fully considered. The results also lend support to policy instruments that act as commitment devices to constrain landowners to their present choices. Future work should focus on the potential consequences of time-inconsistency in other common agricultural economics models such as rural-urban land conversion and food demand, as well as extending the results in this dissertation to account for risk, inflation, and adaptive expectations.

CHAPTER 1
INTRODUCTION

Overview and Purpose

The capitalization approach or net present value model has dominated the literature on farmland values and the general literature on asset pricing as a whole. The method generally states that the value of farmland is determined by the discounted expected future return to farmland (Melichar 1979; Alston 1986; Burt 1986; Featherstone and Baker, 1987). However, a number of empirical issues have arisen from the use of the present value technique, particularly in the arena of farmland pricing. A burgeoning literature has appeared criticizing the capitalization technique for oversimplifying the market fundamental process, leading to empirical rejection of the present value model for farmland (Falk 1991; Clark, Fulton, and Scott 1993; Lloyd 1994).

One serious flaw in the present value model is the inability to explain why land prices rise and fall faster than land rents, particularly in the short-run (Schmitz 1995; Falk and Lee 1998). These so-called boom/bust cycles represent the tendency of markets to overvalue land in periods of prosperity while undervaluing land in periods of relative decline (Schmitz and Moss 1996). As pointed out by Featherstone and Moss (2003), any sustained time period of over-valuation or under-valuation is inconsistent with a rational farmland market. Not only is the presence of boom/bust cycles well documented within the land market, but the causes for these cycles has been the topic of considerable debate in the literature (Lavin and Zorn 2001).

Recent studies on models of land values have attributed the failure of the standard present value method to a variety of causes including the presence of transaction costs (Just and Miranowski 1993; Chavas and Thomas 1999; de Fontnouvelle and Lence,2002), a time-varying risk premium (Hanson and Myers 1995), fads and overreaction (Falk and Lee 1998), or inadequate econometric methods (Gutierrez, Westerlund, and Erickson 2007). However, few studies examine the role of time preferences within the context of agricultural land values or have seriously considered the shape and form of the discount factor in particular. The literature to date has overwhelmingly relied on the *a priori* assumption that individuals, such as farmers and landowners, are time consistent and are described by standard exponential discounting, which implies a constant rate of discount. While such an assumption invokes intertemporal consistency in preferences, this rationale should be called into question. Even Paul Samuelson (1937, p. 156), in his seminal work on the discounted utility model, was keen to state that the assumption of constant discounting was purely arbitrary and "*is in the nature of an hypothesis, subject to refutation by observable facts*." Substantial empirical evidence in experimental, behavioral, psychological, and financial economics has shown that individuals tend to be time-inconsistent (Thaler 1981; Benzion, Rapoport, and Yagil 1989; Benzion, Shachmurove, and Yagil 2004) and that time preferences are better modeled by quasi-hyperbolic discounting (Loewenstein and Prelec1992; Eisenhauer and Ventura 2006).

This dissertation introduces intertemporal inconsistency into a model of land values and tests for the presence of quasi-hyperbolic discounting in the farmland asset equation. Unlike exponential discounting, which implies that individuals apply the same constant rate of discount each year, quasi-hyperbolic discounting implies a non-constant rate of discount that declines over time. Hence, discounting is heavier in earlier time periods with the discount rate falling across the time horizon. This implies that individuals are more impatient when they make short run decisions than when they make long-run decisions. The introduction of quasi-hyperbolic discounting allows the discount factor to be decomposed into short-run and long-run discount rates. Thus the model offers an explanation into the apparent disconnect between short-run and long-run land values and explains why significant short-run deviations from the discounted formulation may occur.

This dissertation makes three important contributions. The first contribution is theoretical, employing a net present value model that generalizes intertemporal preferences to allow for quasi-hyperbolic discounting. The literature often uses intricate and rigorous game theoretic approaches to demonstrate the effect of time-inconsistent preferences on consumption and savings decisions. The approach in this dissertation focuses on a simplified modification of the asset investment equation to account for quasi-hyperbolic discounting. This method of measuring the economic impact of time inconsistent preferences by obtaining the quasi-hyperbolic discount parameter in a reduced-form model is unique in the literature.

The second contribution is empirical. Most studies that estimate the quasi-hyperbolic discount parameter use experimental data. Furthermore, many studies rely on calibration methods rather than estimation methods to obtain the discount parameter (Laibson 1997, 1998; Angeletos et al. 2001). This dissertation uses aggregate field level data and empirically estimates the discount parameter, joining the small but growing number of studies that use field data to structurally estimate discount factors (Paserman 2004; Ahumada and Garegnani 2007; Fang and Silverman 2007; Laibson, Repetto, and Tobacman 2007).

Finally, within the context of land values, and farmland values in particular, the dissertation examines the importance of time-inconsistent preferences in an important area of economics. The dissertation offers an explanation for the observed inconsistency in farmland markets between short-run and long-run farmland values through presence of quasi-hyperbolic discounting. The results in the dissertation also yields insights into land-use decisions and the tendency of landowners to make present decisions for instant gains at the sacrifice of future returns. The short-run discount rates obtained also provide quantitative support for the Golden Eggs hypothesis posited by Laibson (1997) and suggest that landowners may desire commitment devices to help constrain their future selves. To the best knowledge available, this dissertation contributes to the literature on land values with the first theoretical and empirical study of the relationship between time-inconsistent preferences and land values.

The remainder of this chapter is organized as follows. The second section provides a cursory review of the literature on intertemporal preferences and time inconsistency. The third section discusses the nature of hyperbolic discounting in more detail and provides a useful example. The fourth section introduces an important application of intertemporal preferences in the land values literature, the economic decision to develop rural land to urban use. The fifth and last section of this chapter reiterates the study objectives and provides a summary.

Time Preferences and Economics

A growing body of literature on the economics of intertemporal decision-making and time preferences has led to a significant body of research on time inconsistent preferences. For excellent reviews of the literature see Loewenstein and Prelec (1992), Laibson (1997), and Frederick, Loewenstein, and O'Donoghue (2002). There are different ways to model time-inconsistent preferences with a non-constant discount rate, but the most common method is through the use of a hyperbolic discount factor. Hyperbolic discounting originally developed in the psychological literature and was used to model intertemporal discounting in experiments on pigeon behavior in Chung and Herrnstein (1961) and later applied to discounting by people in Ainslie (1975). The financial, behavioral, and experimental economics literature has taken recent note of hyperbolic discounting, being applied to models of savings, investment, economic growth, and addiction.

Unlike time consistent preferences, time inconsistent preferences are characterized by two phenomena. The first are preference reversals and the second are intra-personal games involving a tussle between desires to act patiently against desires for instantaneous gratification (Laibson 1997). A preference reversal occurs when an individual's present self makes a decision and then the future self makes a different decision. A common example is when someone sets their alarm clock before going to bed only to hit the snooze button once, or several times more, when they awake the next morning. The internal tussle comes into play when an individual is torn between the long-run desire to act patiently and the short-run desire to be impatient. An example here would be someone who wants to have a better looking physique next year but still indulges in fast-food that evening for dinner.

Exponential discounting, representing time-consistent preferences, discounts at a constant rate across each time period in the horizon and so cannot account for either preference reversals or internal tussles. Hyperbolic discounting, and the discrete form case of quasi-hyperbolic discounting, accounts for the time-inconsistencies discussed above by imparting a non-constant discount rate, one that declines over time. Robert Strotz (1956) was the first to suggest that individuals may exhibit time inconsistency through an "intertemporal tussle" where the future self may have different preferences from the present self. Strotz (1956) proposes a discount function based on the time distance of a future date from the present moment rather than just the future date as more descriptive of individual behavior. Over the years, several elegant but general models of time-inconsistent preferences have been proposed by Pollak (1968), Peleg and Yaari (1973), and Goldman (1979, 1980). The simple time inconsistency introduced in the previous studies is based upon an individual valuing well-being or utility more at the present time than at some future time, but values future well-being or utility at the same rate.

The application of time inconsistent preferences to important economic models reveals note-worthy conclusions. Barro (1999) adapts the neoclassical growth model of Ramsey to account for a variable rate of time preference. While the basic properties of the neoclassical growth model are invariant under time-inconsistent preferences, the time-varying model yields important welfare implications depending on the ability and level of commitment from households to their future choices of consumption. Gruber and Koszegi (2001) apply time inconsistent preferences to the rational addiction model of Becker and Murphy. While the prediction of their model was equivalent to the Becker-Murphy model, that current consumption of an addictive substance is sensitive to future price expectations, the time inconsistent model reveals substantially different optimal level of government taxation. Laibson (1996, 1997), in his pioneering work on applying hyperbolic discounting to economic models of savings and investment, finds convincing evidence that rates of time preference are not constant. Ahumada and Garegnani (2007) recently found evidence of hyperbolic discounting in consumption-savings decisions using aggregate consumer expenditure data in Argentina. Laibson, Repetto, and Tobacman (2007) use individual level data on credit card borrowing, consumption, income, and retirement savings and strongly reject the constant discount rate model in several specifications.

Intertemporal preferences have been largely ignored in the agricultural economics literature, with few exceptions, ignoring the role time preferences play in farmer or landowner decisions. Flora (1966) represents one of the only attempts to determine how landowners' time preferences affect the discount factor. He finds investment decisions in forest lands can be affected by time preferences. Analysis of survey data finds that some individuals place a higher time priority than the prevailing interest rate (Flora 1966). Barry, Lindon, and Nartea (1996) make a valuable contribution by establishing time attitude measures analogous to the Arrow-

Pratt measures of risk attitudes of increasing, decreasing, and constant absolute time aversion. They point out that farmer time attitudes may change over time, directly affecting choices involving consumption, savings, and investment. Lence (2000) is one of the only studies known that estimates the farmer's rate of time preference based on consumption data using Euler equations. He points out that the literature has largely ignored farmer's intertemporal preferences despite the tremendous benefit such knowledge would endow towards a greater understanding of how agricultural policy can optimally allocate resources across time. To gain a better understanding of how constant and time-consistent discounting differs from non-constant time-inconsistent discount, the following section offers a primer on discount factors.

Discourse on Discounting

Time inconsistency is generated in the hyperbolic discount factor by a rate of discount that falls as the discounted event is moved further away in time. Events in the near future are discounted at a higher implicit discount rate than events in the distant future. The generalized hyperbolic discount factor developed in Loewenstein and Prelec (1992) is $\delta(t) = (1 + \alpha t)^{-\gamma/\alpha}$, where $\alpha, \gamma > 0$. The parameter α determines how much the function departs from constant discounting. As explained by Luttmer and Mariotti (2003), α is the parameter in the discount factor that controls how fast the rate of time preference changes between short run and long run values. The limiting case, as α goes to zero, is the exponential discount factor $\delta(t) = \delta^t$. The γ parameter represents a first period immediacy effect, discounting the initial period more heavily. As noted in Weitzman (2001), the hyperbolic discount function generalizes to the well-known gamma distribution, where the exponential function is simply a more special case.

The instantaneous discount rate at time t is for the hyperbolic discount factor is given by $-\delta^{'}(t)/\delta(t) = \gamma/(1 + \alpha t)$. The noteworthy property of hyperbolic discounting is that as t

increases, the instantaneous rate of discount decreases, meaning the hyperbolic discount rate is not constant, as in exponential discounting, but rather is a function of time, declining over the time interval. The percent change in the hyperbolic discount factor depends on the time horizon, being steeper for the near future and flatter for the distant future, implying a discount factor that declines at a faster rate in the short run than in the long run.

An alternative type of discounting is quasi-hyperbolic discounting, originally proposed by Phelps and Pollak (1968) and developed further by Laibson (1997, 1998, 2007). The quasi-hyperbolic discount factor is a discrete-value time function and maintains the declining property of generalized hyperbolic discounting. At the same time, the discrete quasi-hyperbolic formulation keeps the analytical simplicity of the time-consistent model by still incorporating certain qualitative aspects of exponential discounting. The actual values of the discount function under a discrete setup are with discount values $\{1, \beta \cdot \delta, \beta \cdot \delta^2, \ldots, \beta \cdot \delta^T\}$. To obtain a better understanding of how the form of the discount factor can affect economic analysis, and in particular the economic model of land development, consider a comparison of the following discount factors:

$$Exponential\ discount\ \ factor \equiv \delta^{-t} \tag{1-1}$$

$$Hyperbolic\ discount\ \ factor \equiv (1+\alpha t)^{-\gamma/\alpha} \tag{1-2}$$

$$Quasi-hyperbolic\ discount\ \ factor = \{1, \beta \cdot \delta, \beta \cdot \delta^2, \ldots, \beta \cdot \delta^T\} \tag{1-3}$$

The exponential discount factor is graphed in Figure 1-1 for two values of δ, 0.959 for exponential factor 1 and 0.951 for exponential factor 2. As can be discerned from graphical comparison, exponential discount factor 2, with a value of 0.951, discounts more heavily than exponential factor 1, with a value of 0.959. In discrete time, the exponential discount factor is described by the functional form $\delta(t) = (1+r)^{-t}$, where r is the rate of time preference, often taken to be the prevailing interest rate. Intuitively, exponential factor 2, having a lower value than exponential factor 1, must have a higher rate of time preference. A higher rate of time preference means a greater preference for consumption today than tomorrow. Hence, we can refer to δ as descriptor of individual impatience. The greater the value of δ, the more patient the individual.

The generalized hyperbolic discount factor is graphed in Figure 1-2 for different values of α and γ. Hyperbolic factor 1 has $\alpha = 500{,}000$ and $\gamma = 10900$ while hyperbolic factor 2 has $\alpha = 250{,}000$ and $\gamma = 10000$. Upon comparison of the two hyperbolic factors, it can be seen that hyperbolic factor 2 discounts the future more than hyperbolic factor 1. The initial jump in the value of hyperbolic factor 2 between the first and second time periods is notably greater than the jump in hyperbolic factor 1. The parameters α and γ have counter-balancing effects on the value of the hyperbolic discount factor. Smaller values of α result in a smaller jump between the initial periods while smaller values of γ result in a bigger jump. The parameter γ behaves much like the rate of time preference in the exponential discount factor, while α determines how much the hyperbolic factor departs from constant discounting.

Finally, the quasi-hyperbolic discount factor, graphed in Figure 1-3 is presented for two different value of β and δ. Quasi-hyperbolic factor 1 has $\beta = 0.91$ and $\delta = 0.971$, while quasi-hyperbolic factor 2 has $\beta = 0.85$ and $\delta = 0.964$. Similar to the cases above, quasi-hyperbolic factor 2 discounts more heavily than quasi-hyperbolic factor 1, which has higher values for both β and δ. The β parameter captures the essence of hyperbolic discounting and contains a first period immediacy effect in the individual's time preference. Changes in β determine how much the quasi-hyperbolic factor will deviate form exponential discounting. Higher values of β will result in a larger jump between the first two time periods. This jump in the value of the discount factor is what creates dynamic time inconsistent preferences. The δ parameter behaves similar to the exponential discount factor. When $\beta \geq \delta$, the quasi-hyperbolic factor becomes highly convex, discounting the near term much greater than more distant time period. Smaller values of δ will result in a more bowed-shaped discount factor implying a greater preference for immediate consumption. The quasi-hyperbolic discount function marries the qualitative properties of the exponential and generalized hyperbolic discount functions.

Comparison of the three discount factors is depicted in Figure 1-4. Each of the discount functions have been calibrated so they approximately cross at $t = 8$. As can be seen from the figure, the generalized hyperbolic discount factor is the most convex of the three, with the exponential as the least convex up until time period 8. The greater convexity or more bowed shape of the hyperbolic factor implies that the hyperbolic factor discounts more heavily than either the exponential or the quasi-hyperbolic up until time period 8. After that point, the exponential discount factor is the most bowed of three implying that the exponential factor discounts more heavily than either the hyperbolic or quasi-hyperbolic factors.

With the given calibration of parameters, dynamic time-inconsistent preferences are modeled with the near term discounted more heavily than the more distant term. Here, the near term is time periods up to period 8, with the distant term being time periods after 8. The figures illustrate the sensitivity of discounting to the selection of parameter values with the choice of near term and distant term being subjective in regards to the economic situation being examined. One can easily imagine how the discount factor can affect a wide range of economic decisions, particularly those that are intertemporal in nature. A very important and relevant economic decision is the choice to convert rural land to an urban use. This is the topic of the next section.

Application to Rural-Urban Development

This section discusses the role of time preferences and in particular the impact of time-inconsistent preferences as modeled by hyperbolic discounting in a model of land conversion. The act of rural-urban land conversion remains an important consideration since models of land development and the actual development decision are derivative of models of land values. From a logical standpoint, if one does not have an understanding of how intertemporal preferences affect land values, then one cannot begin to understand how time preferences affect the land development decision. This section attempts to support and promote such an understanding. Loss of agricultural land to developed uses has been a public policy issue for decades. For many years, economists have analyzed the structure of agricultural land prices and the timing of development in an effort to understand alternative uses to agriculture posed by land development. A specific aim of such research is to identify policies to prevent or discourage what may be considered suboptimal land-use changes.

Numerous studies have examined the hedonic characteristics of the land itself as factors in land conversion (Taylor and Brester 2005). However, many land development policies are directed at the developer or landowner, including tax structures aimed at either accelerating or decelerating the rate of land conversion. Despite policies directed at the individual, little account is taken of the individual traits of the decision-maker, particularly excluding any motivational or behavioral forces of the landowner in the decision to convert land from rural to urban use. One behavioral aspect of the landowner is the time preference involved in the intertemporal decision to develop land. Of special interest is relaxing the assumption of time consistent preferences in intertemporal decision-making to allow for dynamic inconsistency using non-constant discounting.

Motivation: The Importance of Discounting

The choice of the discount rate used in the model is a key variable in the determination of land values and development times. The rate of time preference, given by the discount rate, is one central component of intertemporal choice, and is an aspect overlooked in the land economics literature. Typically, the landowner is assumed to be time consistent with a constant discount rate formulated in an exponential discount factor. In theoretical models of optimal development times, the discount rate has been generally found to have negative effects on land values, for clear reasons, and tends to accelerate the development process (Ellson and Roberts 1983; Capozza and Helsley 1989). The rather "conclusive" effects of the discount rate in the land values literature may however stem from the arbitrary nature in the choice of the actual discount factor used. As far is known, all capitalization approaches to modeling land values and the optimal development time have used a single, constant discount rate in their discounted cash flow analyses, implying that farmers and landowners have time consistent preferences (Rose 1973; Markusen and Scheffman 1978, Capozza and Helsley 1989; Arnott 2005). As noted earlier however, recent evidence suggests that individuals are time inconsistent.

The random and potentially capricious nature of a constant discount rate in models of land development was recognized early by Shoup (1970). The potential error of a constant discount rate is compounded when uncertainty is brought into the analysis. The more distant the expected development time, the more uncertain landowners, developers, or investors are regarding the value of land. If uncertainty is the case, then the discount rate used in the present value formulation of undeveloped lands may be higher in time periods closer to the present (Shoup 1970). The actual discount rate would then fall as the conversion time approaches. A declining discount rate through time would imply that the value of land appreciates faster in time periods before development. This reasoning seems highly probable, given the uncertain nature of the land market and makes a particular case against a constant discount rate in favor of one that is a declining function of time.

The internal tussle described by Strotz (1956) was recognized by Mills (1981). Owners of undeveloped land "*exercise restraint in foregoing development opportunities with high immediate returns in favor of future options that are, in the final analysis, more remunerative*," (Mills 1981, p.246). The use of a quasi-hyperbolic discount factor accounts for the propensity of landowners to have both a short run preference for instantaneous gratification and a long run preference to act patiently. The restraint alluded to by Mills (1981) could involve the use of commitment devices by farmers or landowners to prevent future selves from reversing a decision by the present self to not convert land in future time periods. Examples might involve the farmer enrolling in a cooperative agreement or a resource conservation contract, such as the Conservation Reserve Program, which requires landowners to commit their land to some rural use for a contractual period of time (Albaek and Schultz 1998; Gulati and Vercammen 2006).

Modeling the traditional development model with time-inconsistent preferences has important policy implications. Consider the fact that expected net present discounted values for long term projects are infamously hypersensitive to the discount rate being used in the evaluation. Projects involving land development are hence acutely susceptible to this hypersensitivity. Not only does this affect land use policy, but the effects are important to policy makers who wish to maintain lands in either a developed or undeveloped capacity. Numerous studies have argued that the only effective deterrent to farmland conversion may be a policy of compensation to landowners for foregone development rent (Lopez, Adelaja, and Andrews 1988; Plantinga, Lubowski, and Stavins 2002). These rents and the compensation required could be greatly misrepresented under an exponential discount factor if preferences are time-inconsistent.

Relevance: The Time-Inconsistent Landowner

There are many reasons why a landowner might be characterized by time inconsistent preferences. First, landowners like any other consumer or investor might exhibit preference reversals. Consider the following example: a landowner may prefer to contract his land to a developer for \$1.01 million in 21 years, rather than for \$1 million in 20 years. But when the contract is brought forward in time, preferences exhibit a reversal, reflecting impatience. The same landowner prefers to contract his land to a developer at \$1 million today rather than sell for \$1.01 million next year. The primary assumption driving the reversal is the discount factor for a fixed time interval decreasing as the interval becomes more remote. A non-constant or decreasing rate means the discount rate in the short run is much higher than discount rates in the long run. Time inconsistent preferences imply the percent change in the discount factor depends on the time horizon, being steeper for the near future and flatter for the distant future.

Second, a variety of institutional and government policies, such as growth management policies, may create a degree of impatience upon the landowner. A number of empirical studies have examined the effects of various development pressures on the timing of agricultural land transition and also on land values (Bell and Irwin 2002; Irwin and Bockstael 2002; Carrion-Flores and Irwin 2004; Cho and Newman 2005; Livanis et al. 2006). The establishing of priority funding areas, for example, is seen to effect development times. Priority funding areas are growth areas that are designated by the county and receive financial support from the state for infrastructure development. The presence of growth areas could introduce a time inconsistency into a landowner's preference for conversion by creating a sense of impatience. Expectations of land reform may also affect the time consistency of preferences, which may include zoning, taxation, development rights, and clear definitions on the boundaries of urban growth.

Third, landowners' characteristics have been found to influence their land use decisions. Barnard and Butcher (1989) hypothesize that landowner age, education, years of land ownership, income net of taxes, and expected increases in value and development time will have an affect on time preferences, thus influencing the landowners perceived net present value of land and their decision to sell. The authors conclude that not only are landowner characteristics significant but that they are more explanatory than the characteristics of the land itself (i.e., parcel size, distance from CBD, soil quality, etc.) in determining parcel level land sales at the urban fringe. Factor analysis indicates that the expected time until development is the single most important factor for distinguishing between landowners selling versus holding the land with those expecting a shorter wait being more likely to sell. While this result is not evidence of inconsistent preferences, it does suggest that the psychology of the landowner is a critical characteristic in the timing of land development as an intertemporal decision.

Finally, since the land development decision is intertemporal in nature, knowledge regarding future returns to land in competing uses, as well as conversion costs, may be imperfect and uncertain. As time unfolds, landowners may rethink and revise the development decision. Acknowledging future revisions to the landowner's current decision could imply one of two things. First, the current decision might permit flexibility in the plan so that future revisions can be made. For example, the landowner may decide to sell rural land parcels only if an escape clause is written in the contract that allows the landowner to opt out with limited or no financial penalty. Second, the landowner may make the current decision to maintain land in rural use under a commitment device to avoid tempting offers that may present themselves at a future date, thus playing a strategic intertemporal game with himself. For example, the landowner might enroll in a conservation reserve program for a specified number of years, disallowing the conversion of land for a specified time period in exchange for some pecuniary payment. Since the landowner can continually update and revise the optimal plan, time inconsistent preferences offer an attractive method towards analyzing landowner behavior and the optimal development strategy across time.

Theoretical Heuristic: The Development Decision

This subsection aims to first provide a cursory perspective on how the use of a hyperbolic discount rate can affect the traditional model of land development. A simple net present value model is compared between the time consistent case and the time inconsistent case using the model outlined in Irwin and Bockstael (2002). This approach affords an intuitive understanding of the land development model and the effect of discounting regimes on conversion times. The time discounted path of the conversion value of land is the central question the model addresses.

Suppose the landowner is in an infinite-period decision model and owns a quantity of land, l, in some rural use at time t. The landowner receives a rent on rural land, $R(l,t)$, from a use such as agriculture, forestry, or open space. For simplicity, the time path of rural returns is assumed to be constant over time, rather than increasing. The decision facing the landowner is to either keep land in rural use or to sell to a developer for conversion to an urban use for a one-time return, $V(l,T)$, at time T, equal to the sales price. The time path of the gross development return, $V(l,T)$, is assumed to be rising over time due to, for example, rising population and increasing income per capita concurrent with a diminishing supply of unconverted land (Irwin and Bockstael 2002). The landowner may decide to keep land in a rural use for development in future periods, when the future urban return might be higher than the current urban return. There is a cost to the landowner of converting land at time T, $C(l,T)$, which could include administrative fees, permit expenses, institutional costs, or necessary infrastructure expenditures

(Irwin and Bockstael, 2002). The discount factor, δ, is taken to be equivalent to $1/(1+r)$ for the time consistent case. The actual discount rate or rate of time preference is r, usually assumed to be the prevailing interest rate in the real estate market.

Proceeding to solve for the optimal development time, the net returns to the landowner from converting land in time period T is given by:

$$V(l,T)-\sum_{i=0}^{\infty}\left\{\delta^{i}\cdot R(l,T+i)\right\}-C(l,T) \tag{1-4}$$

Equation (1-4) subtracts the costs of converting land, $C(l,T)$, and the present value of forgone returns from rural land use, $R(l,t)$, from the one time return to development, $V(l,T)$ at time T. On the other hand, if land is kept in rural use in period T and conversion is postponed to $T+1$, the net returns from delaying conversion discounted to time period T are given by:

$$R(l,T)+\delta\cdot V(l,T+1)-\sum_{i=1}^{\infty}\left\{\delta^{i}\cdot R(l,T+i)\right\}-\delta\cdot C(l,T+1) \tag{1-5}$$

The first term in Equation (1-5) is the return from rural land in period T. The second term is the value of returns from conversion in period $T+1$ discounted to period T. The last term is the costs of converting rural land in period $T+1$ discounted to period T. In words, Equation (1-5) represents the expected dividends from rural use in time T plus the discounted net capital gains from conversion less foregone rural returns and conversion costs.

Two conditions are required in order for the optimal conversion time to occur in period T. First, Equation (1-4) must be strictly greater than zero, meaning net returns from conversion in period T are positive. Second, Equation (1-4) must be weakly greater than Equation (1-5), meaning returns from converting rural land are greater in period T than in period $T+1$. In mathematical notation, these two conditions can be written as:

$$V(l,T) - \sum_{i=0}^{\infty}\left\{\delta^i \cdot R(T+i)\right\} - C(l,T) > 0 \tag{1-6}$$

$$V(l,T) - 2R(l,T) - C(l,T) \geq \delta \cdot \{V(l,T+1) - C(l,T+1)\} \tag{1-7}$$

The discount factor δ can be substituted with $1/(1+r)$ in Equation (1-7), where r is initially assumed to be the interest rate. The standard discounting case yields the result that the landowner will only convert rural land in period T when:

$$\frac{V(l,T+1) - C(l,T+1) - \{V(l,T) - 2R(l,T) - C(l,T)\}}{V(l,T) - 2R(l,T) - C(l,T)} < r \tag{1-8}$$

Equation (1-8) has the simple interpretation that conversion will occur when the rate of time preference, given by the interest rate, is greater than the percent change of development returns between the two periods. The discount rate, r, is assumed to be constant across time, implying the discount factor declines with the length of the time horizon involved, approaching zero asymptotically. If the assumption of constant discounting holds, the individual is said to exhibit a time-consistent discounting pattern. More generally, however, r must not necessarily remain constant across periods and, in fact, there is no well founded reason to assume so other than for computational ease.

Time inconsistency can be introduced into the model by with quasi-hyperbolic intertemporal preferences, implying a non-constant rate of discount given by the discrete discount function $\left\{1, \beta\cdot\delta, \beta\cdot\delta^2, \ldots, \beta\cdot\delta^\infty\right\}$. By substituting quasi-hyperbolic preferences into Equation (1-7) the inequality becomes:

$$V(l,T) - 2R(l,T) - C(l,T) \geq (\beta\cdot\delta)\cdot\left\{V(l,T+1) - C(l,T+1)\right\} \tag{1-9}$$

Simplifying gives:

$$\frac{\beta \cdot \{V(l,T+1) - C(l,T+1)\} - \{V(l,T) - 2R(l,T) - C(l,T)\}}{V(l,T) - 2R(l,T) - C(l,T)} < r \tag{1-10}$$

While there is a similarity between the time-consistent optimal conversion rule in Equation (1-8) and the time-inconsistent optimal conversion rule in Equation (1-10), note that the net returns received in period $T+1$ is discounted by the quasi-hyperbolic parameter β, reflecting an immediate impatience effect on the landowner. The standard discount factor, δ, and the implied rate of constant rate of discount, r, represent consistent time preferences. However, the presence of β gives a measure of how intense immediate rewards associated with conversion are valued to more distant rewards.

Clearly, the optimal time to conversion will depend on not only the values of the parameters in the discount factor, but also on the time horizon. The form of Equation (1-10) expresses the sensitivity a landowner may have to time delay, an effect not expressed in the standard exponential discounting case. The formulation also expresses quite simply how the landowner would be engaged in an intertemporal tussle as to the development decision. This tussle can be seen by the fact that the parameters β and r appear on different sides of the inequality, in effect revealing the counterbalancing force each parameter has on the discount formulation. The opposing individual trade-offs between present and future conversion are represented by the different values the discount parameters may have.

While the simple theoretical heuristic presented above is intuitive, more intricate theoretical methods are needed to solve the land development model with hyperbolic discounting in order to circumvent the time inconsistency problem, which violates traditional neoclassical assumptions and optimization theory. The mainstream approach to solving economic problems involving time inconsistent preferences uses dynamic game theory to find sets of sub-game perfect equilibrium. The decision-maker is viewed as a collection of sub-individuals, having different rates of time preference at distinct points in time, and so plays a series of multi-player intrapersonal games. The game theoretic approach has been prevalent in the economic literature being used by Peleg and Yaari (1973), Laibson (1996, 1997), Barro (1999), Gruber and Koszegi (2001), and Harris and Laibson (2001, 2004). More recently, Caplin and Leahy (2006) have proposed a recursive dynamic programming approach to obtain optimal strategies under time inconsistency in finite horizon problems. There approach could be generalized for the infinite horizon case to apply to the farmland values problem.

Study Objectives

With the insights, evidence, and questions discussed above, it is important to know whether the traditional model of land values and derivative models of rural-urban development can continue to be depended upon by economists. Despite the large body of research examining the net present value model of farmland values, few investigate the role of time preferences and none consider the presence of time-inconsistent preferences. The fundamental objective of the current study is to partially fill this void.

This dissertation has three central components. First, the notion of time-inconsistency and hyperbolic discounting is related to a critical issue in the agricultural economics literature, rural to urban land conversion and development. Models of land conversion that describe the timing and intensity of development are derivative of models of land values. Therefore, an understanding of the role that time preferences play in a model of land values has a direct impact on the understanding of land development models. The current chapter presented the intuition of why one might suspect the farmer or landowner to be characterized by quasi-hyperbolic discounting and discussed the relevance and motivation in the context of land conversion.

Second, the paper discusses and reviews the vast literature pertaining to the determination of land values and the development decision from an economic perspective. Chapter II presents an examination of the literature on land values and rural-urban land conversion to foster a greater understanding of traditional models of land values and development before time-inconsistencies are introduced. Such a review of the current state of knowledge is lacking in the literature. The theoretical models are described with an emphasis on the three most prevalent approaches to modeling the development decision: capitalization, option value, and transaction cost methodologies. The most common econometric techniques used are discussed followed by an assessment of the potential future research.

Third, the paper enters the ensuing debate regarding the reliability of net present models to adequately explain farmland values, which is the focus of the remaining chapters. Chapter III presents the fundamental theoretical model of this paper and develops a structural model of land values with quasi-hyperbolic discounting and describes the econometric procedure used in the analysis. Many studies have rejected the standard present value model under rational expectations as a viable model for explaining farmland values using both domestic and international data. Previous inquiries into the nature of land values assume a time-consistent discount factor. This dissertation introduces intertemporal inconsistency into a model of land values by including a quasi-hyperbolic discount parameter in the asset equation. Significant evidence is found in favor of quasi-hyperbolic discounting in U.S. agriculture. The Generalized Method of Moments estimator is used to obtain estimates of the parameters, overcoming problems of heteroskedasticity and serial correlation, and provides consistent and robust estimates.

The data used in the analysis and the estimation results are discussed in Chapter IV. Aggregate panel data are used for agricultural asset values from 1960-2002 for nine agricultural regions of the United States including the Appalachian states, Corn Belt states, Delta states, Great Plain states, Lake states, Mountain states, Northeast states, Pacific states, and the Southeast states. The results for each region are discussed distinctly and then comparisons are offered with other studies that have estimated structural models under quasi-hyperbolic discounting.

Finally, Chapter V will conclude the main content and key findings. Intuition on why an agricultural asset, such as land, may be characterized by time-inconsistency in general and quasi-hyperbolic discounting is discussed. Ideas for potential future research will be offered.

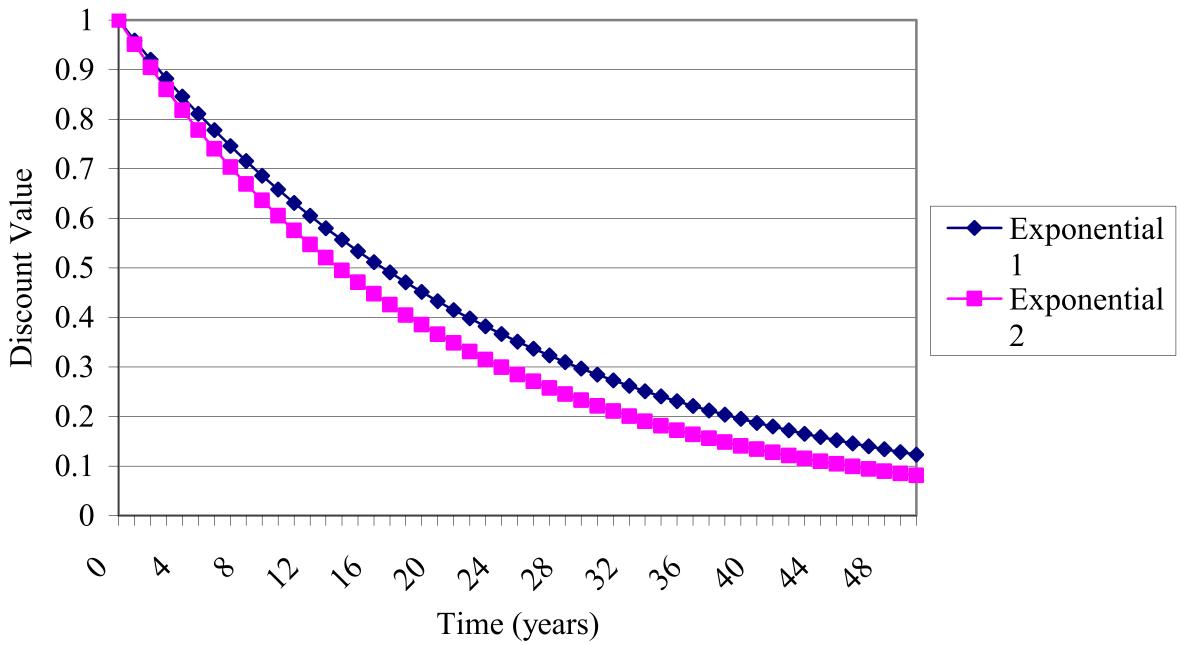

Figure 1-1. Exponential discounting

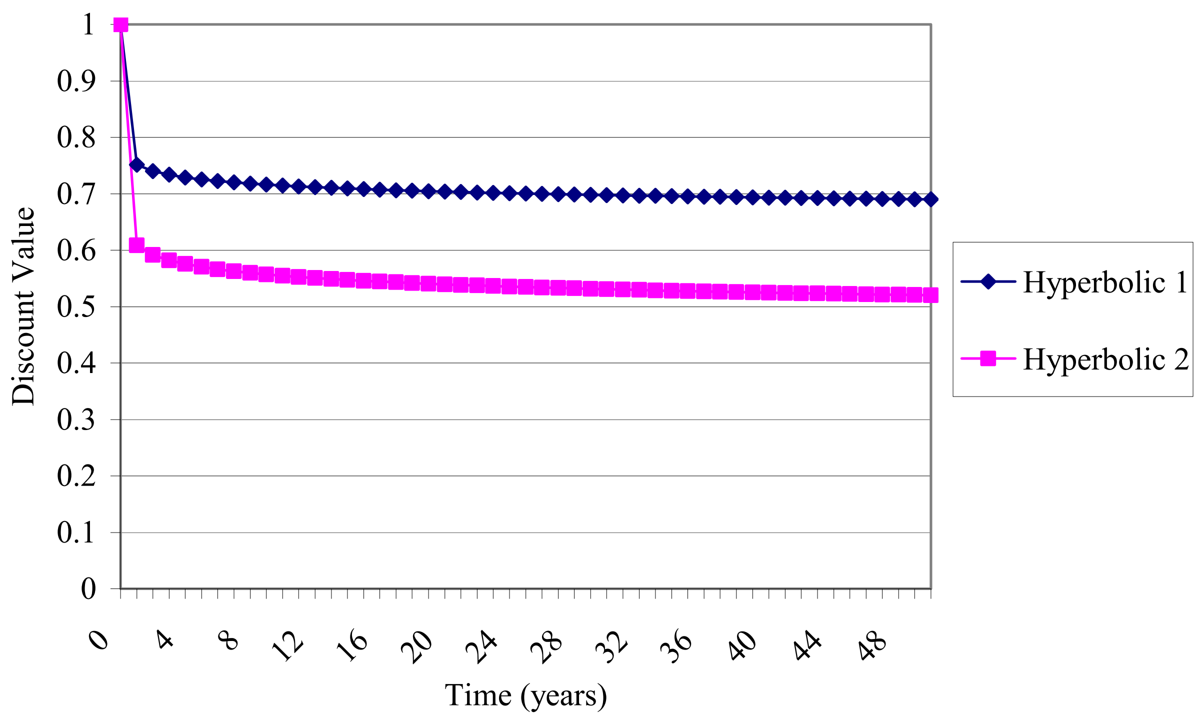

Figure 1-2. Hyperbolic discounting

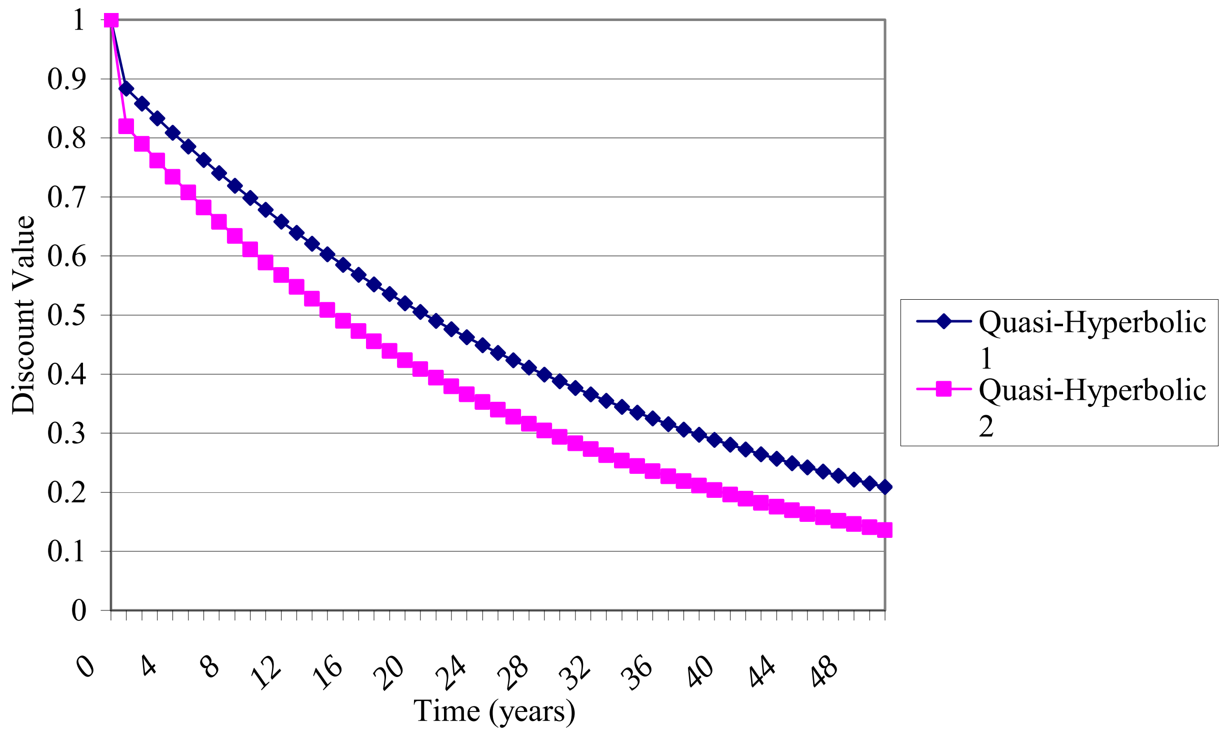

Figure 1-3. Quasi-hyperbolic discounting

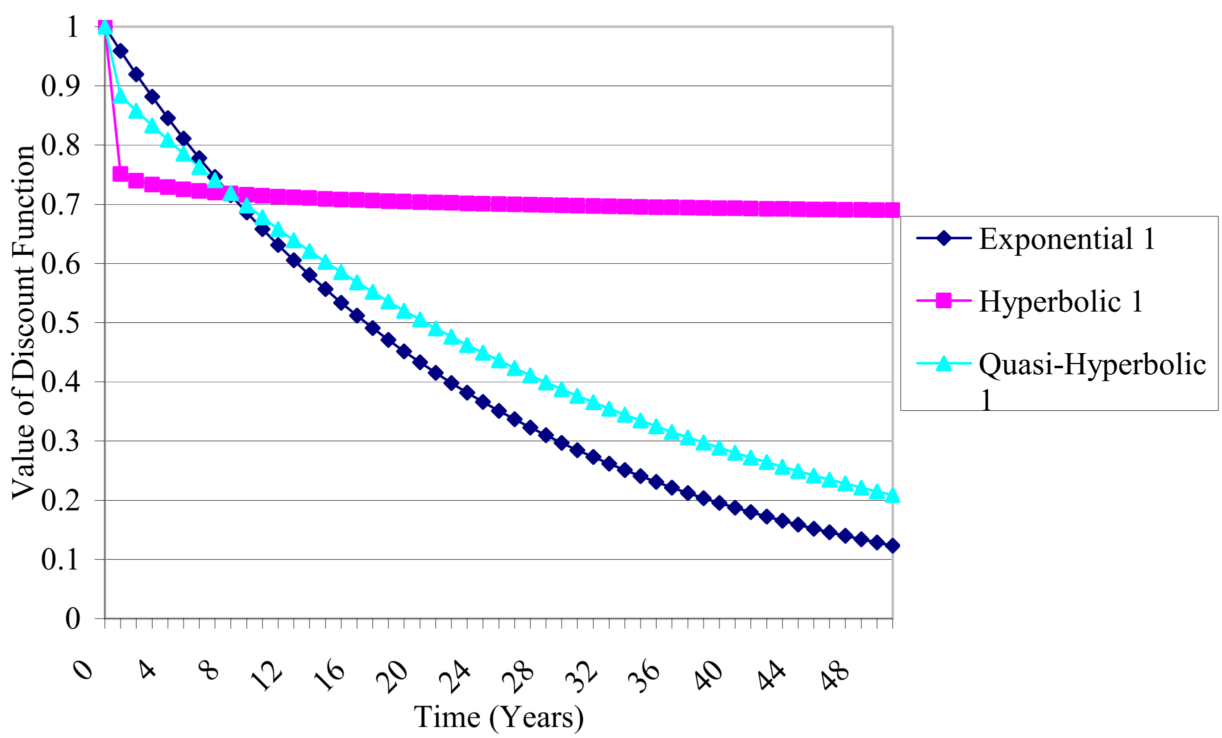

Figure 1-4. Comparison of discount factors

CHAPTER 2
LITERATURE REVIEW

Introduction

The economic question on the rate and timing of land conversion has been the subject of much analysis over the past forty years. Development of rural lands to urban uses, such as converting farmland to residential housing, has been a prominent issue in the economics literature. Once soaring and now falling residential land prices, rapidly growing urban areas, and the sprawling and discontinuous nature of land development around the urban fringe have all served to stimulate interest in the subject by academic researchers from various fields such as urban and regional economics, rural sociology, and urban planning. The timing of land development is also of key interest to many beyond the research arena such as local chambers of commerce, planning authorities, developers, and landowners—all of whom are stakeholders in any future project to convert land.

The critical question the decision-maker faces is: what is the optimal time to develop land? Not only does the decision-maker have a choice as to the form of land use, such as agricultural farming or residential housing, but also a choice as to when the land should be put to such use. Economic doctrine says that this decision is made so that the use of land and timing of conversion maximize the net wealth of the landowner. Since land use and land values are intertwined in the development decision, any model of land development must examine how land values and use affect the development decision. The approach in this chapter emphasizes the role of value and use in land development models.

The purposes of investigating land development models and obtaining optimal conversion rules are many. First, they provide a better understanding of land values in terms of prices, rents, and also capital appreciation (Clarke and Reed 1988). This is important since, unlike many other investments, land development tends to be irreversible. Furthermore, unlike many other resources and commodities, there is only a finite availability of land. Any decision to develop land, residential housing for example, depletes a fixed supply of land available for an alternative use. Second, governments often wish to create policies to encourage or discourage the conversion and development of land. Government policies take the form of property taxes, easement requirements, and conservation initiatives, just to name a few. Any government policy can have unintended consequences. For example, Titman (1985) shows that a policy restricting building height may actually result in a greater number of buildings constructed. Accurate and efficient policy instruments cannot be designed without an understanding of land development models and a thoughtful consideration of the timing of development decisions. Third, a better knowledge of the conversion process facilitates an improved understanding of seemingly random outcomes of conversion, such as discontinuous urban development patterns (also known as urban sprawl), heterogeneous spatial patterns in land use, and the creative destruction of capital structures.

Still in need of investigation is the appropriate timing of land conversion and the optimal intensity of development. When is it optimal to convert land from a lower intensity rural use to a higher intensity urban use? What is the optimal intensity of capital that should be applied to the land development project? How do government policies, such as property taxes and growth controls affect the optimal timing and intensity? What effects do changing discount rates and expected returns imply for land development? How does an uncertain world alter matters?

Many factors affect the optimal timing rule, such as the addition of a property tax or interim rent received from temporary use of the land. Further, both uncertainty and imperfections in the land market will affect the intertemporal conversion decision. For example, landowners tend to make decisions under imperfect information, especially when it comes to forecasting prices or interim rental rates. Many studies have also relaxed the assumption of certainty (Ellson and Roberts 1983; Clarke and Reed 1988; Capozza and Li 2002; Schatzski 2003) allowing land rents, conversion costs, or discount rates to be stochastic. Effects on rents, costs, discounting and other complications on the conversion decision are examined in more detail later.

Temporal variation in decisions regarding conversion by owners of neighboring land is of particular concern. When returns from development appear to be high, some landowners defer development while other owners in similar situations decide to develop their land. This variation creates scattered and discontinuous development patterns, especially along the rural-urban fringe, often referred to as urban sprawl. These questions are addressed in this review, presenting a survey of models and methods in the land conversion literature spanning the past 40 years.

The next section discusses the theory in land development models, addressing economics of land values and land use. The static and dynamic theory of land values and development are explained with an emphasis on how competing uses of land affect how and when land is developed. In the third section, the most pervasive approaches to modeling land values and development are discussed including the capitalization approach, the option values approach, and the transactions cost approach. The fourth section reviews the empirical approaches and methodologies to modeling the land development process. The final section concludes.

Theory

You do not have to be a farmer, or even an astute economist, to know that land is a productive input. Not only is land a factor of production for agriculture, but also for open-space and urban development. Landowner wealth has shifted over time as land prices, and in particular farmland prices, have fluctuated. As Schmitz (1995) notes, farmland values have been subject to boom/bust cycles, just as the stock market has, creating wide variations in the wealth of land-owners. Variations in wealth are also caused by competing uses for land, particularly from agricultural and urban uses. The rapid rate of urban growth has led to soaring rates of land values and landowner wealth causing land initially used for farming, open-space, or other rural uses to be bid out of such use and converted to more capital intensive urban uses (Moss and Schmitz, 2003). Agriculture has been fading away from the landscape because returns from farming are unable to compensate for skyrocketing land prices. This has been the case for land located along the rural-urban fringe, which is especially sensitive to increased urbanization.

This section presents a broad perspective on the economics of land values with a particular emphasis on land located along the rural-urban fringe. Land is discussed in terms of utilization, with rural use referring to agricultural, forestry, or open space use, while urban use referring to residential, industrial, or commercial use. An excellent and extensive examination can be found in Moss and Schmitz (2003) in regards to farmland. Indeed, there is no dearth of studies on land markets and the factors that affect land values. Rather than provide an interminable account on the plethora of economic models and empirical methods, a succinct discussion on the most relevant and informative issues will be presented. A basic theoretical treatment will be given first, followed by a comparative discussion of the most contemporary used models in the literature.

Land Values and Use

The key to understanding how land is valued means a proper understanding of the land market, and in particular the market for rural land. The following traits best characterize the rural land market: heterogeneity, localization, segmentation, high transaction costs, and imperfect information. First, land is not homogeneous; parcels of land differ in size, geographic location, landscape, quality, and other physical characteristics. In this sense, a parcel of land is very unique and cannot serve as a perfect substitute for another. Second, the land market is highly localized and permanent since the location of land itself is fixed—it cannot be moved or transported. In other words, land is a permanent asset. Further, the buyers and sellers of land tend to be limited to a geographic region, though distance buying of land has become more common. Also, land is durable and in some contexts can be considered indestructible. Once land has been allocated to a particular use, such as housing, it tends to remain in that use. As such, land development is often assumed to be irreversible.

Third, land has a finite and fixed supply since new land cannot be produced. In an extreme long-run view, total land supply is perfectly inelastic and thus is characterized by a vertical supply curve. However, particular uses of land may be described by a downward sloping supply curve. Also, countries, states, cities, and other geographic bodies can increase the supply of land by extending their borders. However, this means that some other geographic body must reduce their supply of land by an equivalent amount. Further, land can be used in varying levels of intensity thereby increasing the effective supply. Fourth, land use tends to be mutually exclusive. For example, the allocation of land to agriculture precludes land from being used in residential housing or industry. While there are some exceptions to this (e.g. high rise buildings combing commercial and residential space), generally a unit of land cannot be allocated to multiple uses.

Fifth, the land market is segmented since it is divided into many sub-markets or market segments depending upon geography, land use, ownership, and property rights. Within each market segment, a parcel of land may have a different price. On the demand side, users of land require very specific land types and locations. For example, a farmer cannot use a parcel of land downtown or a land zoned for commercial use anymore than a retail store has use for land hundreds of miles from a residential area. Sixth, the land market is also characterized by high transaction costs. A buyer and developer of land may face zoning restrictions, titling costs, and survey fees before development can be begin.

Seventh, land is both a consumption good and an investment good (Kivell, 1993). An individual may purchase land solely for the utility of owning, possibly for open space or recreational purposes. Likewise, an individual may purchase land for the intention of earning a return from uses such as farming or forestry, or may hold onto the land for later development with the expectation of a higher rate of return. Eighth, uncertainty and less than perfect information are inherent in land transactions. Future rents and returns from land use and development are not known with certainty and both future demand and supply must be forecasted. Risk perceptions and preferences vary widely between landowners. Last, land development tends to be characterized by long delays. For example, the time between the purchase of vacant land and completion of high intensity urban construction can extend years.

How land should be used, or the land allocation problem, has been the subject of much research. Land is used is postulated to be based on its value or the rent it accrues to the owner. David Ricardo first suggested that land would be allocated according to the soil quality. The more productive land would be allocated to farming and agriculture, while less quality land would be allocated to more urban uses. Differences in fertility or productivity determine how much rent the land generates. The most productive lands are used first with increases in demand forcing less fertile lands into use. This places an advantage on owners of more fertile land over owners of less fertile land, equivalent to the value of the difference in the productivity of land.

Location theories of land rent were developed by Johann von Thunen who believed that the distance of land from the core of a city, or the central business district (CBD), would be the primary incentive behind land allocation. The closer a unit of land is to the CBD the more valuable it becomes. The idea is best described as a bid-rent model, which assumes different uses of land have unique bid-rent curves. Each bid-rent curve is unique since the slope depends on each parcel's location from the center of the city. Proximal land units have lower transportation costs, resulting in a savings over more distant land units, resulting in a bid for locations.

Both Ricardo and von Thunen were speaking in terms of agricultural uses for land. However, notable contributions by Alonso (1964) and Muth (1969) have extended these notions to account for urban uses. The bid-rent theory of land uses and values can be described graphically in Figure 2-1. In a free market, the land between the city center and location A will go to urban uses and more distant land will go to rural uses. Thus, point A represents the socially optimal allocation between the two uses. The bid-rent model emphasizes the trade-off between land uses based on the high rents of land in the central region and the costs of transportation incurred by more distant locations.

The equilibrium described in Figure 2-1 is the result of demand and supply forces in the land market at work. In a perfectly competitive market, the supply of land is given by the quantity of prospective individual parcels that compete against one another for potential users or tenants. On the demand side, potential users compete against each other for use of each parcel. In equilibrium, the optimal allocation maximizes the total value of all land with each parcel being used at its highest and best use. In other words, each parcel is used in a manner that is most productive for that given geographic location. However, the value of land is based not only on returns from the land itself, but also on products, such as crops or urban dwellings, produced using land as an input. For example, higher prices for residential housing or agricultural crops will drive up the price for land. Since land offers both production and consumption of goods (e.g., forestry products) and services (e.g. recreation) the demand for land is a derived demand.[1] A common theoretical approach to modeling land valuation is based on the residual value of land, defining the market value by the net land residual income or rents. The difference between the value of what is produced on the land and the production costs yields the net land value, if the development of a hypothetical project is the highest and best use for a given parcel.

A Simple Static Model

The nature of the development decision can be illustrated using a simple static maximization problem where a landowner must decide between two alternative uses of land. Suppose the landowner has a fixed amount of land, L, and two competing uses. Further suppose that land is currently in agricultural use yielding a return of a per unit of land and using l_a land units. Alternatively, the landowner can convert his land to residential housing, yielding a per unit return of h, which uses l_h units of land. Similar in spirit to the analysis in Bell, Boyle, and Rubin (2006), linear returns are assumed implying returns to a particular land use do not depend on the amount of land being used. The assumption of linearity allows net returns to agriculture to be defined as $A = a \cdot l_a$ and net returns to residential housing to be defined as $H = h \cdot l_h$. The maximization problem is:

$$\begin{aligned} &\text{Max}_{l_a, l_h}\ V = A + H \\ &\textit{subject to} \quad (l_a + l_h = L)\ \&\ (0 \le l_a, l_h \le L) \end{aligned} \tag{2-1}$$

The solution to the maximization problem given by Equation (2-1) is a corner solution, implying land should be wholly dedicated to the use yielding the highest net return. If agriculture is more

[1] Derived demand is when one good or service occurs as a result of demand for another. For example, the demand for housing leads to derived demand for land since land must be developed for housing to be consumed.

profitable than housing, meaning $a > h$, then all land should remain in agriculture, $l_a = L$, and none in housing, $l_h = 0$. Likewise, if farming yields a lower return, then the land should be converted into residential housing.

Diminishing returns, rather than linear returns to land use, may be a more realistic assumption, especially in farming where the returns per a unit of land depend on how many parcels currently in use. One can also easily see diminishing marginal returns to many urban projects. The classical example, given by Alfred Marshall and reiterated by Shoup (1970), involves the construction of a skyscraper. As the height of the building increases, certain production and structural elements of the building become necessary, such as additional equipment like specialized cranes and elevators. Additional production and structural items cause the price per square foot of rental space to increase relative to future returns. Assuming declining marginal returns implies declining net returns with the number of units in use. Mathematically, diminishing returns to agriculture is given by $\partial A / \partial l_a > 0$, $\partial^2 A / \partial l_a^2 < 0$, and diminishing returns to housing is given by $\partial H / \partial l_h > 0$, $\partial^2 H / \partial l_h^2 < 0$. The conversion decision now becomes one of allocating the land between the two uses until the marginal returns are equal, or when:

$$\partial A / \partial l_a = \partial H / \partial l_h \tag{2-2}$$

Graphically, the solution represented by Equation (2-2) is depicted in Figure 2-2 and emphasizes the point of land being shifted to the use providing the highest marginal value product.

The static models of both linear and diminishing returns are overly simplistic. The conversion decision in reality involves a number of factors, discussed in more detail in the next section. One factor affecting conversion is the intertemporal nature of the development decision.

While the static model describes how will be land be developed, the model does not address when land will be developed. Other factors complicate the decision, for example property taxes can be introduced into the problem affecting the timing of the conversion decision. The issue of land taxation and land conversion has been addressed by many (Skouras 1978; Bentick 1979; Arnott and Lewis 1979; Anderson 1986). Costs also affect the conversion decision since conversion requires an investment in capital development. Most importantly, the environment surrounding the conversion decision is in reality an uncertain environment. The returns from land are seldom known with certainty, which can have a large impact on development decisions. The issue of uncertainty has been at the very crux of recent research (Capozza and Helsley 1990; Capozza and Li 1994). Models of land conversion under uncertainty inevitably draw upon the investment under uncertainty literature and, in particular, option pricing theory. Models of land conversion can only be examined in a serious way in an intertemporal dynamic context.

A Simple Dynamic Model

Dynamic theories of land development acknowledge the effect future economic expectations have on current land values and how land is allocated for certain uses. This inevitably results in a more focused discussion on the timing of land use change. In a dynamic model, the value of land for a particular use is represented by the discounted present value of expected returns from that use. The simple static model can be extended to account for the intertemporal nature of land allocation and conversion.

Let $A(t)$ be the net return from a given unit of land in period t for land in pre-converted or agricultural use. The term $A(t)$ can equal zero if the land is vacant. The net return per unit of land in period t for land in post-conversion or residential housing use is $H(t,T)$, which depends on the time of conversion given by T. Conversion time is chosen to maximize the value of land, given by $V(T)$:

$$\text{Max} \quad V(T) = \int_0^T A(t)e^{-it}dt + \int_T^\infty H(t,T)e^{-it}dt \tag{2-3}$$

The landowner's discount rate is given by i, often taken to be the prevailing interest rate in the real estate market. The first term on the right hand side of Equation (2-3) is the present discounted value (PDV) of agricultural returns from the start time to the conversion time. The second term on the right hand side of Equation (2-3) is the PDV of housing returns from the time of conversion onward. The level of post-conversion returns depends on both the time when housing returns occur, but also on when the conversion itself occurs. The first order condition with respect to the conversion time is given by:

$$A(t) - H(t,T) + \int_0^\infty \frac{\partial H(t,T)}{\partial T} e^{-i(t-T)}dt = 0 \tag{2-4}$$

The third term on the left hand side of Equation (2-4) is equivalent to the PDV of expected future changes in housing net returns. If the time of conversion is irrelevant to the returns from housing development, then the third term on the left hand side vanishes and the conversion rule is equivalent to the static case. In other words, the optimal conversion time T^* occurs when the net return to agricultural use is equal to the net return from housing use, mathematically represented by $A(t) = H(t,T^*)$.

There are reasons why the third term on the left hand side of Equation (2-4) is non-zero, as explained by Bell, Boyle, and Rubin (2006). For example, costs may increase over time, delaying conversion until a later time, given by T^{**}. The optimal rule with conversion costs is to convert when $A(t) = H(t,T^{**}) - i \cdot H(T^{**})$. The accounting for cost results in a downward shift of the housing net return function, illustrated in Figure 2-3. The case where an increase in housing returns, perhaps due to population growth, results in an upward shift, hastening conversion.

The flow of returns can also be viewed in conjunction with the capitalized value of land in competing uses. In a dynamic model, the value of rural or unconverted land is determined by the expectation of future returns. Figure 2-4 describes Equation (2-4), representing the maximum value of $V(T)$ which occurs when R_A equals R_H. The line R_A represents the returns from land in agricultural use assumed to be constant.[2] The return from housing or post-conversion use is given by R_H. Assuming that conversion takes place at time T, V_A represents the capital value of land in current use (agriculture) and V_H represents post-conversion use (housing) value. The curve V_t is the sum of values before and expected values after conversion. Although the development value of housing is greater than the value of agriculture after time t, conversion occurs until the income returns from housing exceed that of farming at time T. Conversion occurs before time T because R_H is expected to exceed R_A prior to time T, implying that V_H exceeds V_A. The expectation of returns explains why rural lands along the urban fringe have a greater potential value to urban uses over farmland uses (Neutze 1987). At time zero, the present value of returns from agriculture is given by the vertical distance $0V_A$ in Figure 2-4. This value declines over time as the optimal date of conversion approaches. As Goodchild and Munton (1985) and Neutze (1987) explain, conversion can be delayed but at an opportunity cost of the forfeited post-conversion housing rent, R_H.

[2] This implies that agricultural products are sold in large markets and is both a reasonable and simplifying assumption. Similar graphical analysis can be found in Goodchild and Munton (1985) and Neutze (1987).

The dynamic analysis underscores two key points. First, the optimal time to convert land is based on the premise that a decision to convert now is balanced against a possible decision to convert in the future at a higher return. Second, allocations of land to particular uses and land values depend on both the present economic conditions as well as future expectations. Dynamic models of the land development decision are the mainstream method to explain the forces that compel a landowner to convert land. The dynamic model so far assumes a simple setting without any taxes, land use laws, or growth controls. Further, the model does not explain the capital intensity of development nor does the model address conversion costs. Perhaps most paramount to the development decision is the discount rate and the presence of uncertainty, since both have profound affects on the timing of conversion and intensity of development. More complicated dynamic models are examined later as well as the primary models of the development decision in the current literature: the capitalization approach, the option value approach, and the transaction cost approach.

Modeling the Land Development Decision

The theoretical foundation for the land development and conversion literature did not receive rigorous economic analysis until the late 1970s and early 1980s. Most currently used models, largely based on the seminal papers by Shoup (1970) and Arnott and Lewis (1979), describe the optimal timing problem in a Wicksellian framework on the optimal timing of wine maturation.[3] Wicksellian-based partial equilibrium models utilize discounted cash flows to describe land values and the timing of conversion and focus primarily the effects land taxes have on land values and on the development process.[4] The development decision is also influenced

[3] Wicksell, K. (1934). *Lectures on Political Economy, Volume I: General Theory* (translated by E. Chassen). New York, NY: The MacMillen Company, pages 178-183.

[4] The partial equilibrium models also include Rose (1973), Skouras (1978), Douglas (1980), Mills (1981b), Anderson (1986), Bentick and Pogue (1988), Anderson (1993), and Arnott (2005).

by conversion costs, the discount or interest rate, land rents from rural and urban uses, and assessed property value taxes and capital gains taxes.

More recent theoretical models focus on a general equilibrium approach (Markusen and Scheffman 1978; Ellson and Roberts 1983; Capozza and Helsley 1989; Kanemoto 1985; McMillen 1990), questioning the conclusions drawn from a *ceteris paribus* partial equilibrium framework. For instance, the simplifying assumption of a Marshallian land demand curve in Shoup (1970) implies monotonically growing demand over time. Therefore, the land value function $V(T)$ is strictly concave by assumption, presupposing results not guaranteed in a general equilibrium model. For example, the presence of a property tax will reduce the length of time an individual will hold land, thereby hastening land conversion (Markusen and Scheffman 1978).

A general equilibrium model has additional advantages over a partial equilibrium model, allowing the effects of uncertainty to enter into the land development decision. Ellson and Roberts (1983) introduce uncertainty in the context of a government's land zoning decision and find slower rates of conversion compared to the certainty case. As a disadvantage, the added complexity of a general equilibrium model leaves many comparative static results untenable, or in the very least ambiguous, reducing the model's predictive power. A brief summary of the main theoretical results from both partial and general equilibrium capitalization models is provided in Table 2-1. While some results appear heterogeneous, disagreement on the effects of particular exogenous variables, such as taxation, is noticeable. Inevitably, introducing uncertainty to the land development process involves a foray into the investment literature. Once uncertainty is accounted for in the land conversion process, the value of land and the decision to develop becomes an option value. The option value approach has gained recent attention in the literature and shows the most promise for modeling the land development process. Transactions costs can have effects on the development decision and land values as well. Such approaches account for the pecuniary and non-pecuniary costs associated with conversion. Non-pecuniary costs include legal fees for petitioning public officials to rezone the land, promises to dedicate portions of developable land for public use, open-space, or conservation programs, or costs associated with lobbying efforts and campaign contributions.

The Capitalization Approach

The capitalization approach forms the bulk of the literature on the land development decision and assumes land values are solely determined on the basis of expected future income. The simple static and dynamic land allocation theory outlined in the previous section does not make a clear distinction between the price and rent of the land. Evans (1983) distinguishes the price of land and the rent received by land. Land price is what is paid for the ownership of land, while land rent is paid by the tenant or occupier for the prevailing usage of the land (Evans 1983). The relationship between the two concepts of price and rent is fundamentally based on individual expectations. The price paid for land will be a function of the discounted rents expected to be received in the future between land uses. Put simply, the value of land is a capitalized value of future rents.

The capitalization model is equivalent to the dynamic model discussed earlier where current and expected future returns are discounted according to some discount factor, usually the interest rate. The analysis is made simpler by the use of summation signs instead of integral signs. The most general model of the capitalization approach is given by:

$$V_t = \sum_{i=0}^{\infty} \left\{ \delta^i \cdot E_t \left[R_{t+i} \right] \right\} \tag{2-5}$$

The value or price of land at time t is V_t, the discount factor is δ^i, and $E_t\left[R_{t+i}\right]$ is the expectation at time t for returns (or rents) from land in rural use at time $t+i$. To obtain the optimal conversion decision, the model is extended to account for a competing use, such as recreation or urban development. Assuming conversion is irreversible and extending Equation (2-5) to account for competing using, the model becomes:

$$V_t^C = \underset{n}{Max}\left\{\sum_{i=0}^{T}\left(\delta^i \cdot E_t\left[R_{t+i}\right]\right) + \sum_{j=T+1}^{\infty}\left(\delta^i \cdot E_t\left[U_{t+j}\right]\right)\right\} \tag{2-6}$$

The value of land considering conversion potential is V_t^C, T is the time land is converted to urban use, and $E_t\left[U_{t+j}\right]$ is the expectation at t for the rental rate from converted urban land at $t+j$. By comparing Equation (2-5) to Equation (2-6), the value of land with conversion potential V_t^C exceeds the value dedicated to rural use V_t. The key assumptions implicit in Equation (2-6) include costless conversion, a constant discount rate, risk neutrality, perfect information, and no uncertainty. The formulation for conversion potential given by V_t^C in Equation (2-6) is an over-simplifying case that defines a point of reference for studying further models with varying levels complexity.

The time path of land conversion for land on the urban fringe is often described graphically as an S-shaped curve, depicted by curve VV in Figure 2-5. The rate of increase in the value of land, or its conversion value, is declining, as depicted in Figure 2-5. A declining rate of increase in the conversion value implies the base value of land is always greater than the additional value that accrues to the land through time, a necessary condition for conversion to occur. Otherwise, the landowner or decision-maker would delay conversion indefinitely. The slope of the PP curve in Figure 2-5 is the discount rate. The PP curve slope can also be modified to account for property taxes, interim rents, and other effects. At the optimal time to develop, the VV curve is tangent to the PP curve. Before the optimal time is reached, there exists an incentive to hold land and delay conversion, possibly for a more capital-intensive and profitable development or due to profits from interim rents (Fredland 1975).

Delineating from simplifying assumptions implies, however, that not all land may be converted at the optimal time. The presence of imperfect markets or knowledge, transactions costs, uncertainty, barriers to entry, and varying rates of time preference described in the discount rate will cause a degree of heterogeneity and dispersion in the actual conversion times. Further, the lumpy nature of the VV curve, represented by various rapid and slow increases, reflects a variety of factors affecting the demand for land and, more specifically, for land development (Shoup 1970). For example, the rezoning of land or the construction of nearby highway systems or utility services may suddenly make the land more palatable for conversion. More private amenities, such as local shops or golf ranges, could have the same effect. Conversely, the conversion value may rise more slowly or even decline due to negative developments such as prisons, reclamation facilities, or low-income housing. The key insight is that the probability of conversion increases with rises in land value, population, and income.

Dynamic models of land value serve as the basis for most of the theoretical and empirical work on land conversion and development, and vary in complexity. Shoup (1970) explains that growing numbers of inhabitants and rising incomes will escalate the demand for vacant land in a way that increasingly more intensive use of land will be needed. For example, population and wealth may increase requiring a capital-intensive development project, such as high-rise construction, to satisfy future demands. Shoup (1970) also explains the effect of irreversibility on most land developments. Converting land from lower uses, like agriculture or open space, to higher uses, like residential housing, requires lasting changes. For example, zoning regulation, land subdivision, building construction, and changes in the geographic landscape can usually not be undone. The irreversibility of land development makes converting back to a lower use costly, if not impossible. Once conversion has occurred, land and capital are committed to the higher use (Shoup 1970).

These facets of land demand and conversion imply that the form of land development, especially in terms of density and intensity, are intertemporal in nature. As time progresses, and the decision-maker waits to convert land to some later time, an intertemporal trade-off occurs between low capital-intensive conversion and low land payments versus high capital-intensive conversion and high land payments (Shoup 1970). In other words, the decision-maker will be in an internal tussle to either delay or hasten conversion. The observation of a trade-off makes keenly apparent the importance of certain behavioral aspects of the decision-maker. In the context of land development, the decision-maker can take on a number of roles: the developer, the investor, or the landowner. The intention of the decision-maker is to conserve the land, holding onto it to ensure it is not converted too hastily to some lower use when a future date may call for more capital intensive development due to demand increases (Shoup 1970). Thus, expectations regarding future demand for more intensive uses of the land will play an important part in determining the optimal time of development.

The discount rate

Perhaps no other facet of the land development decision than the choice of the discount rate used in the model is so vital to the determination of accurate land values and the optimal conversion time (Gunterman 1994). In Shoup (1970), the problem of the decision-maker is to maximize the present discounted value of land. The simplest analysis begins by assuming no conversion costs and that land is vacant. The vacancy assumption implies that the land is not being used for any temporary revenue generating activity before conversion. The present value of land can be described as:

$$P(t,T) = V(T)e^{-r(T-t)} \tag{2-7}$$

The present value of land at time t for a future conversion time T is $P(t,T)$. The vacant land's conversion value at a future date T is $V(T)$, if the land is converted to its optimal use at date T. The discount rate is r, which assumes the role of opportunity costs to the owner of vacant land. Although not explicitly defined in the analysis by Shoup (1970), the discount rate is often taken to be equal to the interest rate in the real estate market.

The decision-maker then wishes to maximize the land's present value in regards to the conversion time:

$$\frac{\partial P(t,T)}{\partial T} = \frac{\partial}{\partial T}[V(T)e^{-r(T-t)}] = 0 \tag{2-8}$$

Solving Equation (2-8) yields the first order condition that the optimal conversion time occurs when the following is satisfied:

$$\frac{\dot{V}(T)}{V(T)} = r \tag{2-9}$$

The left hand side of Equation (2-9) is the rate of change in the conversion value. The solution states land is converted when the rate of increase in the conversion value of land equals the interest forgone on other possible investments, given by the discount rate. The discount rate has been generally found to have negative effects on land values (for clear reasons) and tends to accelerate the land conversion process (Ellson and Roberts 1983; Capozza and Helsley 1989). Arnott and Lewis (1979) found an indeterminate effect of the discount rate, assumed to be the interest rate. The ambiguous nature of the discount rate in the Arnott and Lewis (1979) analysis stems from the simultaneous relationship between the output elasticity of capital, the interest rate, and the expected rate of growth of rental rates.

Still, critical questions regarding the impact of the discount rate have not been seriously examined. Will the optimal timing of conversion be different under a non-constant discount rate? What are the property tax and other welfare implications? These remain important questions yet to be addressed by the literature.

Land rents and conversion costs

Often times land development along the rural-urban fringe occurs not on vacant land, but on land that is currently engaged in some interim use, such as from agriculture or forestry. This case is more realistic than the case of vacant land since undeveloped land is often held by farmers or investors who temporarily use the land until the optimal conversion time. Now the value of the land is increased by rents received from the temporary improvement. In terms of the model described by Shoup (1970), the optimal time for conversion with interim rent is given by:

$$\frac{\dot{V}(T)}{V(T)} = r - \frac{F(T,T) + e^{rt}\int_0^T e^{-rt}\,\partial F(i,T)/\partial t\,di}{V(T)} \tag{2-10}$$

The second term on the right hand side of Equation (2-10) is the rent received from the interim use, $F(i,T)$, over the whole time period. The effect of a positive interim use is to delay the conversion time since the capitalized present value of the land is higher when current rents are received. This model can be extended to include the future rents from an urban development at time T. Interim rental rate are received until the terminal time. Due to the irreversible nature of most development projects, conversion is assumed to be permanent so that at the conversion time no more rent can be generated from the rural use. Rents received either before or after conversion will increase land values. Generally, increases in the pre-conversion rent will slow the development process, while higher post-conversion rents will speed up the conversion time.

There are some notable exceptions, for example in Markusen and Scheffman (1978) post-conversion rents do not affect the development decision since their model only has two-periods. In Ellson and Roberts (1983), Capozza and Helsley (1989), and Anderson (1986, 1993), increases in the urban use rental rate have an ambiguous effect on the conversion time. In Anderson (1986, 1993), the indeterminacy arises from the model accounting for both pre-conversion and post-conversion tax rates. The tax rate parameters enter into the discount rate, requiring the magnitudes of the parameters be known in order to sign the post-conversion rental rate effect. Additionally, Anderson (1986, 1993) assumes that the partial derivative of the urban rental function with respect to the conversion is zero, implying that income received from a developed property is independent of the time of development. The assumption of independence of developed rental income from development time is not realistic. Both Ellson and Roberts (1983), and Capozza and Helsley (1989) utilize a general equilibrium approach to the land development decision, which requires simulation in order to determine the direction of partial derivatives.

The effects of conversion costs are also quite similar across studies. With higher costs of capital, the price of land will increase to offset the higher conversion expenditure. However, many studies do not explicitly account for conversion costs, usually assuming that capital expenditures are implicitly accounted for in the rental function for urban developments (Shoup 1970; Anderson 1986). Ellson and Roberts (1983) find that conversion costs in the presence of uncertainty will increase the time land is rezoned for development and an urban infrastructure is put place, but reduces the duration between rezoning time and the point developed land is actually consumed or converted. Another exception is Arnott and Lewis (1979) who take the vacant land conversion model from Shoup (1970) and develop it more rigorously by adding construction costs and residential density (i.e., capital intensity) to the problem. The key assumptions the authors make are: zero interim rents from temporary land use, zero fluctuations in capital costs and rental rates, zero property taxes, and zero building depreciation costs. Like Shoup (1970), Arnott and Lewis (1979) assume once conversion occurs the land remains in the developed use permanently and that perfect foresight exits. Unlike Shoup (1970), however, Arnott and Lewis (1979) treat rents and conversion costs in terms of capital, distinctly.

The conversion that Arnott and Lewis (1979) consider is a more specific one of vacant land being converted to residential housing. The objective of the landowner in their model is to maximize the difference between the present value of housing rents and the present value of conversion expenditures with respect to the time of conversion and the amount of capital needed:

$$\max_{T,K} L(T,K) = \int_{T}^{\infty} r(t)Q(K)e^{-it}dt - pKe^{-it} \tag{2-11}$$

The present value of each land unit developed at time T with stock of capital K is given by $L(T,K)$. The output of residential housing on each land unit with capital K is given by $Q(K)$. The rental rate on a housing unit at time t is given by $r(t)$. The discount rate, equivalent to the interest rate, is given by i, and the price per a capital unit is given by p.[5] Optimal conversion time is delayed when the capital price p increases but is hastened when the current housing

[5] Arnott and Lewis (1979) assume rental rates on housing units do not fluctuate, but rather are constant through time, and define η as the housing rental rates expected rate of change. Solving the above partial equilibrium model, the authors conclude that land is developed optimally when:

$$\frac{V(T)}{P(T)} = \frac{\eta}{i}$$

That is, land is converted from a lower use to a higher use when the ratio of the value of land at time T, given by $V(T)$ if land is optimally developed, to the value of the property (including the land and buildings) equals the ratio of the growth rate of housing rental rates to the discount rate.

rental rate $r(t)$ at time $t = 0$ increases (Arnott and Lewis 1979). The density of housing construction is not affected by higher capital outlays, as developers delay construction to compensate for the extra costs. The expected growth rate on the housing rental rate has an ambiguous effect on timing, but increases the density of development.

Many of these results change when uncertainty is brought into the analysis. Clarke and Reed (1988) investigate the development decision under uncertainty and find that conversion is hastened when construction costs are expected to increase, however the conversion time is indeterminate when either rental rates or the discount rate is expected to increase. When increased rental growth is expected or a decrease in growth of costs or discounting is expected land values, housing density, and the ratio of the value of undeveloped land to the value of developed land all increase (Clarke and Reed 1988).

Simulations based on parameter estimates from Arnott and Lewis (1979) reveal that for the most part their model offers a reasonable description of the land development process. However, both simulations on structural density and the discount rate based on results from Arnott and Lewis (1979) reveal that a much higher discount rate (i.e., 4.1%) would be needed to replicate results under higher levels of uncertainty. Models that account for uncertainty are not adequately examined in a capitalization context and require more sophisticated analysis, however. More complicated models involve the use of real options theory and the investment under uncertainty literature—these topics will be addressed later.

Land taxes

One of the most investigated and controversial issues have been on the effects of a property tax and a capital gains tax. The property tax is often referred to as an *ad valorem* or land value tax (LVT) and is assessed based on the value of the property site, ignoring any improvements to land such as buildings and personal property.[6] The capital gains tax, or development value tax (DVT) is levied based upon the actual developments and improvements made to the land. A significant debate ensued in the literature regarding whether or not a tax on land is neutral, meaning a land tax does not alter the allocation of land to different uses. This is the view originally taken by David Ricardo. However, Henry George purported that a land tax would remove land from speculators, transitioning land from future uses to current uses, hastening the conversion process (Bentick and Pogue 1988). This section reviews the tax effects in the theoretical land development decision models and how the effect is sensitive to the specific nature of each model.

Shoup's (1970) analysis indicates that value of land is lower in the presence of a property tax but that the rate of increase in the conversion value is higher. The effect of an *ad valorem* property tax would simply imply a conversion rule of the form:

$$\frac{\dot{V}(T)}{V(T)} = \delta + \tau \tag{2-12}$$

The left hand side of Equation (2-12) is the rate of change in the conversion value. On the right hand side, the tax is represented by τ , and the discount rate is given by δ . According to Equation (2-12), land is developed when the rate of increase in the conversion value of land equals the interest forgone on other possible investments given by the discount rate.[7] In this simple case, an increase in either the discount rate or tax rate would hasten conversion, while earning a positive rate of return from an interim use would delay conversion.

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[6] The nineteenth century economist Henry George was amongst an influential proponent for this type land tax.

[7] This assumes costless conversion and no interim rents received from the land in the Shoup model. If land is not vacant, as assumed above, but rather receives interim rent from some revenue generating activity, like farming or forestry, then the rate of return earned in the interim is subtracted from the rate of increase in the conversion value. Hence, an interim use of the land will delay the optimal date of conversion.

One of the earliest examinations of a DVT is attributed to Rose (1973), who uses a partial equilibrium Wicksellian-type model to distinguish between two types of capital gains taxes. The first DVT is levied at the time the land is rezoned from rural to urban use. The second DVT is levied when the land is actually converted. Rose (1973) finds that a levy at the development time yields an indeterminate derivative of development time with respect to the tax, depending upon the magnitude of the price and tax parameters and the functional form of the rural and urban rent functions. A DVT imposed at the rezoning time is found not to have any effect on the conversion decision, thus supporting Ricardo's view of a land tax as being neutral.

Countering the result in Rose (1973), Skouras (1978) models the development time as an implicit function of the capital gains tax and finds the imposition of a DVT to accelerate the conversion time, owing to the fact that the present value of land falls as a result of the tax. Bentick (1979) supports the result in Skouras (1978) and demonstrates how a tax on the capitalized value of land from urban conversion can change the preferences of the landowner in a manner that may alter decisions to convert land. Hence, a tax on land values (i.e., a property tax) is non-neutral in the sense that the tax distorts the allocation of land as pointed out by Mills (1981b) and more recently by Arnott (2005), supporting George's view of a land tax being non-neutral.

Markusen and Scheffman (1978) and Arnott and Lewis (1979) find contrasting results from the authors above. Using a two-period general equilibrium model of land conversion, Markusen and Sheffman (1978) find that an *ad valorem* tax, or LVT, increases land demand in the first period and decreases it in the final period. However, the effect on the actual timing of land conversion is ambiguous and depends on the magnitude of price changes in the land market. In examining the imposition of a DVT, Markusen and Sheffman (1978) state that such a tax will clearly cause land price appreciation and therefore result in a higher rate of land conversion. However, this outcome is sensitive to the fact that the DVT is anticipated ahead of time.[8]

Arnott and Lewis (1979) model land values and the development decision with land value taxes assessed both before and after conversion. Their pre-conversion tax, equivalent to a LVT, has the same effect as Shoup (1970) and Bentick (1979). However, their post-conversion tax, similar to a DVT, results in a slower rate of conversion. The contrasting results between the pre-conversion and post-conversion tax in Arnott and Lewis (1979) stems from their analysis accounting for conversion costs and the density of land development. The pre-conversion tax reduced density while the post-conversion tax does not affect development density.

Anderson (1986) extends the analysis by Bentick (1979) and Mills (1981b) and generalizes the comparative static results of the property tax in Arnott and Lewis (1979). He finds the post-conversion tax has an ambiguous result on the conversion decision, with the direction of the effect depending on the magnitudes of the pre- and post-conversion tax rates which are influenced by prevailing market conditions. However, Anderson (1986) assumes that the rent from developed property is independent of the conversion time, a restrictive and unrealistic assumption which affects the comparative static results.

None of the studies above distinguish between anticipated and unanticipated taxation and all analyze tax effects in a partial equilibrium framework, with the exception of Markusen and Sheffman (1978)[9]. Kanemoto (1985) models the anticipatory effects of a capital gains tax in a general equilibrium framework. If unanticipated, a DVT will result in a higher price of land and a lower allocation of land to developed uses and hence a slower conversion process. The effect

[8] This special case is pointed out by Kanemoto (1985) who examines the anticipatory effects of a land tax more carefully.

[9] The theoretical models of Shoup (1970) and Arnott and Lewis (1979) appear to examine land taxation from an unanticipated approach.

on capital intensity is ambiguous, depending upon the magnitude of the elasticity of substitution between land and capital. The analysis of anticipated capital gains taxes is similar to the analysis of Markusen and Sheffman (1978), with such a tax resulting in a hastening of land development. Kanemoto (1985) determines that a LVT has an ambiguous effect on the amount of land allocated to developed uses depending again on the elasticity of substitution. If the capital-land substitution elasticity is greater than the rent elasticity of demand for developed uses (i.e., residential housing), then an anticipated capital gains tax will result in a speedier conversion process (Kanemoto, 1985).[10]

McMillen (1990) extends the Kanemoto (1990) model to account for the duration as well as uncertainty in regards to the timing of a capital gains tax increase. Under conditions of certainty, the effect of an unanticipated and permanent tax increase is the same as in Kanemoto (1985): a slower rate of conversion and smaller steady state allocation of land to urban uses. If the unanticipated tax is viewed as being temporary with certainty, the rate of conversion also slows, but by more than a permanent tax increase of the same size. However, once the tax rate returns to its prior level, a period of more rapid development ensues—the shorter the interim tax period, the more the conversion rate slows. The end result in the steady state, the total amount of land allocated to urban uses, is the same between an unanticipated permanent tax and a temporary one. However, the time paths of development are much different.

As noted by McMillen (1990), a temporary capital gains tax may be useful from a policy-making standpoint if the intended goal is a reduction of rural land conversion in the short-run. If a permanent tax increase is anticipated, the end result may be completely opposite of what the policy-making authority intended. In this case, the amount of developed land in the steady state

[10] The effect on the price of land from an anticipated DVT could not be determined from the model due to analytical intractability, however, in the steady state land prices will be lower as a result of such a tax.

is smaller, just as in the unanticipated cases, however, the rate of conversion once the tax is anticipated (usually before the actual levy of the tax), results in a faster rate of conversion due to landowners trying to avoid the tax. The earlier the tax rate is anticipated, the faster rate of conversion will last even longer. If the anticipated tax is viewed as being temporary with certainty, the conversion rate also increases, but at a slower pace than the anticipated permanent tax case—the shorter the duration of the tax, the smaller the rate of increase in land conversion. These results underscore the importance of understanding the land development decision, as intended goals of government policies may cause the very outcome they are attempting to prevent, usually a loss of rural lands. Uncertainty over the timing and duration of the above tax systems does not alter the effects described above, but does magnify them (McMillen 1990). The steady state is the same regardless of whether the world is certain or not, however, the land development path of convergence will be different.

Much of the prevailing disagreement on the effects of a land tax is attributable to the imprecise definition between a land's market value and development value, as explained by Douglas (1980). The market value depends on whether the land development decision is immediate or delayed for a higher net present value whereas the development value is independent of this effect. This distinction has a profound implication on how land is valued and on the development decision, especially when real options valuation is used. The use of real options theory allows for the value in delay to be explicitly accounted. Also, mixed predictions are largely attributed to the individual intricacies of the theoretical model. As explained by Bentick and Pogue (1988), there are three types of partial equilibrium models prevalent in the literature—one assumes urban rents are constant, the second does not account for redevelopment options, and the third accounts for both of these. Each type of partial equilibrium model is uniquely sensitive to how the tax enters the formulation and so each differs in their implications. For example, when urban rents do not grow, a capital gains tax changes the land values in rural and urban uses proportionately, so in this regard the tax is neutral. However, when redevelopment is considered the model imparts an option value in the development decision, possibly resulting in delay due to the value of waiting. Another reason for the heterogeneity of tax results is due to the fact that partial equilibrium models are unable to carefully account for two distinctive features of taxation: the expectation of its arrival and the duration of its levy. The results from general equilibrium approaches suggest that expectations regarding the timing of a tax will affect whether land conversion increases or decreases, depending on whether the tax is anticipated or not. Expectations regarding the duration of a tax will affect the magnitude of the change, with rates of conversion being slower or faster depending on the permanent or temporary nature of the tax.

Despite the abundance of theoretical land development models that examine the effects of taxation, only one study is known that empirically tests theoretical prediction. Zax and Skidmore (1994) use data from Douglas Country, Colorado from 1986 to 1991 and examine how changes in a property tax affect the duration of time a parcel remains undeveloped. At the initial time period, parcels of land described in the data were undeveloped, with subsequent tax changes and conversions recorded until 1991. Since the dependent variable is the length of time until a parcel is development, the authors use a duration or hazard function to determine the effect of tax on the conversion time. The general form is given by:

$$P_{it} = P\left(D_{it=1} \mid D_{i,t-j} = 0, \forall j > 0, X_{it}\right) \tag{2-13}$$

The D_{it} term in Equation (2-13) is a dummy variable representing whether or not parcel i has been development in year t, and a vector of other conversion factors for parcel i in year t is given by X_{it}. The main results suggest that a relative modest property tax increase that is anticipated will not only increase the probability of development, but substantially increase the number of developed parcels.[11] The results are generally consistent with the theory outlined by Kanemoto (1985) and McMillen (1990) and underscore the potentially significant impacts even a modest property tax may have.

Market and information imperfections

Aside from the use of a general equilibrium model, the Markusen and Scheffman (1978) study is also of interest since it is one of the first to examine the effects of a monopoly market on land development. Interestingly, they show that contrary to the standard view, a monopoly developer may not result in slower conversion rates and higher price appreciation rates. Rather the effect on development and prices will largely depend on the elasticity of demand (Markusen and Scheffman 1978). Further, the property tax and capital gains tax effects outlined above for the competitive case are indeterminate for the monopoly case. In the competitive case, a landowner converts when the price of land equals the forgone opportunity cost. A monopolist, however, is willing to convert land up to the point where marginal revenue net of capital outlays is equal to the opportunity cost of the rural use (Markusen and Scheffman 1978).

Generally, the monopoly price will exceed the competitive price, but this may not necessarily lead to changes in the rate of conversion since under a monopoly market, rate increases in land supply and land price go in opposite directions. The impact of a capital gains tax in a monopoly market will largely depend on demand and supply responses and, in particular, on the magnitude of the elasticity of demand. One already noted limitations of the Markusen and Scheffman (1978) study involves the use of only two time periods when, in reality, the land

[11] Zax and Skidmore (1994) also examine the effects of an unanticipated tax increase, but find inconsistent significance across multiple equations and thus could not make an explicit conclusion on their effect.

development decision involves a greater number of periods in continuous time. Further, the model unrealistically assumes perfect information.

The paper by Mills (1981a) represents an effort to relax the perfect information assumption and examines three types of informational settings of the decision-maker: perfect foresight, zero foresight or myopia, and imperfect foresight. Generally, economic outcomes under cases of uncertainty tend be inefficient, as is the case with land development. The Mills (1981a) model is of the general equilibrium and perfect competition type, and envisions three types of decision-makers. The key decision makers are the landowners who earn rent, R_u, on unconverted land and decide when to develop the parcel for housing. Landowners also decide the housing type, of which n types are assumed. Each type of housing has its own requirement for parcel size given by the vector $\alpha = (\alpha_1, ..., \alpha_n)$. The second types of decision-makers are the housing construction firms who incur costs to building each type of housing, given by the vector $c = (c_1, ... c_n)$. The firms supply the housing units at time t according to the vector $x(t) = \left(x_1(t), ..., x_n(t)\right)$. The residents, or so-called tenants, compose the final type and demand housing according to the inverse demand function, $f_i\left(x(t), t\right), i = 1, ... n$, and pay rent $R(t) = \left(R_1(t), ..., R_n(t)\right)$.

Under the assumption of perfect foresight, the landowner is able to forecast exactly both the supply of housing, $x(t)$, and the demand for housing, $f_i\left(x(t)\right)$. Given a discount rate defined by r, the landowner will not develop a unit of land unless it generates a profit in excess of the present discounted value of unimproved land, given by R_u / r. Therefore, the landowner's maximization problem is:

$$\max_{i,t} \left\{ V_i(t) \middle/ \alpha_i \right\} = \frac{1}{\alpha_i} \int_t^{\infty} e^{-r\tau} \left[f_i\left(x(\tau), \tau\right) - \alpha_i R_u \right] d\tau - e^{-rt} c_i \tag{2-14}$$

As noted by Mills (1981a), the landowner has a set of infinite options given by the type of housing development and the timing of housing development: (i,t). An option by the landowner will not be exercised if a more profitable one exists, implying not only that all options are equally profitable, but that the solution is a competitive equilibrium and is efficient (Mills, 1981a). Under perfect foresight, in either the land or housing markets, prices represent profit expectations. These expectations are shared equally among all types of landowners meaning they each have the same base of information. Since all landowners base profit expectations on the same set of information, no individual landowner is better off than another in terms of informational advantages. The conversion rule resulting from the Mills (1981a) analysis states the rent received from building a type of housing will be maintained over any time horizon until the rental rate equals the opportunity cost. The opportunity cost is defined as the point where the revenues received from the housing market equal the combined costs of construction and opportunity land-cost (Mills, 1981a).

In the case where landowners are myopic, decisions are made using only the current stock of information and do not consider future expectations. As a result, the myopic landowner will not heed the opportunity cost level and will continue converting land until the supply is exhausted. In this case, not all options are equally profitable, and so not only will some landowners gain more than others, but the equilibrium is not competitive and thus inefficient. The case of imperfect information lies between these two extremes. Landowners do not have perfect foresight regarding prices and rents, but neither do they have complete disregard for future outcomes. In this case, landowners are speculative investors, with some having better forecasts than others. Options are still not all equally profitable, like in the perfect information case, but the land will not be converted until the point that supply is exhausted, like in the myopic case. Rather, landowners behave much like speculative investors, and the conversion rates are moderated between the two extreme cases of perfect information and myopia. One of the key insights about the Mills (1981a) paper is the fact that operating under a circumstance of uncertainty and of less than perfect information will reduce economic efficiency.

Urban growth

Urban growth models are based on dynamic constructs of spatial structure accounting for population increases and higher demands for urban developments. One of the earliest contributions is Anas (1978) who shows under circumstances of population growth that as the commuting distance to employment centers increase, the density of housing developments will also increase. Other studies in this spirit include Arnott (1980), Brueckner (1980), and Wheaton (1982). Capozza and Helsley (1989) model the land conversion process under conditions of a growing urban area. Like Arnott and Lewis (1979), the authors assume perfect foresight and irreversibility. Next, the value of land to owners is defined as four components: rent received from undeveloped agricultural land, expected rent from developed urban land, the development cost, and the value associated with how accessible the land is viewed. This final assumption is largely based on the von Thunen concept of proximity in determining land values. The closer a unit of land is to the central business district (CBD), the more valuable the land unit is due to greater transportation and commuting costs for more distant locations.

Models of this type are often described as a monocentric urban area. In regards to the timing of conversion, the landowner chooses the optimal time, t^*, to maximize the present value of undeveloped agricultural land:

$$P^a(t,z) = \int_{t^*}^{\infty} R(\tau,z)e^{-r(\tau-t)}d\tau + (A/r)\left[1-e^{-r(t^*-t)}\right] - Ce^{-r(t^*-t)} \qquad (2\text{-}15)$$

Rent received from urban land uses is given by $R(\tau, z)$, where z is the boundary of the urban area which indexes the distance of a unit of land from the CBD (Capozza and Helsley 1989). Agricultural land rents are given by A is, C is the conversion cost for a unit of land, r is the discount rate, and t^* is the time of conversion. The first-order condition solved using Leibnitz' rule is of the following familiar form:

$$R(t^*, z) = A + rC \tag{2-16}$$

Conversion is optimal at the time period when the sums of the opportunity costs from capitalization and from agriculture equal the urban use rental rate. A similar expression is obtained for the average price of developed land. Comparative static results indicate that the average price of urban land rises with higher agricultural land rents, conversion costs, commuting costs, the size of the city, and population growth. The average price of urban land falls with the discount rate. The Capozza and Helsley (1989) model explains the substantial gap between the value of agricultural rent and the price of land at the urban fringe, which may be explained by land rental growth expectations in the future. High growth rates of land rentals are due in part to the large degree of speculation by land developers on undeveloped land.

In the context of uncertainty, discussed in more detail below, Capozza and Li (1994) find generally higher growth rates raise the hurdle or reservation rent leading to delayed conversion times and a larger, denser, urban area. However, density levels are also dependent upon the degree of uncertainty and the elasticity of capital. Higher growth rates can have a negative effect on rents under conditions of high uncertainty and low capital elasticity, leading to a less dense urban area. Therefore, the effect of growth rates on conversion timing is ambiguous overall.

Uncertainty

Ellson and Roberts (1983) also investigate the effects of uncertainty on the timing of land rezoning and infrastructure development. Using a dynamic model, the key decision-makers analyzed are governments and planning agencies that make the conversion decision rezone parcels for urban uses. An aspect not considered in earlier studies, Ellson and Roberts (1983) model the planner's problem as one of consumer surplus maximization as a way of finding the socially optimal rezoning time. Using a simulation of a trans-log utility function, they conclude uncertainty tends to slow the rate of conversion, which is sensitive to the discount rate and the elasticity of demand. Increases in the discount rate, assumed to be the interest rate, tend to speed up the rate of conversion or rezoning (Ellson and Roberts 1983). As the time to development advances further into the future, the uncertainty on the conversion value of land becomes greater. This may imply the presence of a declining discount rate in the present value problem, with discount rates being greater in periods before development, declining as the conversion time approaches, as noted in the discussion on the discount rate (Shoup 1970).

One creative approach to modeling uncertainty has been through the use of stochastic processes. When returns are uncertain, they exhibit a type of random walk. Clarke and Reed (1988) describe the evolution of capital prices and rental rates on housing units as stochastic differential equations following a geometric Brownian motion with a Weiner process drift.[12] Like some earlier studies, their analysis does not allow for any interim uses of the land, but does maintain the assumption of irreversibility of development. The optimal conversion rule obtained is familiar: "develop land when the ratio of unit rentals to unit construction costs exceeds a critical barrier, otherwise do not," (Clarke and Reed 1988). This type of conversion rule would

[12] The authors examine the implication of defining the stochastic equations based on an Ito versus Stratonovich solution but, for the purposes of this review, this difference is not critical.

lend itself to econometric estimation under a hurdle or hazard function (Capozza and Li 2001; Irwin and Bockstael 2002). Despite the use of complicated stochastic differential calculus, their development rule is quite similar to others, and more specifically to the one obtained by Arnott and Lewis (1979). Simply put, conversion takes place when:

$$\frac{\text{expected land value}}{\text{sum of conversion costs}} = \frac{1+\tau}{\tau} \tag{2-17}$$

The value τ in Equation (2-17) is defined as a stochastic parameter in the equation for the market value of land (Clarke and Reed 1988). The effects obtained through comparative statics are revealing. Greater uncertainty in either construction costs or housing rentals results in a greater land value and an increase in density of construction. However, while increasing uncertainty in construction costs raises the so-called "critical barrier," and hence, delays conversion, the effect of uncertainty on rental rates is indeterminate (Clarke and Reed 1988). Similar to Mills (1981a), the Clarke and Reed (1988) describe the decision to develop as an option value. This makes sense, especially since the nature of conversion is assumed to be irreversible in the land development literature. With assumed irreversibility, the conversion problem is related to the work in financial economics on irreversible investment projects under uncertainty.

The development decision is predominately modeled in a stochastic uncertain framework in the literature (Capozza and Helsley 1990; Capozza and Li 1994, 2001, 2002; Majd and Pindyck 1987; Titman 1985). However, the capitalization approach is not able to accurately model land values and conversion timing in an option value context. Primarily, the failure of standard capitalization approaches is due to the incapability of the standard net present value calculations to explicitly account for the value in waiting to develop. This so-called option value is absent in the standard models of Shoup (1970), Arnott and Lewis (1979) and Capozza and Helsley (1989).

The Real Options Approach

The introduction of uncertainty changes the analysis of the development process considerably. The study of investment under uncertainty has spawned a whole body of literature culminating in the influential work of Dixit and Pindyck (1994).[13] The traditional investment rule in finance is to undertake a project when its net present value is positive. Likewise, if two projects are being considered and are mutually exclusive in the sense that both cannot be undertaken at the same time, then the project with the higher NPV is the optimal choice. Such basic rules form the foundation of the analysis in the seminal papers by Shoup (1970) and Arnott and Lewis (1979). However, all investment projects, especially those involving land conversion and development, come with an ability to delay or postpone investment until some later time. This means that the project competes with itself through time, imparting a value in the option to postpone investment. The idea of an investment opportunity, and land conversion in particular, as an option has acquired recent interest. The groundbreaking work of Dixit and Pindyck (1994) in investment under uncertainty underscores the value of waiting to invest. In reality, the land development decision, or any investment decision for that matter, is rarely a now or never decision since the individual can exercise the option to delay development or investment.

Introduction to real options theory

Although options theory has a long history, the first rigorous theoretical treatment can be found in the works of Black and Scholes (1973) and in Merton (1973). In finance, options can be categorized as either a call or a put option. A call option is the opportunity to buy or sell a

[13] For an excellent review of the investment under uncertainty literature, see Pindyck (1991).

commodity or unit of stock at some future time at a specified price. Another type of option is a put option where the holder has the right to sell a stock or unit of commodity at a stated price. In this sense, options are contingent assets since they only have a value contingent on certain outcomes in the economy. The exercise price of an option is usually referred to as the striking price, while the current value or quoted price of the stock or commodity is referred to as the spot price. The date at which an option is exercised is also referred to as the terminal time, or the date of expiration or maturity. A call option has a positive value when the spot price exceeds the strike price, or is "in the money." Put options are "in the money" when the strike price exceeds the spot price. Options are only exercised in this range. An important characteristic of an option is that it will always have a positive or zero value, never negative. This is because the point at which the option is worthless the holder of the option will simply disregard it, or "abandon the option." When an option has zero value it is referred to as "out of the money." The payoff function from a call option can be represented graphically in Figure 2-6.

Two types of options in the finance literature are European options, which can only be exercised on the final date of expiration, and American options, which can be exercised at any point in time until the final data of expiration. Land development and conversion decisions are best represented by an American call option since the option to convert can be exercised at any time until the terminal date. The value of an option is made up of two basic parts: the intrinsic value and the time value. The intrinsic value of an option is the difference between the strike price option and the spot price. The time value represents the possibility that the option may increase in value over time due to volatility in the stock or commodity price. At the terminal or expiration time of the option, the time value is zero, declining over time, at which point the option is equal to its intrinsic value. The value of an option can be obtained by different methods. An often used numerical procedure for options pricing is presented in Cox, Ross, and Rubinstein (1979) and is based on a discrete binomial process. An alternative method is the well-known Black-Scholes method presented in Black and Scholes (1973), which utilizes stochastic drifts to model the option price. Various extensions of the current methodologies are present in the literature (Alvarez and Koskela 2006; Rodrigo and Mamon 2006). An excellent discussion of option pricing theory and its applications can be found in Merton (1998).

A brief account of real options

Abel (1983) is one of the earlier studies on optimal investment under uncertainty. Additional studies have examined the irreversibility of some investments and have shown this to impart an option value in the investment decision (Bernanke 1983). McDonald and Siegel (1986) rigorously derive the value in the option to delay investment. Assuming investors are risk averse and hold a diverse portfolio, the authors examine the value in waiting to invest and develop rules on the optimal timing of investment for an irreversible project. Using the firm as the decision-making unit, the key component of the model is the choice between two mutually exclusive projects with only one being able to be undertaken at any given time. This mutual exclusiveness, concurrent with assumptions of uncertainty in project payoffs and investment costs, irreversibility of the investment, and risk averseness of the firm, impart a value in the firm's choice to delay investment. This option value is higher under conditions of greater uncertainty due to the increased variance in possible values of project returns. The standard assumption when uncertainty is considered in investment returns is to model the payments from an investment according to a standard Brownian motion process. McDonald and Siegel (1986) also consider a form of the Poisson process which allows for the present value of future returns to take a discrete jump to a zero value.

Ingersoll and Ross (1992) generalize McDonald and Siegel (1986) and show that option values exist in nearly all investment projects regardless of whether or not there is uncertainty in the expected payoffs or cash flows as long as there is some uncertainty in the interest rate. In Ingersoll and Ross (1992), there is an optimal acceptance rate of interest at which point the project is undertaken. As the real interest rate moves away from the optimal acceptance rate, greater postponement of investment occurs, causing the project value to decline (Ingersoll and Ross 1992). Depending on the length of delay and the average rate of discount, the cost of waiting is the forfeited present value of the project. Their results underscore the flaw in using the traditional NPV approach to decide on investment projects which dictates investment in all projects with positive net present values. Uncertainty effects on land conversion decisions are even more important due to the long duration of most land development projects. Projects which tend to have a longer time-span have more volatile present values which make the investment option more valuable.

The focus in the literature has often been on the effects of uncertainty on the timing of investment, however the effect on intensity of investment is investigated by Bar-Ilan and Strange (1999). In particular, they look at how price uncertainty affects the intensity and timing of investment when capital investment can be either lumpy or incremental. When investment is lumpy, the level of capital required for a project is decided at the moment the investment occurs. However, incremental investment involves units of capital that may be added over time. Some examples might include a rental car agency updating its fleet of vehicles or the addition of books in a library. Lumpy investment, like the construction of a building or a roadway, best describes the type of investment in land conversion. Under lumpy investment decisions when both timing and intensity of investment are considered, uncertainty tends to increase the trigger price. A higher trigger price indicates the value to delay is higher, postponing investment. However, once investment does occur it tends to occur with higher capital intensity when uncertainty is present. This stands in contrast to the incremental case when only intensity is a factor in the decision where greater uncertainty tends reduce the intensity of capital.

Application of real options to land development

One of the first studies to formally model land prices and development using an option value approach to investment decisions is Titman (1985). Under conditions of uncertain future real estate prices, the option to delay construction on vacant land becomes valuable since future development may be more profitable than current development given current prices. When the landowner is assumed to be risk neutral, the option value in the conversion decision will increase under conditions of greater uncertainty since the expected value of vacant land increases, resulting in current vacant land values to increase under uncertainty (Titman 1985). Using a Black-Scholes model of options values, several interesting comparative static results are obtained from the Titman (1985) model. For example, if the interest rate rises, the value of vacant land will increase, resulting in a greater incentive to hold onto the vacant land for future construction. An increase in rental rates will have the opposite effect, decreasing the value of vacant land resulting in a greater attractiveness to initiate building construction. The results in Titman (1985) are interesting when compared to the studies of land conversion when certainty is assumed. For example, in Arnott and Lewis (1979), an increase in the interest rate has an indeterminate effect on timing.

The impact of uncertainty on land development underscores the importance of a more robust understanding of land development models, particularly when government policies are issued with the objective of shaping landowner behavior and land development. For example, Titman (1985) shows that under a building regulation stipulating the maximum allowable height of a new building, the actual number of new buildings could actually increase as a result. No doubt part of this effect is due to the fact that more buildings are needed since each new building must be necessarily smaller. However, this effect is also due in part to the reduction of uncertainty in the optimal building size. A height restriction mitigates the uncertainty of future prices from the decision to build now or later, and since lower uncertainty means a lower option value from delaying construction, vacant land could be developed sooner than it would have if there was no height restriction (Titman 1985).

Extending Capozza and Helsley (1989) to account for uncertainty, Capozza and Helsley (1990) models household income, land rents, and prices as stochastic processes. The introduction of uncertainty is shown to impart an option value to the price of agricultural land. This has the effect of delaying the time to conversion, with the option value falling as the urban size grows and the distance from the boundary of the fringe region increases. Clarke and Reed (1988) also find that uncertainty adds an option value to the conversion decision, but do not examine the effects on urban growth and city size. The introduction of uncertainty in Capozza and Helsley (1990) required a reformulation of the standard problem of the landowner maximizing the value of land. Thus, Capozza and Helsley (1990) form the landowners' problem as a hitting time problem.

A specific type of the stochastic optimal stopping time problem, a hitting time refers to the point, or first hit time, where an outcome is optimal. In this problem, the first hit time is defined as a reservation or hurdle rent level. Once land rents reach the reservation rent level conversion is optimal. This hurdle rent is given by:

$$R^* = A + rC + \frac{r - \alpha g}{\alpha r} \tag{2-18}$$

Agricultural returns in Equation (2-18) are given by A, conversion costs are given by C, and the discount rate is r, which have the same interpretation as in Capozza and Helsley (1989). Additional parameters include, α and g, which is the drift parameter in the Brownian motion process for household income. When compared to the reservation rent in the certain case given by Capozza and Helsley (1989), the uncertain case has a higher trigger level (Capozza and Helsley 1990).

The last term in Equation (2-18) is defined as the irreversibility premium. Despite risk neutrality of landowners, the presence of uncertainty affects equilibrium land rents and prices due to the permanence of land conversion. The authors' equations on expected prices of agricultural and urban lands show that uncertainty increases land price, but only if city size is exogenous. If the size of the city is endogenously determined, then the effect of uncertainty on the price of agricultural land is ambiguous and largely depends on the degree of uncertainty (Capozza and Helsley 1990).

In recent years, the land development problem has been described using concepts from the financial economics literature, namely investment theory under uncertainty, and in particular, options theory. Capozza and Li (1994) represent one of the more rigorous attempts to model the timing and intensity of land conversion as an investment decision. The timing of urban residential development is framed as an option in the model developed by Mills (1981a), but focuses on the effects of conversion decisions under conditions of myopia and perfect foresight. Clarke and Reed (1988) more carefully examine the conversion decision as a perpetual option framework using stochastic calculus, however they ignore the interaction that capital intensity has on the timing decision and also on rents and property taxes. Capozza and Li (1994) fill in these gaps by describing how urban areas are affected by capital intensity, particularly in the land's spatial patterns, as well as obtaining effects on the discount rate, conversion costs, rental rates, capital elasticity, and expected growth rates. Using the theory of optimal-stopping, Capozza and Li (1994) frame the land conversion decision as an American option value with varying levels of intensity. In a general sense, the time required to take some specific action is described by the theory of optimal stopping based on a series of random variables which are randomly observed. Often times this is done for the purpose of maximizing an expected reward or minimizing an expected cost (Kamien and Schwartz 1991).

The presence of the option is based on the decision to invest between two different activities. Suppose the land has two revenue generating activities per unit or parcel, R_1 and R_2, with output per parcel, $q_1(k_1)$ and $q_2(k_2)$, where $K = (k_1, k_2)$ is the capital-land ratio (i.e., capital intensity). Further, suppose the initial case is activity one with revenue R_1, then the landowner has the option at any time, t, to convert to activity two by replacing the current capital intensity, k_1, with intensity k_2. Thus, not only does the landowner choose the time t, but also the optimal capital-land ratio (Capozza and Li 1994). In the case of vacant land in the initial period, here period one, it is assumed that there are no rents and that no capital is applied to the land.

The decision becomes one of choosing a benchmark or hurdle rent, given by R^*, and corresponding capital intensity, k^*, at some time t. Capozza and Li (1994) make the following assumption: positive variable conversion costs, c; the discount rate r is taken to be the interest rate; and the net rental rate follows a normal diffusion process with a constant drift g and standard deviation σ, which are both constants. The equation of motion for rents is given by:

$$dR = gdt + \sigma dB \qquad (2\text{-}19)$$

The price per parcel of land is given by the present value of future cash flows:

$$p = R/r + g/r^2 \tag{2-20}$$

The value of the conversion option is:

$$P^c(t) = W(R) = \max_T E_t \left\{ V\left(R(t)\right) e^{-r(T-t)} \right\} \tag{2-21}$$

The stopping time is T, $W(R)$ is the value of a perpetual warrant moving from no capital to capital intensity k^*, and the intrinsic value of the warrant, given by $V(R)$, is the value of the warrant if exercised at time t. The intrinsic value of conversion is defined as:

$$V(R^*) = q(k^*)p^* - ck^* \tag{2-22}$$

Using the fundamental differential equation of optimal stopping time, the model is solved to obtain the following conversion rule:

$$q(k^*)R^* = rck^* + q(k^*)\left(1/\alpha - g/r\right) \tag{2-23}$$

In Equation (2-23), α is a parameter. Thus, the option to convert will take place when the sum of the cost of capital for conversion and a risk premium from uncertainty equals the rent given up by delaying conversion (Capozza and Li 1994). By assuming a Cobb-Douglas functional form of the production function, the authors obtain equations for the optimal hurdle rent and capital intensity.

Like in other models, greater levels of uncertainty increase the conversion or option value. As a result of uncertainty the hurdle rent rises, delaying conversion, increasing the necessary capital-land ratio, and reducing the structural density of the urban area (Capozza and Li 1994). The costs of conversion have a negative effect on the intensity of capital which in turn will lead to lower density and lower land values. Increasing costs, however, have no effect on either the hurdle rent or the conversion time. The elasticity of capital, on the other hand, has a positive effect on the both the reservation rent and the conversion time, but has an ambiguous effect on the capital intensity. The discount rate has an overall negative effect on the endogenous variables. Reservation rents are lower, and so conversion times tend to be delayed. Land values and capital intensity are also lower under higher discount rates. If a property tax is set on post-development land, then the model predicts decreasing capital intensity and land values, but a higher hurdle rent, implying delayed conversion. A pre-development property tax has the opposite effect on hurdle rents, implying more hasty conversion.

Capozza and Li (2002) simplify their earlier analysis by assuming only one possible investment project. Assuming net rents from the project grow exponentially and that capital intensity is variable, the authors obtain rules for the optimal timing of land conversion under both certain and uncertain growth rates using internal rate of return (IRR) and net present value (NPV) principles. Under certainty, the conventional rule for undertaking a project arising from the real options approach in investment theory is to delay investment until the current yield, or IRR, equals the cost of capital (Capozza and Li 2002). This level of yield is often referred to as the reservation or hurdle IRR since investment only occurs until this level is reached.

In the case of land development, not only is conversion irreversible, or assumed to be so, but the added assumption of increasing rents over time further delays the optimal time to invest. Under conditions of perfect foresight, the hurdle rate is given by:

$$IRR^{*} = r + g \tag{2-24}$$

The discount rate is r, taken the prevailing interest rate in the real estate market, and g is the growth rate of rents. In this case, the internal rate of return must not only exceed the interest rate but also the rate of increasing cash flows. Assuming a constant elasticity of substitution production function, explicit solutions for the optimal hurdle level of rents and capital intensity are obtained:

$$X^* = r\left[\frac{1-a}{1-g/r}\right]^{1/\rho} \tag{2-25}$$

and,

$$K^* = \left(\frac{1/a - 1}{r/g - 1}\right)^{1/\rho} \tag{2-26}$$

The asset's coefficient of distribution is given by a, and ρ is the elasticity of substitution. The growth rate has a positive effect on optimal capital intensity while intensity is decreasing in the interest rate.

Unlike in Capozza and Li (1994), the effect of growth rates on conversion time is clear. A higher rate of increase in cash flows implies a higher hurdle rent and hence greater delay in conversion. Exponentially increasing rents tend to have an effect on future option values rather than on current options values (Capozza and Li 2002). Further, the interest rate in Capozza and Li (1994) has an unambiguous affect on timing whereas in the present case the effect of interest rates is unclear. Note however, that in Capozza and Li (1994) a Cobb-Douglas form of the production function is assumed.

In the stochastic case, a continuous time version of the Capital Asset Pricing Model is utilized to describe the option value to invest. The rental rate is assumed to grow with uncertainty according to a Brownian motion with a standard Weiner process. Under uncertainty the IRR hurdle level for the timing of investment in land development is made when:

$$IRR^* = r + g + \frac{\sigma^2}{2}\alpha \tag{2-27}$$

The variance of the growth rate of cash flows is given by σ^2, and α is a parameter that approaches one as σ approaches ∞, and approaches r/g as σ approaches zero. This is equivalent to the certainty IRR hurdle except for the addition of a term accounting for the value of waiting under conditions of uncertainty (Capozza and Li 2002). Using again the CES production function, explicit solutions for the optimal hurdle level of rents and capital intensity are obtained:

$$X^* = \left(r + \frac{\sigma^2}{2}\alpha\right)\left(\frac{1-a}{1-\frac{1}{a}}\right)^{\frac{1}{\rho}} \tag{2-28}$$

$$K^* = \left(\frac{\frac{1}{a}-1}{\alpha-1}\right)^{\frac{1}{\rho}} \tag{2-29}$$

The effects of the growth rate are the same as in the certain case. A higher rate of growth of cash flows will delay conversion and increase the level of capital. The uncertain option value increases the variance of rental flows, increasing the time horizon of the investment and the capital intensity required when the decision to invest is made (Capozza and Li 2002).

The effect of the interest rate is a bit more complicated due to the limiting nature of the α and σ parameters. There are two offsetting effects to increased interest rates in an option value under uncertainty with positive growth rates. Increases in capital costs from higher interest rates serve to delay investment, while lower waiting option values serve to hasten investment. Generally, however, for any level of growth, if the uncertainty is high enough so that σ is large, then an increase in the interest rate will have a declining affect on the optimal hurdle rent, hastening conversion.

As noted by Capozza and Li (2001), when the world is uncertain, irreversibility impacts the optimal timing of investment in a real options framework. The IRR has a higher hurdle level when investment is irreversible resulting in increased delay of a project. When capital intensity is variable and the economy is growing, delay also occurs. When a landowner commits to a certain lower level of capital in the current time period, some amount of revenue is forfeited in a future time period from an optimal project that requires higher capital than if the landowner had waited (Capozza and Li 2001).

The Transactions Cost Approach

The capitalization approach or present value method has dominated the literature on land values and the general literature on asset pricing as a whole. However, a number of empirical issues have arisen from the use of the present value techniques, particularly in the arena of land pricing. Indeed, a burgeoning literature has appeared criticizing the capitalization technique for oversimplifying the valuation of land and leading to empirical rejection of present value methods, particularly for farmland (Falk 1991; Clark, Fulton, and Scott 1993; Lloyd 1994). One flaw in present value techniques is the inability to explain why land prices rise and fall faster than land rents, especially during boom-bust cycles (Schmitz 1995).

While the option value approach discussed above is one alternative to the failure of capitalization methods, another approach has called for the incorporation of transaction costs in the model. As noted, the land market is particular prone to costly transactions, which have been estimated by some authors. Wunderlich (1989) estimates transaction costs from the transfer of land between buyer and seller around 3 percent of the total land value net of brokerage fees. This estimate is in line with the 2.5 percent estimated transaction costs given by Moyer and Daugherty (1982). However, neither of these estimates includes the cost of brokerage firms, which most land transactions occur through. Once accounted for, Wunderlich (1989) estimates the transaction cost to be as high as 15 percent. Clearly, such costs are not trivial and the need for more recent estimates is also clearly warranted.

Land development and institutions

The notion of transaction costs and institutions is not new, beginning with the work of Ronald Coase in 1937 and expounded on by Williamson (1985) and North (1990). Transaction costs can take on many forms in the land development process. While the mainstream literature has not yet fully developed a framework for the land development process under market frictions, some enlightening initial investigations are available (Healey 1991; Alexander 1992; Lai 1994; Benjamin and Phimister 1997; Buitelaar 2004). For example, zoning restrictions, titling cost, survey fees, and brokerage fees are all embedded in the transfer of land from rural to urban use. Any cost not accounting for in the physical production of urban land can be considered a transaction cost. As stated by Coase, transaction costs arise from two key failures in neo-classical economics: perfect information and rationality. Models of the land development decision with imperfect information have already been described. The landowner or developer may attempt to close the information gap by trying to acquire new information. For example, the conversion to residential property may involve research into housing preferences (Buitelaar 2004). The presence of uncertainty also introduces transaction costs in the land market as landowners and developers will attempt to gain information to reduce uncertainty. For example, a landowner might be in possession of a substantial size of unzoned property. The zoning of her land into residential or commercial use has a profound implication on its potential value and the decision to convert. In an attempt to eliminate such uncertainty, she may lobby the local municipality to zone the property to its value-maximizing use. One purpose for the creation of institutions is to reduce uncertainty.

There is also a degree of institutional cost in the land market and in the development process. Largely based on the work of North (1990), institutions can be described as the rules of the game in a society. Institutions define the constraints conceived by people and shape human interaction. By providing rules or constraints, institutions provide a structure to human interaction and reduce uncertainty in everyday lives. Local zoning restrictions are an example of institutional constraints in the land development process. As noted by North (1990), the creation of institutions involves a transaction cost itself, referred to as institutional cost. For example, the planning agency is the organization which places an institutional cost, zoning, on the land development process.

Transactions tend to be costly due to the fact that information itself is costly. For example, the costs of measuring the attributes of value to the individual of what is being exchanged and also the costs of protecting the rights of the individual as well as the costs of enforcing agreements. These costs constitute the source of social, political, and economic institutions. Indeed, stark implications for the land conversion decision are implied by the very notion of an exchange process with transaction costs. Since these costs are embedded in the costs of production, North believes that an entire restatement of the production relationship is necessary. This restatement must recognize that the costs of production are "the sum of transformation and transactions costs."

Before one can understand however the implications on a theory of institutions, one must understand why transacting can be costly. Consider the following statement by North:

> We get utility from the diverse attributes of a good or service, or in the case of the performance of an agent, from the multitude of separate activities that constitute performance…The value of an exchange to the parties, then, is the value of the different attributes lumped into the good or service. It takes resources to measure these attributes and additional resources to define and to measure rights that are transferred.

The underlying aspect of transactions costs stem from both parties involved in the exchange trying to ascertain the value of the individual attributes of the unit being exchanged. The seller or owner of a tract of rural land would likely have full information on the quality of land and its suitability for urban development, whereas the potential buyer or developer would have to approximate that information. Enforcement is another factor that adds to the costs of transacting. As mentioned earlier, land transactions are infrequent and occur over long time periods. Land transactions are often specified according to some written contract as to development dates, limitations to urban uses, etc. The developer might later find out that the land is not well suited for a commercial property, despite having already contracted to purchase the land and therefore would want to opt out of the contract.

The enforcement of such a contract involves a cost. This additional cost would not present an issue if it is in the best interests of either party to concede to the original agreement. However, as North points out (as did Adam Smith 250 years ago) individuals are very much self-interested which invokes feelings of uncertainty in either party that the other will not renege on the agreement. Uncertainty about possible reneging produces a premium on the risk that the other party will in fact renege, presenting a cost to the losing party. Information costs and uncertainty, conjoined with the behavior of the individual, presents challenges both to traditional economic theory and institutional theory.

North (1990) obtains a better understanding of how individual behavior and society's institutional structure are related. Property rights are the rights individuals appropriate over the labor, goods and services they own. This "appropriation" is a function of the institutional framework, such as legal rules, organizational forms, enforcement and norms of behavior. North describes that because of the presence of transaction costs and ill-defined property rights, certain attributes valued by the individual, "remain in the public domain." Individuals gain then by devoting resources to try to obtain such attributes. How this plays out is a function of the institutional structure, which facilitates exchange and determines the cost of transacting. Now how well this "game is played," North describes, depends on the extent that the rules—institutions—can solve the problems of coordination and production. The outcome of the game is determined by the motivation of the players, the complexity of the environment, and the ability of players to decipher and order the environment.

Despite the need for an institutional model in the land development literature, to date none have been formally described. However, a number of studies have both theoretically and empirically described the impact of quantifiable transaction costs on land values. While notions of transaction costs in these papers are limited to exchange costs (i.e., brokerage fees) and do not examine institutional costs, they remain a revealing and potentially promising alternative to the capitalization approach to modeling land values and the land conversion decision.

Models of land values with transaction costs

Borrowing from the notation in Lence and Miller (1999), the capitalization model given by Equation (2-5) can be extended to account for transactions costs. Let T_P and T_S denote the transaction costs on the purchase and sale of land, respectively, defined in terms of a percentage of the total price of land. Then define the purchasing and selling conditions of land as:

$$\left(1+T_P\right)V_t < \sum_{i=1}^{\infty}\left\{E_t\left[R_{t+i}\prod_{n=0}^{i-1}\delta^{t+n}\right]\right\} \tag{2-30}$$

$$\left(1-T_S\right)V_t > \sum_{i=1}^{\infty}\left\{E_t\left[R_{t+i}\prod_{n=0}^{i-1}\delta^{t+n}\right]\right\} \tag{2-31}$$

As in Lence and Miller (1999), the condition being tested is:

$$-T_S \le E_t\left[g_t\right] \le T_P \tag{2-32}$$

The term g_t is a stochastic variable that denotes the excess return yielded by holding the land indefinitely beginning at time t discounted at the rate δ. The excess return is defined as:

$$g_t \equiv \frac{1}{V_t}\sum_{i=1}^{\infty}R_{t+i}\prod_{n=0}^{i-1}\delta^{t+n} - 1 \tag{2-33}$$

The formulation given by Equations (3-30) through (3-33) imply the transfer of land will only occur if the transactions costs do not exceed the expected excess returns of the land (Lence and Miller 1999). The conversion rule in Equation (2-30) and Equation (2-31) collapse to the familiar capitalization formula given by Equation (2-5) if $T_S = T_P = 0$, which is equivalent to assuming a perfectly frictionless transfer of land.

Therefore, one way of explaining the gap between land prices and land rentals is through the presence of transactions costs. The sum of the land's expected discounted rent may differ from the current value or price, but not by an amount greater than the transaction costs associated with the transfer from seller to buyer. The capitalization model of the land development decision does not account for these transaction costs and assumes that the land market is frictionless.

Just and Miranowski (1993) is one of the first known studies to include such frictions in a structural model of land prices. Their analysis empirically demonstrates that real land values do not closely follow land rentals. The theoretical model accounts for transaction costs by including parameters on the sales commissions incurred in selling land. The values of these parameters are simply imposed in the econometric model as those given by Wunderlich (1989). The results in Just and Miranowski (1993) imply a superior fit over the capitalization method. Taking a different approach, Chavas and Thomas (1999) use a dynamic model of land prices, relaxing the assumption of time-additive dynamic preferences, risk neutrality, and zero transaction costs. The model is an extension of Epstein and Zin (1991) but allows for frictions in the transfer of land. Rather than impute the parameters describing transaction costs, like Just and Miranowski (1993), Chavas and Thomas (1999) estimate the marginal transaction costs as a proportion of changes in land quantity as a result of buying and selling land using the generalized method of moments. Not only do the results in Chavas and Thomas (1999) also support a strong rejection of the capitalization approach, but also provide substantial statistical evidence that transaction costs have a significant effect on land prices.

However, the result from both studies should be taken with caution as Lence (2001) notes serious flaws with both Just and Miranowski (1993) and Chavas and Thomas (1999). According to Lence (2001), incorrect first order conditions on the expression describing land values leads to imprecise theoretical predictions and possibly inconsistent econometric results. Lence (2001) also notes the inherent flaw in assuming a representative agent when using aggregated data, as in Chavas and Thomas (1999), since such an assumption is invalid when transaction costs are present. Further, the complicated structures inherent in the Just and Miranowski (1993) and Chavas and Thomas (1999) models lend themselves to difficult estimation procedures and sometime vague intuition whereas Lence and Miller (1999) and de Fontnouvelle and Lence (2002) model land values with frictions in a very analytically tractable way.[14]

The method of Shiha and Chavas (1995) modifies the traditional capitalization model in a manner similar to Lence and Miller (1999) and de Fontnouvelle and Lence (2002) by modeling market frictions as barriers to investment in agriculture. Such barriers are postulated to result in market segmentation and include legal fees, information and search costs, and represent the transaction costs in the model. Their model imposes these barriers on nonfarm investors attempting to hold equity in the farmland market. Similar to Lence and Miller (1999) the transactions costs are assumed to be proportional to the value of land holdings. To estimate the transaction cost parameter in their model, the authors use iterative nonlinear seemingly unrelated regressions. The Shiha and Chavas (1995) result suggest that not only is the farmland real estate market segmented, but that this segmentation is the result of transaction costs. In fact, the

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[14] The theoretical model of de Fontnouvelle and Lence (2002) is the same as Lence and Miller (1999), however the former uses a kernel estimation method and an expanded data set while the latter relies ordinary least squares.

estimates are somewhat larger than those reported by Moyer and Daugherty (1982) and Wunderlich (1989) reaching a peak of 6.18 percent per year during the 1949-1983 period (Shiha and Chavas 1995).

Empirical Models of Land Change

There is voluminous empirical work that attempts to estimate land values. An historical and comprehensive look at the literature, with particular attention to farmland values, can be found in Moss and Schmitz (2007). The particular attention in this section is on how the land valuation approaches described affect the empirics behind the land development decision.

Capitalization Empirical Methods

In one of the first and simplest empirical tests of the conversion model, Arnott and Lewis (1979) examine the real estate data for 21 metropolitan areas in Canada from 1961-1975 from the Central Mortgage and Housing Corporation. Actual ratios of land values to property values for the periods 1961-1971 and 1972-1975 are compared to those predicted by the model. Results indicate that the model explains 60 percent of the variation in the land value to property value ratio for the given areas. An elasticity of substitution between land and capital is also estimated.

Using a CES form of the housing production function $Q(K)$, the authors perform a regression on the following equation

$$\ln\frac{V(T)}{p(T)K} = \ln\left(\frac{\gamma}{1-\gamma}\right) - \rho\ln K \qquad (2\text{-}34)$$

The elasticity of substitution between land and capital in Equation (2-34) is given by ρ, γ is a coefficient describing the distribution of land, $p(T)$ is the price of a unit of capital at time T, and K is assumed be equal to the average area of floor space to the average size of the residential lot (Arnott and Lewis 1979). Using data for 23 Canadian metropolitan areas from 1975-1976 on new single family homes, results imply an elasticity of substitution of 0.372 for 1975 and 0.342

for 1976. The authors take the low values as evidence that the model does in fact produce an optimum. However, a weakness in the Arnott and Lewis (1979) model involves the assumption that on the urban periphery, the supply of land is perfectly elastic and developable. This may not be realistic given the heterogeneity of spatial land characteristics and the location of some parcels to more amenities.

More rigorous approaches to modeling the conversion decision can be found in the literature and generally fall into two categories: Probit models and duration models. The general intuition behind the Probit specification is an attempt to capture the effects of variables that increase or decrease the probability of a landowner to convert land from rural to urban uses. Many of these variables will be measurable and relate to certain characteristics of the land, such as land rentals, current land use, proximity to other rural or urban areas, estimated nearby land prices, and spatial characteristics. Other measurable variables may be unique to the landowner such as age, gender, income, and occupation. However, many characteristics of both the land and the landowner are not directly measurable or observable and so a stochastic framework is necessary.

Suppose we have a land-use decision rule derived from the capitalization approach given by Capozza and Helsley (1989) of the form:

$$R(\mathbf{w}_i, T) = A(\mathbf{x}_i, T) + rC(\mathbf{z}_i, T) \tag{2-35}$$

The functions $R(\bullet)$, $A(\bullet)$, and $C(\bullet)$ in Equation (2-35) represent the returns from conversion, rural land rent, and conversion costs, respectively. The discount rate is given by r and the optimal time of conversion is T. Vectors of observable characteristics describing conversion returns, rural rents, and development costs for parcel i are given by $\mathbf{w}_i$, $\mathbf{x}_i$, and $\mathbf{z}_i$, respectively.

If we define a vector of unobservable characteristics for parcel i as $\boldsymbol{\psi}_i$, the probabilistic model of the development decision can be formulated as in Carrion-Flores and Irwin (2004):

$$\Pr\left\langle D(i,T) = R(\mathbf{w}_i, T) - A(\mathbf{x}_i, T) - rC(\mathbf{z}_i, T) + \varepsilon(\boldsymbol{\psi}_i, T)\right\rangle \geq 0 \tag{2-36}$$

The decision to develop rural parcel i at the optimal time T is given by $D(i,T)$. The error term $\varepsilon(\boldsymbol{\psi}_i, T)$ associated with the development decision is assumed to follow a normal distribution. The parameterization of the model can be made explicit:

$$\Pr\left\langle D(i,T) = \boldsymbol{\varphi}(i,T)^{'}\boldsymbol{\beta} + \varepsilon(\boldsymbol{\psi}_i, T)\right\rangle \geq 0 \tag{2-37}$$

The vector $\boldsymbol{\varphi}(i,T)^{'}$ denotes the vector of observable characteristics $(\mathbf{w}_i \quad \mathbf{x}_i \quad \mathbf{z}_i)^{'}$ and the vector of parameters to be estimated is given by $\boldsymbol{\beta}$. The equation becomes more specific depending on the choice of variables to include. Further, if spatial characteristics are included, the model may require correction for spatial error autocorrelation in the error term $\varepsilon(\boldsymbol{\psi}_i, T)$.

This specification was used by Carrion-Flores and Irwin (2004) to determine the factors associated with rural land conversion to residential uses in Medina County, Ohio. Using parcel level data from a Geographic Information System (GIS), the authors use the model in Equation (2-37) to explain the conversion pattern between 1991 and 1996. Among the variables included in the Probit function are: distance to Cleveland, distance from nearest town, population, neighboring residential, agricultural, commercial, and other areas, population density, size of parcel, and soil quality. Results show the probability of conversion decreases with distance from Cleveland, population density, size of parcel in acres, and if the parcel is considered large.

Conversely, conversion is more probable with greater distances to the nearest town, better soil quality, and greater neighboring residential and commercial areas. Of interest is the variable on distance to Cleveland, a highly urbanized location. For parcel located within 14 miles of the

Cleveland fringe, the probability of development decreases at a decreasing rate, but outside this 14 mile boundary the probability of conversion increases. Of contrary expectation is the result that larger parcels are less likely to be developed. The authors state, however, this may be a result of the limited data available since the model is unable to distinguish between undeveloped land and land that is undeveloped but zoned for development (Carrion-Flores and Irwin 2004).

Ding (2001) also utilizes GIS data for Washington County, Oregon and estimates the probability that a parcel of vacant land is developed into an urban use between 1990 and 1994. His data set is comprised of nearly 14,000 identified vacant parcels with almost 5,000 converted into an urban use during the studied time period. Variables in the Probit analysis include access time to the central business district for four urban areas (Beaverton, Forest Grove, Hillsboro, and Portland), dummy variables indicating what urban area the parcel is located in, dummy variables indicating adjacency to major roads, adjacency to existing urban land, and adjacency to parcels also being converted. Dummy variables are also included to indicate if the parcel is located in a flood plain, a growth boundary, and a one mile zone of light rail. Two continuous variables are included for distance to the urban growth boundary and a tax rate.

Ding (2001) also finds that the likelihood of conversion decreases with parcel size like in Carrion-Flores and Irwin (2004). Similarly, he finds that land is more likely to be converted if it is closer to Portland but further away than the less urban areas of Beaverton, Forest Grove, and Hillsboro. Interestingly, Ding (2001) finds the probability of conversion greater in areas with a higher tax rate. While he explains this as a possibility of higher tax regions producing better amenities such as schools, he does not investigate this further. Another likely possibility, as is the fact that higher tax rates, when they are anticipated, tend to speed up the conversion process as developers try to avoid the higher tax penalties. A lagged and lead tax variable ought to capture this effect, but Ding (2001) does not include these in his Probit model.

Claassen and Tegene (1999) take a slightly different approach and use a Probit equation to model the conversion of pastureland to cropland, rather than to urban uses. Although the end development is different, the concept is the same: conversion from a lower to higher use. Another alternative use is given by the Conservation Reserve Program (CRP), established by the 1985 farm bill. The CRP pays landowners to keep their land out of any productive uses, such as forestry or agriculture, in order to preserve the land. One of the variables in Claassen and Tegene (1999) is the difference in rental rates between cropland and pastureland. The estimate on the rental rate difference is positive and significant suggesting that when cropland rents are large relative to pastureland rents, then the probability of conversion to cropland is greater. Estimates on the first and second lag of the rental rate difference are positive and negative, respectively, but not significant. The estimated interest rate effect suggests that the probability of conversion from pastureland to cropland conversion is smaller with higher interest rates. The estimated coefficient on the rent received if land is enrolled in the CRP program is negative, suggests that as the rent received under CRP increases the likelihood of land remaining in pastureland decreases.

Cho and Newman (2005) provide an innovative three-stage analysis of the development process. In the first stage they estimate a hedonic regression of land values. The results of this equation are used in the second stage in which a Probit equation is used to estimate the probability of a parcel of land being converted to a developed use. Finally, a third-stage Probit equation is used to estimate the density of development. Their data on vacant land parcels for Macon County, North Carolina was obtained from the land records division of the tax administration department for over 40,000 parcels, of which nearly 16,000 were converted between 1967 and 2003.[15] Cho and Newman (2005) find that an undeveloped parcel is more likely to be developed if it is located near a parcel that is already developed. The predicated value of land, quantity of roadways in the area, and degree of flatness of the land all are estimated to increase the probability of conversion.

The Cho and Newman (2005) results are intuitive and follow from the theoretical analysis. For example, as a parcel of land increases in value it becomes too costly for the landowner to keep the land in vacant or agricultural use, as the rentals received from agriculture are not enough to compensate for the opportunity cost of conversion. Further, the flatter a parcel of land is, the more amenable it is for residential housing and commercial projects. The probability of conversion and the density of development declines with the size of the parcel, distances to roadways, and the median elevation on the land. Large lots are less likely to be developed since residential developments occur after rezoning, which will break a larger lot size into many smaller lots. The presence of a large lot, say 10 or more acres, indicates the possibility that the land may not have been zoned for development yet. In fact, Cho and Newman (2005) find that parcel sizes greater than 10 acres have nearly a zero chance for high density development.

Another common econometric method of modeling the conversion process is through the use of duration or survival models. Duration models are often used to answer questions regarding the duration of unemployment spells, or time intervals between human conceptions. In general, duration models are concerned with how a variable changes through time, from one state to another and are particularly well suited to the land conversion decision. Two key questions are addressed by estimating the conversion process through a duration model. First, what is the

[15] According to the authors, the data set was updated every 4 years.

length of time a parcel of land will remain undeveloped? Second, what is the likelihood that it will be developed in the next time period? Typically the duration of time a parcel spends in an undeveloped state, the key variable of interest, is described by a hazard function. Other variables may change during the conversion duration such as population growth rates, conversion of nearby parcels, capital costs, interest rates, and even the landowner's discount rate.[16] Such time-varying covariates represent additional complications and can also be included in the hazard function.

The hazard function is the probability density of the duration of being undeveloped and is a function of time. To provide intuition for this method, modify Equation (2-36) so that we have:

$$\Pr\left\langle \varepsilon\left(\boldsymbol{\psi}_i,T\right) < R\left(\mathbf{w}_i,T\right) - A\left(\mathbf{x}_i,T\right) - rC\left(\mathbf{z}_i,T\right)\right\rangle \tag{2-38}$$

Landowner's who currently engage in farming receive rent $A\left(\mathbf{x}_i,T\right)$ and are characterized by a vector of unobservables given by $\varepsilon\left(\boldsymbol{\psi}_i,T\right)$. Individuals who are better farmers or who place higher value on land if it is in farming use will have a later conversion time than individuals who are not as able farmers or who place less value on the land in farming use. Therefore, the probability that a parcel will be converted at time T can be defined as the hazard rate for that time period for a given set of characteristics (Irwin and Bockstael 2002). This hazard rate is given by:

$$h\left(T\right) = \frac{G\left[\varepsilon^*\left(T+1\right)\right] - G\left[\varepsilon^*\left(T\right)\right]}{1 - G\left[\varepsilon^*\left(T\right)\right]} \tag{2-39}$$

[16] A burgeoning literature has spawned beginning with Strotz (1956) on how individual time preferences may change through time possibly exhibiting declining preferences or even preference reversals. This may suggest the need to model the conversion process with a non-constant discount rate, such as the hyperbolic discount rate. For more discussion on this literature see Frederick, Loewenstein, and O'Donoghue (2002).

The cumulative distribution function for the unobservables is given by $G[\bullet]$ and ε^* is the unobservable value that makes Equation (2-39) hold with equality. As noted by Irwin and Bockstael (2002), this is the value that makes the landowner indifferent between keeping the land in an undeveloped use or convert to a developed use.

There are multiple methods of calculating the hazard function. One involves parametric estimation which requires an assumption on the distribution of Equation (2-39). Common distributions include the exponential, Weibull, and variants of the logarithmic and normal distributions such as the log-normal and log-logistic (Bell and Irwin 2002). However, as noted by Greene (2003), the choice of distribution has profound implications on the answers to the questions regarding the timing of conversion. For example, the hazard function can slope either upwards or downwards, depending on whether the duration length increases or decreases the likelihood of the parcel not being converted in the next time period.

One way of avoiding this problem is to estimate the hazard function through semi-parametric methods.[17] This is often referred to as a proportional hazard model or a Cox regression model. Two distinct parts comprise the hazard function in a Cox model: the baseline hazard function and the explanatory function. The general form of the proportional hazard function is:

$$\lambda(t) = \lambda_0(t)e^{\mathbf{x}'\beta} \tag{2-40}$$

The baseline hazard in Equation (2-40) is $\lambda_0(t)$ and represents the heterogeneity among individual observations, the explanatory component is given by $e^{\mathbf{x}'\beta}$. The vector of exogenous variables is defined as $\mathbf{x}'$ and the vector of estimated parameters is β. The key feature of the

[17] Another approach would be through a fully nonparametric estimation method. However, this method introduces its own complexities and thus the Cox method serves as a nice median between parametric and nonparametric estimation methods.

formulation above is that time is distinct from the vector of explanatory variables. An implication of this distinction of time is that the hazard function for each individual observation is a proportion of the baseline hazard. Being set up as a proportion implies that as values in the explanatory variables change, the function $\lambda_0(t)$ shifts so that a value of the hazard $\lambda(t)$ is attained (Greene 2003). Cox (1972) defines a partial likelihood function which is maximized to obtain estimates of the parameters without having to estimate the baseline hazard.

The proportional hazard approach is used in Irwin and Bockstael (2002) to obtain undeveloped parcel conversion rates. In particular, the authors focus on the effects of neighboring parcel conversions by measuring surrounding developments as a way of identifying potential spill-over effects. They use an intricate data set on a seven county region of Maryland including Washington, D.C. and Baltimore as major urban areas. The data set was obtained from the state's panning office. Variables in the analysis include an index of zoning potential, a variable measuring the maximum permitted development density, distance measures to Washington, D.C. and Baltimore, an indicator for parcels that are relatively more costly to develop due to steep slopes or poor drainage, and an indicator for prime agricultural land.

Estimates from Irwin and Bockstael (2002) fully specified model imply a reduced hazard of development with greater commutes to Washington, D.C., steeper and more poorly drained soils, being prime agricultural land, and greater allowable density. If greater density is allowed and development returns are increasing over time with a concave production function, then a landowner will find it optimal to delay conversion until a later time. Of particular interest is the result of negative spill-over effects, implying a negative interaction between undeveloped and developed parcels in the decision to convert land (Irwin and Bockstael 2002). While this negative interaction might seem conflicting with the theory, the authors note that the analysis is of land along the rural-urban fringe where amenities such as open space are more highly regarded. Further, the magnitude of the negative interaction is based on commuting distances between Baltimore and D.C. being held constant.

Option Value Empirical Methods

While options value theory is a relatively recent development in the financial economics literature, empirical testing of real options models is even more recent. The empirical models of the capitalization approach have a firm ground in econometric theory. Option-based econometric approaches are not afforded the same luxury. However, in recent years, a number of empirical studies have emerged, particularly in the real estate economics literature, due in part to the attractive nature of the theoretical aspects of the option value model. A review of some of the most noteworthy studies is discussed in this section.

One of the first such tests is Shilling et. al (1990) who use a simple t-test to determine if a time premium is present in a real option model of land development. The authors estimate both the current market value of developable land, $\hat{V}$, given by the appraisal value and the discounted exercise price Xe^{-rT}. The discount rate is given by r, the development time is T and the exercise price is X. The authors then calculate the mean difference between the option premium and the intrinsic value. A t-test on the null hypothesis of the presence of a time premium is given by:

$$t = \frac{\overline{c} - \overline{Q}}{\left[\left(s_c^2 + s_Q^2\right)\big/ N - 1\right]^{0.50}} \tag{2-41}$$

Shilling et. al (1990) define $\overline{c}$ as the mean option price, and $\overline{Q}$ as the mean intrinsic value given by the mean difference of $\hat{V} - Xe^{-rT}$. The respective sample variances are s_c^2 and s_Q^2, and the number of observations is N. The null hypothesis could not be rejected at the 90 percent confidence level, indicating a zero mean difference between the option premium and the intrinsic value (Shilling et. al 1990). However, this test is far from rigorous and does not explicitly examine how an empirical model of option pricing affects the conversion decision.

The first rigorous empirical study is Quigg (1993) and examines the option-based value of undeveloped land by directly incorporating the value of waiting to invest in land development into a simultaneous equations model. Relaying on the hedonic methods of Rosen (1974), the author specifies a hedonic price function, $p(Z)$, on how market prices of land characteristics, Z, affect the price of land. The estimates from the hedonic price function are used to estimate another equation describing the potential value of construction on an undeveloped parcel. The data comes from the Real Estate Monitor Corporation and consists of a substantial number of land transactions in Seattle, Washington from most of 1976 through 1979 and includes 2,700 transactions of undeveloped land parcels (Quigg 1993). The central conclusion is that the development option represents a premium in the market price for undeveloped land at an average of 6 percent of the land's value. Further, the model does well at predicting transaction prices unlike the net present value methods discussed earlier.

Capozza and Li (2001) investigate the effects of positive interest rate changes in an uncertain real option with variable capital intensity and a project that is irreversible. The general view from real options model of investment is that increases in the interest rate tend to increase investment (Ingersoll and Ross 1992; Capozza and Li 1994; Capozza and Li 2002). In the context of real estate development, Capozza and Li (2001) test this response using panel data on residential building permits, to empirically test the presence of a positive relationship between the interest rate with the land investment decision. The response on the hurdle level of net rents to interest rate changes varies with the level of growth and uncertainty. When either growth rates or uncertainty, measured by the variance or volatility of growth, are high, positive responses to development or conversion from interest rate changes tend to occur. Data from the U.S. Department of Commerce on building permits and population growth is obtained for 56 metropolitan areas from 1980 to 1989. Population growth rates are used as a proxy variable for net rental growth rates. The primary home mortgage rate is used as the nominal interest rate variable. The authors estimate a regression of the form:

$$\frac{GHPC_{it}}{GRM_t} = \alpha + \beta_1 \frac{AGPOP_i}{RM} + \beta_2 AGPOP_i + \beta_3 AGPOP_i^2 + \beta_4 SGPOP_i + \Gamma_i(year_i) + \varepsilon_{it} \quad (2\text{-}42)$$

The term GHPC is the annual growth rate of building permits per capita in percent for single family homes in area i for year t. GRM is the annual percentage change in the real mortgage rate for year t. RM is the annualized real mortgage rate in percent terms defined as the beginning of the year yield on the primary conventional mortgage minus the current CPI inflation rate. AGPOP is the average annual growth rate of population in area i. SGPOP is the standard deviation or volatility of population in area i.

The ratio of GHPC to GRM measures the elasticity of residential investment in terms of building permits (Capozza and Li 2001). The authors also include variables for government regulations, tax rates, and monetary policies. Several forms of the regression above are estimated. In particular, deterministic and stochastic versions are obtained to estimate effects in a certain and uncertain world given by variable growth rates and volatility. In the certain case, the ratio AGPOP/RM, serving as a proxy for the ratio of growth rates to the interest rate, is positive and significant, supporting the Capozza and Li (1994, 2001, 2002) model. In the uncertain case, AGPOP is used as the explanatory variable and is also positive and significant suggesting again that growth rates respond positively to interest rate increases. Regressions including the variable SGPOP for population growth volatility reveal positive and significant estimates, also indicating positive responses to interest rate changes under greater uncertain conditions. The Capozza and Li (2001) regression results point to the importance of accounting for growth rates in any policy with a purpose of affecting investment rates. Since metropolitan areas are quite heterogeneous in terms of the population growth, interest rate policies can have very different effects between localities. Further, extreme care is warranted in any changes to the interest rate, since investment can be hastened beyond which the monetary authority intended depending on the volatility of growth rates.

Further empirical evidence on the importance of option values on the decision to convert land under uncertainty is presented in Schatzki (2003). The standard expected net present value model is compared to a real option investment model with uncertain returns. Under expected NPV models, the decision to convert land is made by the landowner once the discounted stream of returns from the converted use exceed that of the unconverted use after accounting for conversion costs. However, conversion decisions under a real options framework with uncertainty tend to have higher necessary returns to induce conversion than under the expected NPV method. The higher returns needed are due to the option to delay and sunk costs which cannot be recovered after conversion (Schatzki 2003). Since landowners have an incentive to delay conversion from additional information about future returns, there is value in the option to convert land. Schatzki (2003) conducts empirical tests on the effect of uncertainty in the decision to convert land from agriculture to forested using panel data from the National Resources Inventory (NRI) from 1982-1992. The NRI is a statistical survey of land use and land-use changes on parcel-level non-federal lands with a particular focus on the conversion of croplands to forests.

In the Schatzki (2003) model, the problem of the agricultural landowner is to choose the maximum of two alternative uses. The first is the sum of the expected returns from cropland in the first period with the expected value of land in agriculture while the second is the expected value of bare forest minus conversion costs (Schatzki 2003):

$$\max V_t^a = \max\left\{E\left[R_t^a\right] + e^{-rt}E\left[V_{t+1}^a\right], e^{-rt}E\left[V_{1,t+1}^f\right] - C_t^a\right\} \tag{2-43}$$

The expected value operator is given by $E[\bullet]$, the annual agricultural returns are R_t^a, the value of land in agriculture is V_{t+1}^a, the value of land in forests is $V_{1,t+1}^f$, the cost of conversion is C_t^a, and the discount rate is given by r. If returns are uncertain and assumed to follow a Brownian motion with drift, the conversion rule can be written as:

$$\frac{R_t^f}{R_t^a} = R^F\left(\sigma_{at}, \sigma_{ft}, \mu_{at}, \mu_{ft}, \rho_t, r, C^a, g_f(t)\right) \tag{2-44}$$

The annual return to forests is R_t^f. The variances of the motion process are given by σ_{at}, σ_{ft}, and the Brownian motion drift parameters are μ_{at}, μ_{ft}. The correlation between agricultural and forest returns is ρ_t; and the growth rate of forests is $g_f(t)$. Thus, the landowner will convert land from agriculture to forests when the relative return of forest to agriculture is greater than a threshold based on the set of variables. Due to the uncertain nature of returns, the threshold necessary to induce investment in the conversion decisions is higher than in the standard expected NPV model without an option value. This is because the option to delay conversion has value.

To determine the probability of a parcel being converted from cropland to forests, the author estimates a limited dependent variable regression model of the form:

$$\Pr(conversion) = \Pr\left(\ln R_{fit} - \ln R_{ait} > \ln R_{it}^F\right) \tag{2-45}$$

Parcel-level returns to forests and agriculture are given by $\ln R_{fit}$ and $\ln R_{ait}$, respectively, and the conversion threshold is defined by R_{it}^{F}. Relevant explanatory variables in the NRI data set that are in the regression include indicators of land quality, conservation practices, population density, irrigation, uncertainty, agricultural revenue and forest return trends, current revenues and returns, and the correlation between agricultural revenues and forest returns. Schatzki (2003) finds the probability of conversion falls with increased uncertainty of returns in agricultural revenues and of forest returns, suggesting that option values affect landowner decisions. Thus, as either agricultural revenues or forest returns increase, the conversion threshold also increases. Interestingly, the coefficient estimate on the correlation of agricultural revenues and forest returns is positive and significant, indicating that the likelihood of conversion is greater with a higher correlation. Finally, conversion is more likely when agricultural returns are low and forest returns are high, the land is not irrigated, population density is low, and no conservation practices are used (Schatzki 2003).

Chapter Summary

The literature review contained in this chapter has examined both theoretical and econometric models of land use and land development. The land development decision in regards to conversion use and timing can be modeled by three approaches: capitalization, option value pricing, and transaction costs. Within the capitalization framework, the standard net present value of land is the primary method of obtaining land values and the decision time to develop land. Capitalization approaches use both partial and general equilibrium models of the development process. However, capitalization methods have failed to accurately predict land values (Falk 1991) and do not explain the gap between land rents and prices (Capozza and Helsley 1989). Two alternative approaches were discussed. The option value approach accounts for the inherent value of waiting to invest in land development arising from both uncertainty and irreversibility. While option value models have the advantage of being more realistic, they are conceptually more difficult to employ. The transaction costs approach accounts for the fact that land transactions are long, infrequent, and costly. Typical costs such as informational and institutional costs, not captured by either the capitalization or option value approaches, are expressed in a transaction costs framework. While this method holds particular merit, the lack of a sophisticated conceptual model prevents it from mainstream utilization.

Recall the questions posited at the beginning of this discourse. When is it optimal to convert land from a lower rural use to a higher urban use? What is the optimal intensity of capital that should be applied to the land development project? How do government policies, such as property taxes and growth controls affect the optimal timing and intensity? What affects to changing discount rates and expected returns imply for land development? How does an uncertain world alter matters? This review has attempted to compare and contrast how answers to these questions differ depending on the choice of theoretical and empirical model. Further, even within the same approach, disagreement occurs between authors as to the correct answer due to the unique nuances within a particular framework.

This disagreement not only remains problematic for academic researchers, but also especially for policy makers who require a keen understanding of the development process in order to formulate policies intended for rural conservation or urban growth. Accurate and efficient policy instruments cannot be designed without an understanding of land development models and a knowledge regarding timing decisions. A better knowledge of the conversion process will facilitate an improved understanding of numerous outcomes of development that seem random such as discontinuous urban development, heterogeneous spatial patterns in land use, and the creative destruction of capital structures. This review contributes to the understanding of the development process through a comprehensive critique of the currently used conceptual and empirical models, something which is lacking in the literature. Recommendations for future work include continued advancement of real options and transaction costs models, as these remain the most encouraging in terms of accurately describing the development process. Further, since the development process is an intertemporal decision, it is recommended that models from the economics of time literature be applied. Methods proved fruitful in other fields, such as dynamic programming, have yet to be applied to the land conversion problem.

Since models of land development are derivative of models of land values, a complete understanding of the development decision must come from a thorough knowledge on the nature of land values. This paper serves to enhance the body of knowledge by introducing time inconsistent preferences to a model of land values. The next chapter will present the theoretical model.

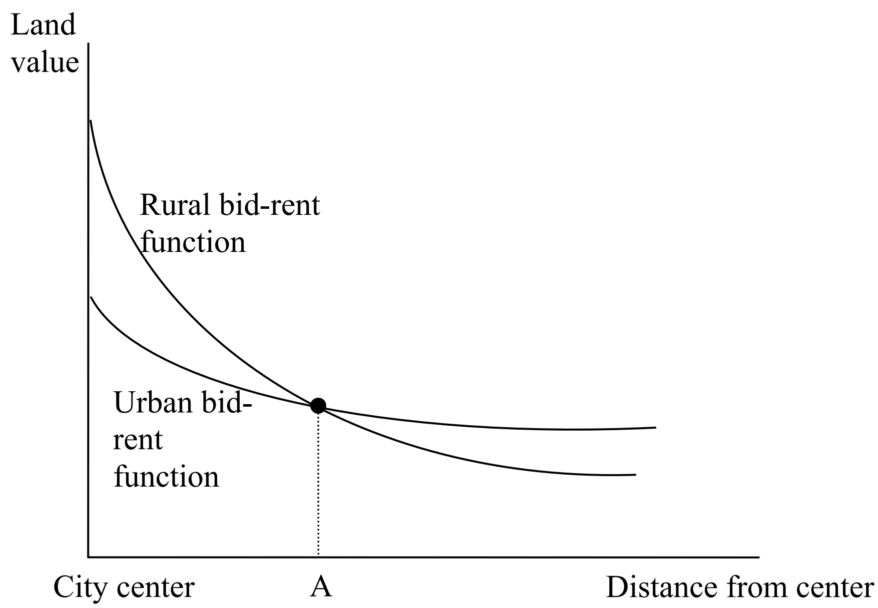

Figure 2-1. Land allocation and bid-rent model

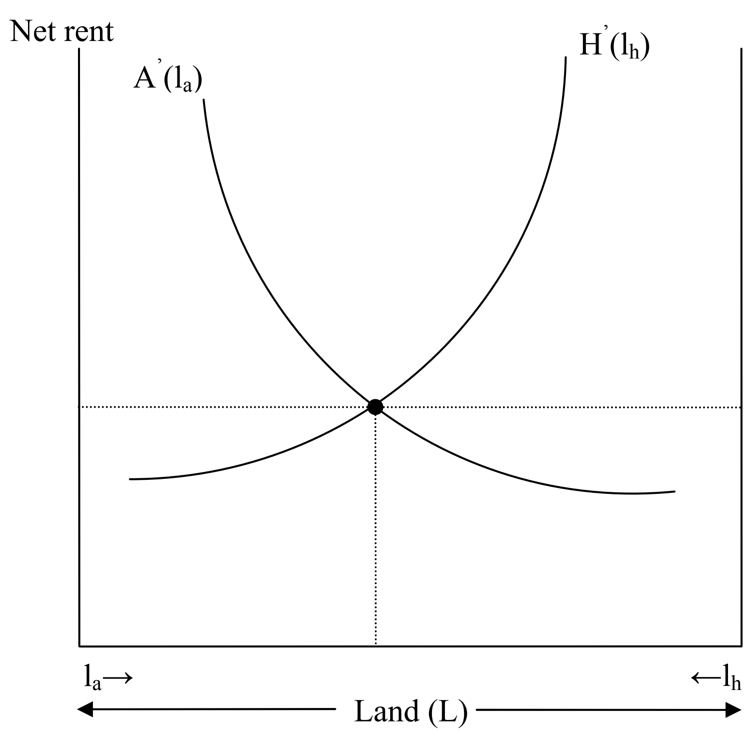

Figure 2-2. Optimal land allocation

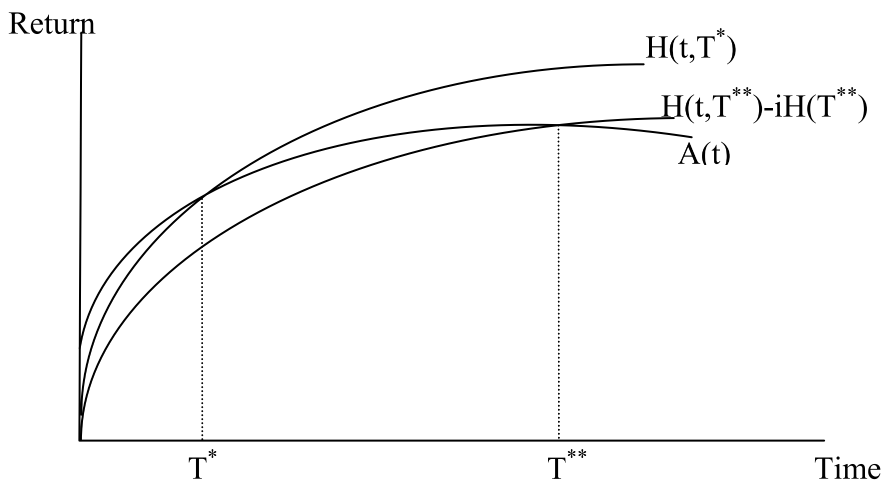

Figure 2-3. Optimal conversion time

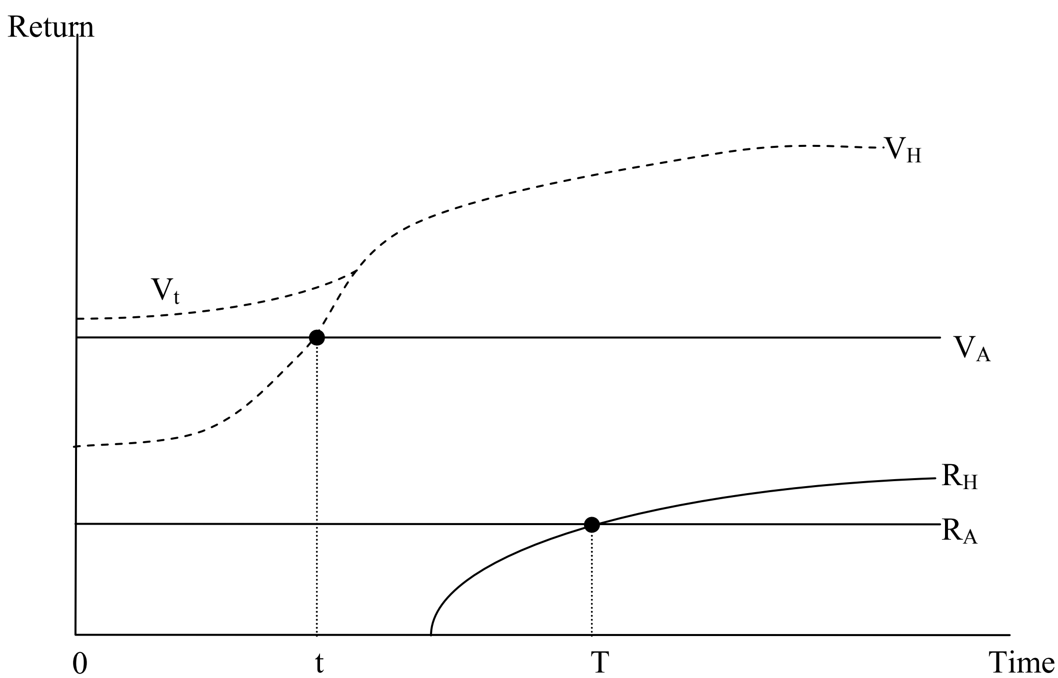

Figure 2-4. Change in value of agricultural land awaiting conversion

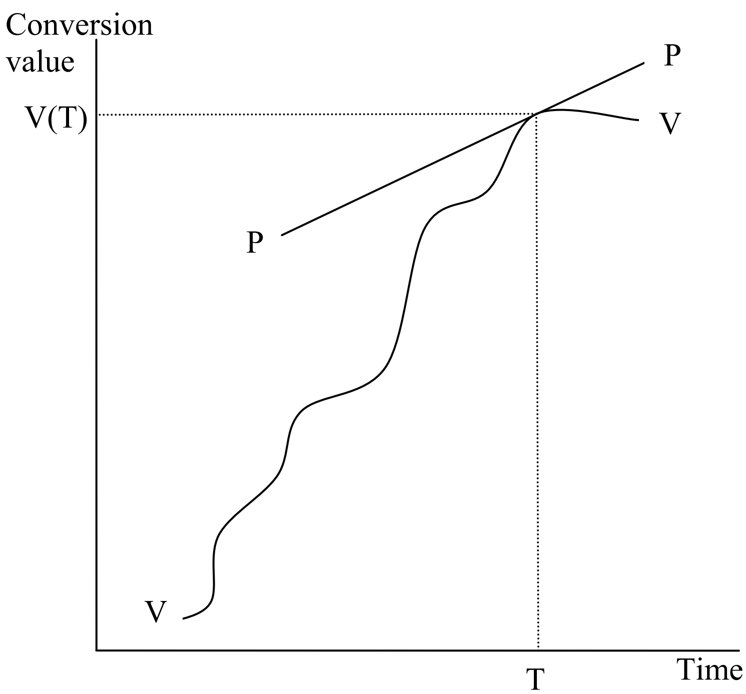

Figure 2-5. Timing of conversion decision

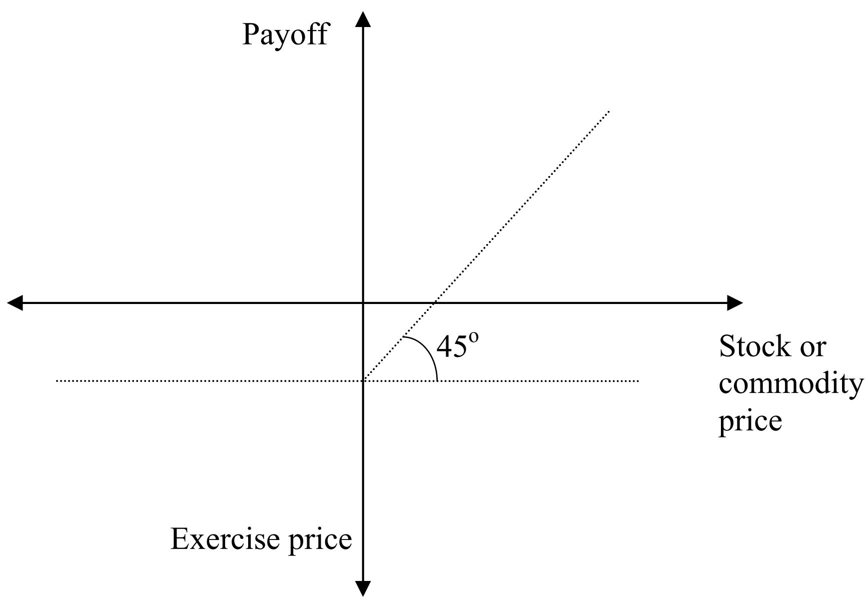

Figure 2-6. Call option payoff

Table 2-1. Selected comparative static results from capitalization papers

Study	Endogenous variables	Capital / conversion costs	Discount rate	Pre-development rental rate	Post-development rental rate	Pre-development property tax	Post-development property tax
		Exogenous variables					
Shoup (1970)	Land value / price	N/A	–	+	N/A	–	N/A
	Conversion time	N/A	–	+	N/A	–	N/A
Skouras (1978)	Land value / price	N/A	–	+	+	–	–
	Conversion time	N/A	–	+	–	–	–
Markusen & Scheff-man (1978)	Land value / price	–	–	+	0	–	–
	Conversion time	+	–	+	0	?	+
Arnott & Lewis (1979)	Land value / price	–	–	N/A	+	–	–
	Conversion time	+	?	N/A	–	–	+
	Capital intensity	0	–	N/A	0	–	0
Ellson & Roberts (1983)	Land value / price	+	–	+	0	N/A	N/A
	Conversion time	+	–	+	?	N/A	N/A
Anderson (1986)	Land value / price	N/A	–	+	+	–	–
	Conversion time	N/A	–	+	?	–	?
Capozza & Helsley (1989)	Land value / price	+	–	+	+	N/A	N/A
	Conversion time	+	–	+	?	N/A	N/A

CHAPTER 3
THEORY AND EMPIRICS

This chapter presents a present-value framework for land price determination using rational expectations in the context of farmland values. The theoretical model is formulated, generalizing time preferences to permit for quasi-hyperbolic discounting. The empirical model is developed from the theory presented and allows the exponential and quasi-hyperbolic discount parameters to be obtained. A hypothesis test is constructed, permitting for a direct test on the discount parameters. Finally, the econometric procedure is presented. The parameters are estimated using the linear panel Generalized Method of Moments estimator. The discussion pays particular attention to the selection of instruments.

Theoretical Framework

The main assumption underlying present-value models of farmland values is that the expected rents received from land exclusively determine the value of land, holding other factors fixed, such as taxes. While this is a strong assumption, present value models of asset prices under rational expectations rely on this principle of rental determination. The other implied assumptions are risk-neutral landowners and a time-consistent discount factor with a constant rate of discount. The time-consistent assumption will be relaxed, permitting for quasi-hyperbolic discounting in the asset value equation. Specifically, a model for values based on changes in asset valuation over time will be derived and will nest both the standard case of exponential discounting and the case of quasi-hyperbolic discounting.

Financial theory typically stipulates that a firm or individual decision-maker should adopt a project, such as converting or developing land, if the net present value of the project is positive. Under simplifying assumptions of risk neutrality and time-consistency, the value of land today can be written as the discounted stream of expected future rents:

$$V_t = \sum_{s=0}^{\infty} \delta_{t+s} E_t \left[R_{t+s} \right]. \tag{3-1}$$

The price or value of land at time t in Equation (3-1) is V_t. The expected rental rate or nominal cash flow from land use at time $t+s$ is $E_t\left[R_{t+s}\right]$ and is based on the information available to the landowner in period t. The standard exponential discount factor is defined as:

$$\delta_{t+s} = \prod_{i=1}^{s} \left(1+\rho_{t+i}\right)^{-1}. \tag{3-2}$$

The discount factor is taken to be $\delta \in [0,1]$. The rate of time preference in period t is given by the constant rate of discount, ρ_{t+i}, which is often assumed to be the nominal or real interest rate.

The formulation given in Equation (3-1) and Equation (3-2) is the basic expression for land values examined by many authors to test how well the PV model can explain movements in farmland values when a rational expectations framework is assumed (Falk 1991; Clark, Fulton, and Scott 1993; Tegene and Kuchler 1993; Schmitz 1995; Schmitz and Moss 1996). Based on this formulation, the expectations in the land market that both buyers and sellers have on discounted future returns play a central role in determining the value of land. Some studies have rejected the present value model as a rejection of rational expectations (Lloyd, Rayner, and Orme 1991; Tegene and Kuchler 1991, 1993; Engsted 1998). However, this rejection may be due in part to a potentially anomalous assumption of exponential discounting.

An alternative formulation takes note of potential time inconsistency and assumes a quasi-hyperbolic discount factor implying a non-constant rate of discount. Quasi-hyperbolic discounting, developed by Laibson (1997), is a discrete-value time function and maintains the declining property of generalized hyperbolic discounting. At the same time, the discrete quasi-hyperbolic formulation keeps the analytical simplicity of the time-consistent model by still incorporating certain qualitative aspects of exponential discounting. The actual values of the discount factor under a discrete setup are $\left\{1, \beta\cdot\delta, \beta\cdot\delta^{2},\ldots, \beta\cdot\delta^{\infty}\right\}$, with the time periods defined as $t = 0,1,2,\ldots,\infty$. When $t = 0$, the discrete discount function is normalized to one. The δ parameter behaves similar to the exponential discount factor. The β parameter captures the essence of hyperbolic discounting and contains a first period immediacy effect in the individual's time preference. Discount rates under a quasi-hyperbolic discount function clearly decline over time as the short-run discount rate, given by $-\ln\left(\beta\cdot\delta\right)$, is greater than the long runs discount rate, given by $-\ln\left(\delta\right)$ as computed in Laibson (2007).

Setting up the problem under quasi-hyperbolic intertemporal preferences implies that Equation (3-1) takes the form:

$$V_t = \beta\cdot\sum_{s=1}^{\infty}\delta_{t+s}E_t\left[R_{t+s}\right]. \tag{3-3}$$

Changes in the β parameter in Equation (3-3) determine how much the discount factor will deviate from exponential discounting. If discounting is time-consistent then $\beta = 1$, and is time-inconsistent if $\beta\in\left(0,1\right)$. Following the literature, $\beta\cdot\delta$ represents the discount factor between the current time period and the next time period, while δ represents the discount factor between any two future time periods (DellaVigna and Paserman 2005). The expression in Equation (3-3) can be modified to derive a model for asset values based on changes in the asset valuation over time.

Specifically, taking the time difference of Equation (3-3) yields:

$$\Delta V_t = V_t - V_{t-1} = \beta\cdot\sum_{s=1}^{\infty}\delta_{t+s}E_t\left[R_{t+s}\right] - \beta\delta\cdot\sum_{s=0}^{\infty}\delta_{t+s}E_{t-1}\left[R_{t+s}\right]. \tag{3-4}$$

The expression in Equation (3-4) can be simplified by aggregating over like exponents to:

$$\Delta V_t = -\beta\delta \cdot E_{t-1}\left[R_{t+s}\right] + \beta\delta \cdot \sum_{s=1}^{\infty} \delta_{t+s} \left\{\delta^{-1} \cdot E_t\left[R_{t+s}\right] - E_{t-1}\left[R_{t+s}\right]\right\}. \tag{3-5}$$

Under rational expectations there is a forecast error in the second term on the right hand side of Equation (3-5) between the two expectation operators, meaning $E_t\left[R_{t+s}\right] = E_{t-1}\left[R_{t+s}\right] + e_t$, where e_t is an uncorrelated residual term. Equation (3-5) can be written as:

$$\Delta V_t = -\beta\delta \cdot E_{t-1}\left[R_{t+s}\right] + \beta\delta \cdot \sum_{s=1}^{\infty} \delta_{t+s} \left\{\left(\delta^{-1} - 1\right) E_t\left[R_{t+s}\right] + e_t\right\}. \tag{3-6}$$

The residual e_t represents a "white noise" forecast error if expectations are in fact rational, implying that no information is present in the error term. Simplifying gives:

$$\Delta V_t = -\beta\delta \cdot E_{t-1}\left[R_{t+s}\right] + (1-\delta)\beta \cdot \sum_{s=1}^{\infty} \delta_{t+s} E_t\left[R_{t+s}\right] + e_t\ . \tag{3-7}$$

The observed cash flow in the next period is assumed to proxy the expected return in the next period, that is, $E_{t-1}\left[R_t\right] \to R_t$.

Equation (3-3) can also be substituted in for the second term on the right hand side of Equation (3-7). Making these changes yields the structural model:

$$\Delta V_t = -\beta\delta \cdot R_t + (1-\delta) \cdot V_t + e_t\ . \tag{3-8}$$

To test for hyperbolic discounting, the structural equation given by Equation (3-8) can be parameterized into an identified reduced-form linear panel regression. Doing so gives:

$$\Delta V_{it} = \alpha_0 + \alpha_1 \cdot R_{it} + \alpha_2 \cdot V_{it} + e_{it}\ . \tag{3-9}$$

The reduced form model given by Equation (3-9) includes a constant term, α_0, which is included in most regressions on land values. The reduced form specification in Equation (3-9) has also been extended to account for observations over time and space. Observations come from a sample of i geographic regions over a period of t years. The nice feature of Equation (3-9) is that the formulation nests both the exponential and hyperbolic discount factors.

The discount parameters in the structural specification in Equation (3-8) can be obtained once the reduced-form coefficients in Equation (3-9) have been estimated. Since $\alpha_1 = -\beta\delta$ and $\alpha_2 = (1-\delta)$, then:

$$\delta = (1-\alpha_2), \tag{3-10}$$

$$\beta = \frac{-\alpha_1}{1-\alpha_2}. \tag{3-11}$$

If the assumption of exponential discounting is true, then one would expect α_1 to be close to -1 and α_2 to be close to zero. The constant term, α_0, should not be statistically different from zero under rational expectations regardless of the shape of the discount factor.

Based on the reduced-form parameter estimates, two types of hypothesis tests can be devised to test for the presence of hyperbolic discounting. The assumption of $\beta = 1$ is equivalent to assuming exponential discounting, which implies $\alpha_2 - \alpha_1 = 1$ using Equation (3-10) and Equation (3-11). Hence, an appropriate test for exponential discounting would test the null hypothesis of $H_o : \alpha_2 - \alpha_1 = 1$ against the alternative hypothesis of $H_a : \alpha_2 - \alpha_1 \neq 1$. This test will be referred to as the implicit test of hyperbolic discounting, since the value of β is assumed and since the test basically amounts to a test of exponential discounting. A second test is a direct nonlinear hypothesis test on Equation (3-11) with the null hypothesis of $H_o : -\alpha_1/(1-\alpha_2) = 1$ against the alternative of $H_a : -\alpha_1/(1-\alpha_2) < 1$. This test is referred at as the explicit test of hyperbolic discounting since the standard error on the hyperbolic parameter is computed. While both tests are equivalent in theory, the implicit test is more efficient while the explicit test introduces some noise due to the Taylor series approximation. Overall, the explicit test is better empirically since it provides an exact test on hyperbolic discounting.

Since β is a nonlinear function of the parameters, a linear Taylor series approximation is used to obtain the standard error:

$$h(\hat{\alpha}) = h(\alpha) + \left(\frac{\partial h(\alpha)}{\partial \alpha}\right)' (\hat{\alpha} - \alpha). \tag{3-12}$$

The hyperbolic parameter is defined as a vector function of the estimated coefficients, $h(\hat{\alpha})$, in Equation (3-9) to obtain the linear Taylor series approximation. The formulation in Equation (3-12) appeals to the Central Limit Theorem and asymptotic theory for consistency. If the Law of Large Numbers holds and if the data are independently and identically distributed then obtaining the standard errors through a Taylor series approximation is appropriate. If these assumptions hold, then the standard error of $h(\hat{\alpha})$ is given by:

$$S.E.\left[h(\hat{\alpha})\right] = \left\{\left(\frac{\partial h(\alpha)}{\partial \alpha}\right)' \left(VAR\left[\hat{\alpha}\right]\right)\left(\frac{\partial h(\alpha)}{\partial \alpha}\right)\right\}^{1/2} \tag{3-13}$$

The partial derivatives in Equation (3-13), while functions of the unknown parameters, can be computed using the sample estimates.

Econometric Procedure

Given the nature of the data on land values, using a simple estimator such as least squares for estimating the panel regressions in Equation (3-9) would not be appropriate for a number of reasons. First, while the error term, e_{it}, is assumed to be independently and identically distributed with zero mean, heteroskedasticity across years and farms remains a possibility. Second, while the error term is not correlated with the dependent variable ΔV_{it}, the first difference of farmland values, e_{it} is serially correlated across time. For these reasons, estimation by the Generalized Method of Moments (GMM) is preferred. Originally proposed by Hansen (1982) and Hansen and Singleton (1982) for estimating consumption-based asset pricing models, GMM provides consistent estimates of the parameters. The consistency of the estimates however is largely determined by the selection of instruments, which often remains a difficult task. Despite the benefits of GMM, however, surprisingly little work has been done applying GMM to the econometric problems inherit in land values data (Chavas and Thomas 1999; Lence and Mishra 2003).

The regressors in Equation (3-9) have both time-varying and time-invariant components, with observations assumed to be independent over i. The time period T is fixed, and the variables can be stacked for the i^{th} region over all T. Rewriting Equation (3-9) in more general terms yields:

$$y_i = X_i\alpha + \varepsilon_i \tag{3-14}$$

The dependent variable and the error term in Equation (3-14) have been reduced to $T \times 1$ vectors, while the matrix of independent variables, X_i, is $T \times K$, with K denoting the number of regressors:

$$y_i = \begin{bmatrix} \Delta V_{i1} \\ \vdots \\ \Delta V_{iT} \end{bmatrix}; \quad X_i = \begin{bmatrix} V_{i1} & R_{i1} \\ \vdots & \vdots \\ V_{iT} & R_{iT} \end{bmatrix}; \quad \varepsilon_i = \begin{bmatrix} e_{i1} \\ \vdots \\ e_{iT} \end{bmatrix}. \tag{3-15}$$

Panel GMM estimation of Equation (3-9) follows from the sample moment condition:

$$E\left[Z_i^{'}\varepsilon_i\left(\alpha\right)\right] = 0, \quad i = 1,\ldots,N. \tag{3-16}$$

The matrix of instruments, $Z_i = \left[z^{'}_{i1} \quad \cdots \quad z^{'}_{iT}\right]^{'}$, has dimension $T \times r$, with r denoting the number of instruments and T denoting the number of time periods. In the residual vector,

$\varepsilon_i(\alpha)$, α is a $K \times 1$ vector of K parameters to be estimated. The foundation of GMM estimation is the specification of the orthogonality or moment condition in Equation (3-16). The goal of the GMM estimator is to find a vector of parameter estimates so that the residuals are orthogonal to the set of instruments.

Given this background, if there are more instruments than parameters, that is if $r > q$, the form of the minimand for the linear panel GMM model, $Q_N(\alpha)$, can be expressed as (Cameron and Trivedi, 2005):

$$Q_N(\alpha) = \left[\sum_{i=1}^{N} Z_i^{'}\varepsilon_i(\alpha)\right]^{'} W_N \left[\sum_{i=1}^{N} Z_i^{'}\varepsilon_i(\alpha)\right]. \tag{3-17}$$

The matrix W_N is a $r \times r$ positive semi-definite weighting matrix, akin to a variance matrix, which depends on the data. The weighting or distance matrix, W_N, converges in probability to a non-stochastic positive definite matrix of constants, W. The orthogonality conditions in Equation (3-16) are in a way being emulated by minimizing the function $Q_N(\alpha)$, which is a quadratic form of the sample means across both time and space.

The panel GMM estimator $\widehat{\alpha}_{GMM}$ can be defined as:

$$\widehat{\alpha}_{GMM} = \operatorname{argmin}_{\alpha \in \Phi} Q_N(\alpha). \tag{3-18}$$

Equation (3-18) states that GMM estimation selects the value of the vector α from a subset of the parameter space Φ, which is itself a subset of the q-dimensional Euclidean space $\Re^q$, so that the value of the function $Q_N(\alpha)$ is minimized (Hall 2005). The GMM estimator is asymptotically normal with variance matrix consistently estimated by:

$$\widehat{V}\left(\widehat{\alpha}_{GMM}\right) = N\left[\widehat{X}^{'} Z W_N Z^{'} \widehat{X}\right]^{-1}\left[\widehat{X}^{'} Z W_N \left(\widehat{S}\right) W_N Z^{'} \widehat{X}\right]\left[\widehat{X}^{'} Z W_N Z^{'} \widehat{X}\right]^{-1}, \tag{3-19}$$

where $\hat{S} = N^{-1}\sum_{i=1}^{N} Z_i \hat{\varepsilon}_i \widehat{\varepsilon_i'} Z_i'$. A White-robust estimate of $\hat{S}$ is obtained by assuming independence over i in the residual vector ε_i, where $\hat{\varepsilon}_i = y_i - X_i\hat{\alpha}$. The standard errors obtained from Equation (3-19) are robust to heteroskedasticity and serial correlation over time (Cameron and Trivedi 2005).

The choice of the weighting matrix remains an integral component of the estimation procedure. The matrix W_N determines how the information in the instruments based upon the moment condition is weighted in the estimation of the parameters. There is little guidance on how to select W_N, and so estimation of Equation (3-17) proceeds in two stages. First, the weighting matrix is computed as $W_N = \left(Z_i'Z_i\right)^{-1}$ in the initial stage of the GMM estimator. Then $\hat{V}\left(\hat{\alpha}_{GMM}\right)$ is estimated next based on the first stage estimation of $\hat{\alpha}_{GMM}$. Thus, in the second stage, the first stage estimate of $\hat{V}\left(\hat{\alpha}_{GMM}\right)$ is used in the second stage GMM estimator based on the weighting matrix now computed as $W_N = \widehat{S^{-1}}$.

A numerical optimization routine is typically necessary to estimate the panel GMM estimator. While the Newton-Raphson method is the usual choice, as noted by Hall (2005), this routine and others does not guarantee a global optimum has been achieved, even after a large number of iterations. The numerical procedure used here is that of Nelder and Mead, which performs well for nonlinear and non-differentiable functions. Since this method uses only function values, computing a large number of iterations can be slow, but is also robust. The Nelder and Mead simplex algorithm is also preferred because of the degree of non-convexities in quasi-hyperbolic functions, as noted by Laibson, Repetto, and Tobacman (2007). All parameter estimates were obtained using R© version 2.6.0 software. The procedural code for each panel region is available in the Appendix.

Instrument Selection and Identification

The choice of instruments remains a crucial, but problematic, aspect of GMM. Nearly any variable that is correlated with a regressor but independent of the error term can be selected as an instrument, thus ensuring the over-identifying restrictions introduced by Hansen (1982) are in fact met. A benefit of the two step procedure of panel GMM estimation outlined above is that the estimator allows for the instrumental variable matrix Z to include regressors in the X matrix as well, thus aiding identification. Additionally, a benefit of panel data over cross-sectional data is the availability of a weak exogeneity assumption: $E\left[z_{is}e_{it}\right]=0$, $s \le t$, and $t=1,\ldots,T$. As noted by Cameron and Trivedi (2005), this condition arises in models involving rational expectations and in models of intertemporal choice, like in the present paper. The condition given by $E\left[z_{is}e_{it}\right]=0$ allows for lagged or lead values of regressors as instruments.

The number of over-identifying restrictions is given by $r-K$. A test of the over-identifying restrictions is given by:

$$J_N = \left(1/N\right) Q_N\left(\widehat{\alpha}_{GMM}\right)\left(1/N\right) = \left(1/N\right)\varepsilon_i\left(\widehat{\alpha}_{GMM}\right)' Z_i \widehat{S_N^{-1}} Z_i' \varepsilon_i\left(\widehat{\alpha}_{GMM}\right)\left(1/N\right) \tag{3-20}$$

The J_N statistic converges to a χ^2 distribution with $\left(r-K\right)$ degrees of freedom. The null hypothesis is that the moment condition in Equation (3-16) is true, that is, $H_o : E\left[Z_i'\varepsilon_i\left(\alpha\right)\right]=0$. If the value of the test statistic results in rejection of the hypothesis, then model misspecification may be the case. If the J_N statistic is large, then another possibility could be the presence of endogenous instruments, that is, instruments that are correlated with the error term.

Problems of weak identification occur when the moment condition in Equation (3-16) is non-zero but very small. Under such a situation the moment condition provides very little information about the parameter vector, calling into question the reliability of the estimates. However, one cannot take an insignificant statistic to imply that weak identification is not a problem. Although recent work has examined possible procedures for identifying and handling weak instruments, such as Stock, Wright, and Yogo (2002), there is no firm method to correct for weakly identified instruments and so the J_N test remains the best available tool for examining model specification. Clearly, caution must be exercised regardless of the test results.

Chapter Summary

This chapter laid the theoretical foundation for empirical analysis. A net present value model for farmland is developed. The structural equation for the annual change in farmland values is obtained. The reduced form parameters for the quasi-hyperbolic and exponential discount factors, β and δ, respectively, are solved in an indentified framework. The empirical strategy is to first estimate the reduced-form in Equation (3-9). Second, the structural parameters identifying the exponential and quasi-hyperbolic discount factors are obtained through Equation (3-10) and Equation (3-11), and then appropriate hypothesis tests are conducted. Hence, testing for hyperbolic discounting is a two-step process.

This chapter also worked out the econometric method used in the analysis, describing the linear panel GMM. Particular attention was paid to the choice of the weighting matrix and the numerical procedure used to obtain the estimated. The choice of instruments was described as well as the over-identification test explained. In the next chapter, the data are described and the primary estimation results are presented for the major U.S. agricultural regions.

CHAPTER 4
DATA AND RESULTS

To examine the possibility of hyperbolic discounting in U.S. farmland, annual observations on asset values and returns to agricultural assets are used. The data represent a 43 year panel from 1960 to 2002 of the nine major agricultural regions of the United States. The data come from the U.S. Department of Agriculture's (USDA) Economic Research Service (ERS). The primary source of data is the USDA's state level farm balance sheet and income statement. A detailed description of the agricultural regions and the variables are discussed first. Then the estimation results including estimates of the discount parameters are presented.

Data and Variable Description

The nine regions investigated include the Appalachian states (Kentucky, North Carolina, Tennessee, Virginia, and West Virginia), Corn Belt states (Illinois, Indiana, Iowa, Missouri, and Ohio), the Delta states (Arkansas, Louisiana, and Missouri), the Great Plain states (Kansas, Nebraska, North Dakota, Oklahoma, South Dakota, and Texas), the Lake states (Michigan, Minnesota, and Wisconsin), the Mountain states (Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, and Wyoming), the Northeast states (Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont), the Pacific states (California, Oregon, and Washington), and the Southeast states (Alabama, Florida, Georgia, and South Carolina). Other regional definitions exist, such as those defined by Theil and Moss (2000). However, the USDA/ERS defined regions are used since they remain the most commonly used.

The dependent variable is the first difference of farmland values, which represents the annual change in the value of farmland for each state. The independent variables are annual farmland values and annual farmland returns. Farmland values are defined as the value of farmland per acre. The definition of farmland returns is gross revenues per acre less the expenditure on variable inputs and follows Mishra, Moss and Erickson (2007). While many studies opt for a more complete specification of returns, such as the aggregate series of imputed returns as defined in Melichar (1979), the definition used in this dissertation is preferred. As revealed in Mishra, Moss, and Erickson (2004), measurement error problems are possible in more complete formulations of imputed returns if quasi-fixed assets are present.

The data used in the analysis are the nominal data. The use of nominal data is preferred over the real data for two main reasons. First, the deflated real data has a higher variance, indicating more radical changes in both farmland values and returns between years. Secondly, and most importantly, the results are sensitive to the choice of deflator used. The estimation results were obtained under three different deflators: the consumer price index (CPI), the producer price index (PPI), and personal consumption expenditure index (PCE). The values of the discount parameters vary depending upon the choice of deflator used. In order to focus on the rate of time preference and avoid a debate on the best choice of deflator, the nominal data is used.

Figure 4-1 through Figure 4-9 show the historical trend in the annual change of farmland values from the 1960 to 2002 time period for nine farm production regions (Appalachian, Corn Belt, Delta, Lake, Great Plains, Mountain, Pacific, Northeast, and Southeast). Within each region, states tend to follow the same pattern in the change of land values over time, that is, the year to year fluctuations by state within each region tend to be closely followed. However, notable exceptions can be discerned. Virginia departs substantially from the other Appalachian states between 1988 and 1991. Both California in Figure 4-4 and Florida in Figure 4-5, deviate from the other states in their panel region over the time horizon. Florida and California are quite distinct in the agricultural products each state produces, as well as the urban pressures generated from within each state compared to others the Southeast and Pacific regions.

The overall pattern between agricultural regions is similar, namely the clear representation of the boom/bust cycle, which occurred from around 1970 to 1985. However, the magnitude of the fluctuations for each region are notably different, hitting the Corn Belt and Delta states the hardest followed by the Lake and Pacific states next. Land values for the Appalachian, Great Plain, and Southeast states were comparatively the least hurt during the boom/bust cycle. The Northeast states have the widest variation in land values over the 43 year time period. This is attributed to several reasons, but primarily because urban pressures are greatest for this region. Further, farmland and agriculture are not the highest value activity for land in the Northeast states. Also, the agricultural industries within the Northeast vary widely.

As mentioned earlier, the selection of instruments can be a challenging task. Instruments ideally satisfy the orthogonality condition in Equation (3-16). Good instruments represent the nature of how land is valued and the expectations of the economic agent. For these reasons, lagged values of farmland values and return on assets are preferred instruments. Not only do they reflect the expectations of the agent, but they are known to both the econometrician and the farmland agent at the current time, making for a good choice of instrument (Chavas and Thomas, 1999). In addition to the regressors, the instrument set includes squared terms and lagged terms of land returns and land values, for a total of four over-identifying restrictions.

Estimation Results

Equation (3-9) is estimated using annual aggregate panel data for nine agricultural regions of the United States (Appalachian, Corn Belt, Delta, Great Plains, Lake, Mountain, Pacific, Northeast, and Southeast) over a 43 year time period from 1960 to 2002. Since the dependent variable is a first difference, an observation is lost for each state per a panel reducing the sample size by the number of states in the panel. A fixed effects dummy variable approach is used in the panel GMM. While this approach does have the unfortunate effect of losing degrees of freedom depending upon the number of states in each panel, the inclusion of dummy variables for controlling state fixed effects remains a simple way of acquiring estimates of the parameters.

Tests for heteroskedasticity and serial correlation are conducted. The Breusch-Pagan test for heteroskedasticity is used in both the farmland values and returns series with the null hypothesis of no heteroskedasticity, and is distributed Chi-square with two degrees of freedom providing a critical value of 5.991 for each panel. The Box-Ljung test for serial correlation is used on the change in farmland values series with the null hypothesis of no autocorrelation, and is distributed Chi-square with one degree of freedom providing a critical value of 3.841.

Finally, Hansen's over-identifying restrictions J-test is used to test whether the model is correctly specified with the null hypothesis that the over-identifying restrictions hold. Since there are four over-identifying restrictions and the test statistic has a Chi-square distribution, the critical value is 9.488. The critical values of all three test statistics are based on a 5% level of significance. The results for each regional panel are discussed first, followed by a general discussion of the results overall.

Appalachian States

The Appalachian states consist of Kentucky, North Carolina, Tennessee, Virginia, and West Virginia. The total sample used in the analysis is 210, with the omitted dummy variable being Virginia. The Breusch-Pagan (BP) test resulted in a test statistic of 16.405, implying rejection of the null hypothesis and indicates heteroskedasticity in the farmland values and returns series. The Box-Ljung (BL) test is next conducted and results in a test statistic of 42.290, which also implies rejection of the null hypothesis, indicating the presence of serial correlation in the change in farmland values series. Finally the test statistic for the over-identifying restrictions test is 0.069, hence the over-identifying restrictions cannot be rejected. Since heteroskedasticity and serial correlation are present in the data, and since the over-identifying restrictions cannot be rejected, the discussion will focus on the GMM results.

The parameter estimates are summarized in Table 4-1. The constant term is not significantly different from zero, as expected for a net present value model under rational expectations. The estimated coefficients on farmland returns (α_1) and farmland values (α_2) are of the expected sign with α_2 being statistically significant while α_1 is not. None of the estimated coefficients on the state dummy variables are significant. Based on the parameter estimates in Table 4-1, values of the exponential and hyperbolic discount parameters can be obtained through Equation (3-10) and Equation (3-11). The exponential discount factor is $\hat{\delta} = 0.939$, and significantly different from zero. The hyperbolic discount parameter is $\hat{\beta} = 0.060$, and is also significantly different from zero. However, if hyperbolic discounting is in fact present, $\hat{\beta}$ will be significantly different from one.

To test whether the estimates represent exponential or hyperbolic discounting, the implicit test of $H_o : \alpha_2 - \alpha_1 = 1$ is first conducted. The calculated F-statistic is 119.963, which implies the null hypothesis of exponential discounting can be rejected at any conventional level of significance. The explicit test of hyperbolic discounting, $H_0 : -\alpha_1 / (1 - \alpha_2) = 1$, is next conducted resulting an F-statistic of 102.152, implying the null hypothesis of $\hat{\beta} = 1$ can also be rejected. Again, the null hypothesis can be rejected at any significance level. The results lead to the conclusion that discounting is not exponential but hyperbolic in the Appalachian panel.

Based on the estimates of $\hat{\beta}$ and $\hat{\delta}$, short-run and long-run discount rates can be computed. Given the values of the discount parameters, the long-run rate of discount is

$-\ln(0.939) = 6.3\%$ and the short-run discount rate is $-\ln(0.060 * 0.939) = 287.6\%$. An interpretation of the estimated discount rates can be offered. The long-run discount rate of 6.3% says that the value of a dollar is worth 6.3% less in the long run than the present time or that a dollar in the long run is worth .063 cents less to you now. In other words, you value a dollar in the long run at about .94 cents right now. The short-run discount rate can be interpreted similarly, though discount rates in excess of 100% are difficult to interpret. Suppose the short-run discount rate was 75%. In this case you view a dollar in the short-run 75% less than you do right now. In other words, if you discount rate is 75%, then you value a dollar in the short-run as 0.25 cents to you right now. With a short-run discount rate of 287.6%, you view a dollar in the short run at 287.6% less than you do right now. Such a high discount rate attaches a negative value to a dollar in the present. The key result, however, is that not only are the short-run and long-run discount rates significantly different from each other, but the magnitudes starkly contrast one another and suggest that the initial time periods in the farmland values market are critical.

Corn Belt States

The Corn Belt states consist of Illinois, Iowa, Missouri, and Ohio. The total sample size used in the analysis is 210, with the omitted dummy variable being Missouri. The BP test resulted in a test statistic of 10.418, implying rejection of the null hypothesis and indicating the presence of heteroskedasticity. The BL test is next conducted, resulting in a test statistic of 86.902, which also implies rejection of the null hypothesis and indicates the presence of serial correlation. Finally, the test statistic for the over-identifying restrictions test is 0.069, implying that the moment conditions cannot be rejected.

The parameter estimates are summarized in Table 4-2. The constant term is not significantly different from zero, as expected for a net present value model under rational expectations. The estimated coefficients on farmland returns (α_1) and farmland values (α_2) are of the expected sign and both are statistically significant from zero. None of the state dummies are statistically significant, though all are negative in sign. Based on the parameter estimates in Table 4-1, values of the exponential and hyperbolic discount parameters can be obtained through Equation (3-10) and Equation (3-11). The exponential discount factor is $\hat{\delta} = 0.929$, and significantly different from zero. The hyperbolic discount parameter is $\hat{\beta} = 0.584$, and is also significantly different from zero.

To test whether the estimates represent exponential or hyperbolic discounting, the implicit test of $H_o : \alpha_2 - \alpha_1 = 1$ is first conducted. The calculated F-statistic is 1.637, which does not exceed the critical value at (1, ∞) degrees of freedom of 3.840 at 0.05 level of significance. Hence, the null hypothesis of exponential discounting cannot be rejected. The explicit test of hyperbolic discounting, $H_0 : -\alpha_1 / (1 - \alpha_2) = 1$, is next conducted resulting an F-statistic of 1.417, implying the null hypothesis of $\hat{\beta} = 1$ cannot be rejected. The results lead to the conclusion that discounting is not hyperbolic but exponential in the Corn Belt panel. However, long-run and short-run discount rates can still be computed based on the parameter estimates. Given the values of the discount parameters, the long-run rate of discount is $-\ln(0.929) = 7.4\%$ and the short-run discount rate is $-\ln(0.584 * 0.929) = 61.2\%$. However, these discount rates are not significantly different from each other since $\hat{\beta} = 1$ could not be rejected.

Delta States

The Delta states consist of Arkansas, Louisiana, and Missouri. Land returns and land values are characterized by both heteroskedasticity since the BP test statistic is valued at 18.210. The change in land values variable is serial correlated as evidenced by the LB test statistic value of 46.401. Table 4-3 lists the parameter estimates. The total sample size is 126 and Louisiana is the omitted dummy variable in the analysis. The over-identifying restrictions cannot be rejected in the GMM regression since the value of the J-test statistic is 0.089, which is less than the critical value of 9.488 for a Chi-square distributed test statistic with 4 degrees of freedom.

In regards to the parameter estimates, the constant term is positive, but not significant. The coefficient estimate on farmland returns (α_1) is negative, as anticipated by the theoretical model, but also is not significantly different from zero. The coefficient estimate on farmland values (α_2) is positive and significant. Neither of the coefficient estimates for the two state dummy variables are significant, though both are positive and similar in magnitude.

Based on the estimates of α_1 and α_2, the quasi-hyperbolic discount factor is $\hat{\beta} = 0.155$, and is significantly different from one based on the explicit test of hyperbolic discounting since the value of the F-statistic is 11.199. The exponential discount factor is $\hat{\delta} = 0.963$, with the null hypothesis of no hyperbolic discounting for the implicit test being rejected since the value of the F-statistic is 13.869. Thus, in addition to the Appalachian states, evidence of quasi-hyperbolic discounting is found in the Delta states. The results imply that the long-run rate of discount is given by $-\ln(0.963) = 3.8\%$ and the short-run rate of discount is $-\ln(0.155 * 0.963) = 190.2\%$. Clearly, the shape of discounting is different for the Delta states between the long-run and short-run, with this difference being statistically significant.

Great Plain States

The Great Plain states consist of Kansas, Nebraska, North Dakota, Oklahoma, South Dakota, and Texas. Based on the value of the BP test statistic of 15.104, and on the value of the LB test statistic of 89.157, heteroskedasticity and serial correlation are in fact present in this panel series. The parameter estimates are summarized in Table 4-4, noting that the total sample size is 252 and that South Dakota is the omitted dummy variable. The critical value of the Hansen J-test is 0.063, which indicates that the moment conditions are not incorrectly specified.

Results are similar to the Corn Belt states: the constant term is not significant and none of the dummy variables are significant. Also, the parameter estimates on farmland returns and farmland values are of the same sign and similar in magnitude. Based on the parameter estimates, the value of the exponential discount factor is also $\hat{\delta} = 0.929$ and the value of the hyperbolic discount parameter is $\hat{\beta} = 0.508$, however the standard errors are notably smaller in magnitude than the Corn Belt results. Conducting the implicit test of hyperbolic discounting yields an F-statistic of 6.389 while the explicit test yields an F-statistic of 5.064, both reject exponential discounting at the 5% level for (1, ∞) degrees of freedom and imply that $\hat{\beta}$ is significantly different from one. Therefore, discounting is better represented by a hyperbolic discount factor for the Great Plain states. More importantly, the results imply a significant difference between the long-run and short-run rates of discount. The long-run discount rate is $-\ln(0.929) = 7.4\%$ and the short-run discount rate is $-\ln(0.508 * 0.929) = 75.1\%$.

Lake States

The Lake states consist of Michigan, Minnesota, and Wisconsin. Heteroskedasticity and autocorrelation are indicated based the BP test statistic of 14.463 for the values and returns series and the LB test statistic is 64.008 for the change in land values series. The parameter estimates are summarized in Table 4-5. Total sample size for the Lake states is 126, with the omitted dummy variable being Michigan. Based on the choice of instrument, the J-test statistic for this panel is 0.089, again suggesting that the over-identifying restrictions cannot be rejected. The calculated value of the exponential discount factor is $\hat{\delta} = 0.890$. The hyperbolic discount parameter is $\hat{\beta} = 0.546$, with a critical value of the F-statistic of 3.920 based on (1, 121) degrees of freedom and a 5% level of significance. The implicit F-test statistic is 5.090 and the explicit F-test statistic is 4.187, both suggesting a rejection of exponential discounting and implying that again $\hat{\beta}$ is significantly different from one. Thus the Lake states panel is better described by quasi-hyperbolic discounting. The long-run rate of discount is $-\ln(0.890) = 11.6\%$ while the short-run rate of discount is given by $-\ln(0.546 * 0.890) = 72.2\%$.

Mountain States

The Mountain states consist of Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, and Wyoming. The omitted dummy variable in the analysis is Arizona and the total sample size is 336 observations. The value of the BP test statistic, 13.434, implies that the land returns and values variables are heteroskedastic. The BL statistic, with a value of 42.712, suggests that the change in land values series is serially correlated. The GMM regression estimates, presented in Table 4-6, yield a J-test statistic of 0.055, and so over-identification is met.

The constant term is negative and insignificant. The parameter estimate of farmland returns is negative and significant, while the estimate of farmland values is positive and significant. None of the state dummy estimates are significant, though they differ in sign and magnitude. The value of the exponential discount factor is $\hat{\delta} = 0.897$ and the value of the quasi-hyperbolic discount factor is $\hat{\beta} = 0.637$. The implicit test, which has a null hypothesis of exponential discounting, has an F-statistic of 3.949, and so the null hypothesis is rejected at the 5% level of significance. The explicit test, which has no hyperbolic discounting as the null hypothesis, has an F-statistic of 3.305, implying that the null hypothesis cannot be rejected at the 5% level, but can be rejected at the 10% level. Based on the values of the discount parameters, the long-run rate of discount is $-\ln(0.897) = 10.9\%$ and the short-run discount rate is given by $-\ln(0.637 * 0.890) = 56.8\%$. Again, evidence of quasi-hyperbolic discounting over exponential discounting is found.

Northeast States

The Northeast states consist of Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont. Rhode Island is the omitted dummy variable in the analysis, with 462 total observations in the sample. The BP test statistic of 82.065 indicates heteroskedasticity in the independent variables. The dependent variable is serially correlated, as evidence by the BL test with a statistic of 106.067. The over-identifying restrictions cannot be rejected, based on a J-test statistic of 0.047.

The parameter estimates are summarized in table 4.7. The constant term is positive and insignificant. The estimate on farmland values is positive and significant, which is contrary to the theoretical model prediction of a negative coefficient. The coefficient estimate is just barely significant at the 5% level, though significant nonetheless. The estimate on farmland returns is positive and significant. None of the state dummy variables are statistically significant. Based on the estimates of α_1 and α_2, the exponential discount parameter is $\hat{\delta} = 0.966$ and the quasi-hyperbolic discount parameter is $\hat{\beta} = -.107$. The negative number on the quasi-hyperbolic parameter is a strange result, and is a statistically significant one. The implicit test yields a F-statistic of 315.572 and the explicit test yields a F-statistic of 278.590, which rejects exponential discounting at any level of significance. However, based on the negative value of the quasi-hyperbolic parameter, the implication of the hypothesis tests is questionable. The results imply a negative short-run discount rate of -227.07% and a long run discount rate of 3.5%. Most studies of farmland values ignore the Northeast region completely, owing to the diverse nature of the land market and the weak agricultural sector in these states.

Pacific States

The Pacific states consist of California, Oregon, and Washington. The BP test statistic of 22.462 implies heteroskedasticity in the independent variables and the BL test statistic of 61.317 implies autocorrelation in the dependent variable. The parameter estimates are summarized in Table 4-8, noting that the omitted dummy variable is California and that the total sample size is 126 observations. The exponential discount parameter is $\hat{\delta} = 0.933$ while the hyperbolic discount parameter is $\hat{\beta} = 0.361$. The implicit and explicit tests of hyperbolic discounting yield F-test statistics of 8.881 and 6.563, respectively. Hence, at 5% level of significance and (1, 126) degrees of freedom, the null hypothesis of exponential discounting, that is the null hypothesis of $\hat{\beta} = 1$, is strongly rejected. Again, evidence of hyperbolic discounting is found over exponential discounting. The implied long-run and short-run discount rates are $-\ln(0.933) = 6.9\%$ and $-\ln(0.361 * 0.933) = 108.8\%$, respectively.

Southeast States

The Southeast states consist of Alabama, Florida, and Georgia. The total sample size used in the analysis is 168, with the omitted dummy variable being Florida. The Breusch-Pagan test for heteroskedasticity resulted in a test statistic of 33.245, indicating the presence of heteroskedasticity. To test for autocorrelation, a Ljung-Box test is conducted, resulting in a test statistic of 56.392, which indicates the presence of serial correlation. Hansen's test of overidentifying restrictions resulted in a test statistic of 0.077. Since the critical value is 9.488, the over-identifying restrictions cannot be rejected.

The parameter estimates are summarized in Table 4-9. The constant term is not significantly different from zero, as expected. The estimated coefficients on farmland returns (α_1) and farmland values (α_2) are of the expected sign and both are statistically significant from zero. None of the state dummies are statistically significant. The exponential discount factor is $\hat{\delta} = 0.910$. To test whether these calculations represent exponential discounting, the implicit test of $H_o : \alpha_2 - \alpha_1 = 1$ is conducted. The calculated F-statistic is 9.900, which exceeds the critical value at (1, 162) degrees of freedom of 3.840 at 0.05 level of significance. Hence, the null hypothesis of exponential discounting is rejected. The hyperbolic discount factor is $\hat{\beta} = 0.313$ with a computed standard error of 0.259. The explicit test of hyperbolic discounting, $H_0 : -\alpha_1 / (1 - \alpha_2) = 1$, is next conducted resulting an F-statistic of 7.043, hence rejecting the null hypothesis of no hyperbolic discounting at any conventional level of significance. Further, the values of β and δ imply a short-run discount rate of $-\ln(0.313 * 0.920) = 124\%$ and a long-run discount rate of $-\ln(0.920) = 8.4\%$.

Chapter Summary

The data set used in the analysis was described and the exact definition of the variables utilized was also provided. This chapter also presented the estimation results from the quasi-hyperbolic farmland value asset equation. Three key remarks regarding the nature of the results are warranted. First, a clear case has been made not only against the standard exponential discounting model, but for the presence of hyperbolic discounting as a viable alternative. Second, an important consideration is that the discount parameters were obtained without constraining $\delta \in [0,1]$ or $\beta \in [0,1]$, a fact which should lend additional credibility to the estimates. Based on the values of the exponential and quasi-hyperbolic discount parameters, strong evidence has been found that the short-run discount rate is both different and substantially larger than the long-run discount rate.

Lastly, estimates of the discount parameters suggest that $\beta < \delta$ is true for farmland values. This result is concordant with the existing body of studies that estimate or calibrate a quasi-hyperbolic discount parameter (Laibson et al. 1998; Angeletos et al. 2001; Eisenhauer and Venture 2006; Ahumada and Garegnani 2007). Smaller values of both β and δ imply a greater tendency of the farmer-landowner to consume now rather than in future periods and therefore tend to save and invest less. Lower values of β will result in a larger jump between the first two time periods. This jump in the value of the discount factor is what creates dynamic time inconsistent preferences. As $\beta \to 1$, the discount factor converges to the standard exponential case. Smaller values of δ will result in a more bowed-shaped discount factor implying a greater preference for immediate consumption. As δ gets closer to zero, meaning the rate of time preference ρ increases, the shape of the discount factor becomes more convex to the origin.

The values of the short-run and long-run discount rates for each region are summarized in Table 4-10, along with the value of the F-statistic for statistical difference from the explicit test of hyperbolic discounting. Most of the long run discount rates are below 10%, which is reasonable when compared to prevailing interest rates in the land market, although on the higher end. Data obtained from the USDA/ERS on the average nominal interest rate in the U.S. on farm business debt yields a national average of about 3.92% for 1960-2002 time period. As reflected in Table 4-10, the short-run discount rates are extremely high and cover a wide range in values from 57% for the Mountain states to 288% for the Appalachian states. Four regions have short-run discount rates under 100%, which include the Corn Belt, Great Plain, Lake, and Mountain states. Three regions have short-run discount rates above 100%, which include the Delta, Pacific, and Southeast states. The Appalachian region has a short-run discount rate of over 200% and the Northeast region has a negative discount rate below 200%. Note that the difference in the short-run and long-run discount rate is not statistically significant for the Corn Belt region and is only statistically significant at the 10% level for the Mountain region. In the next and final chapter, a more in-depth commentary on the meaning of the results is presented along with concluding statements.

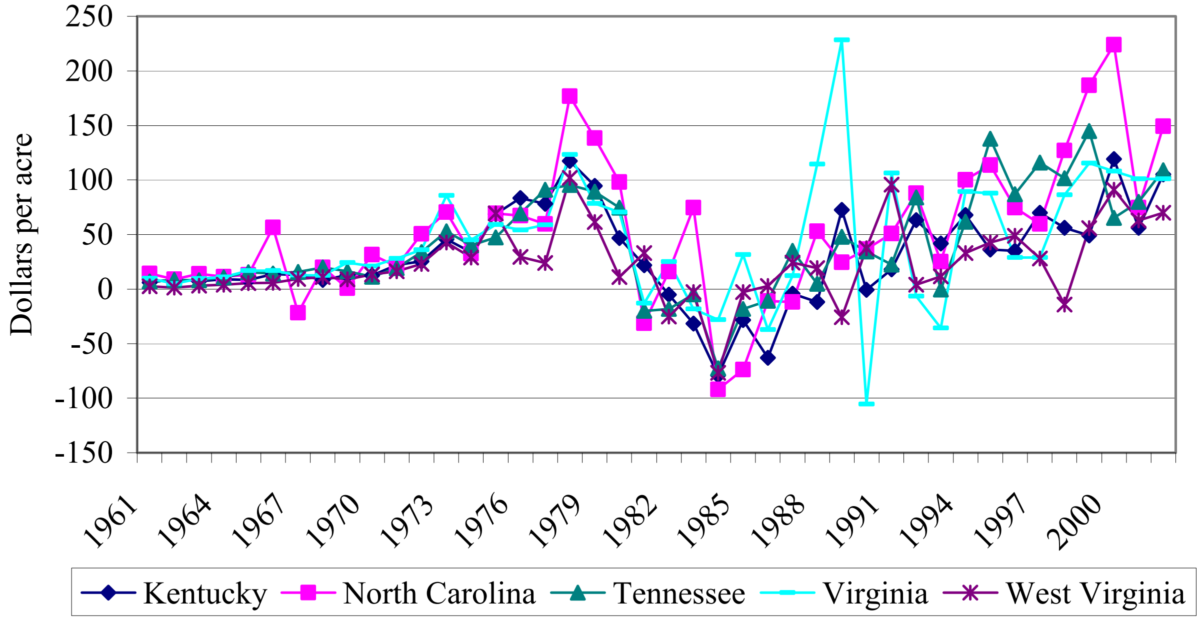

Figure 4-1. Change in farmland values for the Appalachian states

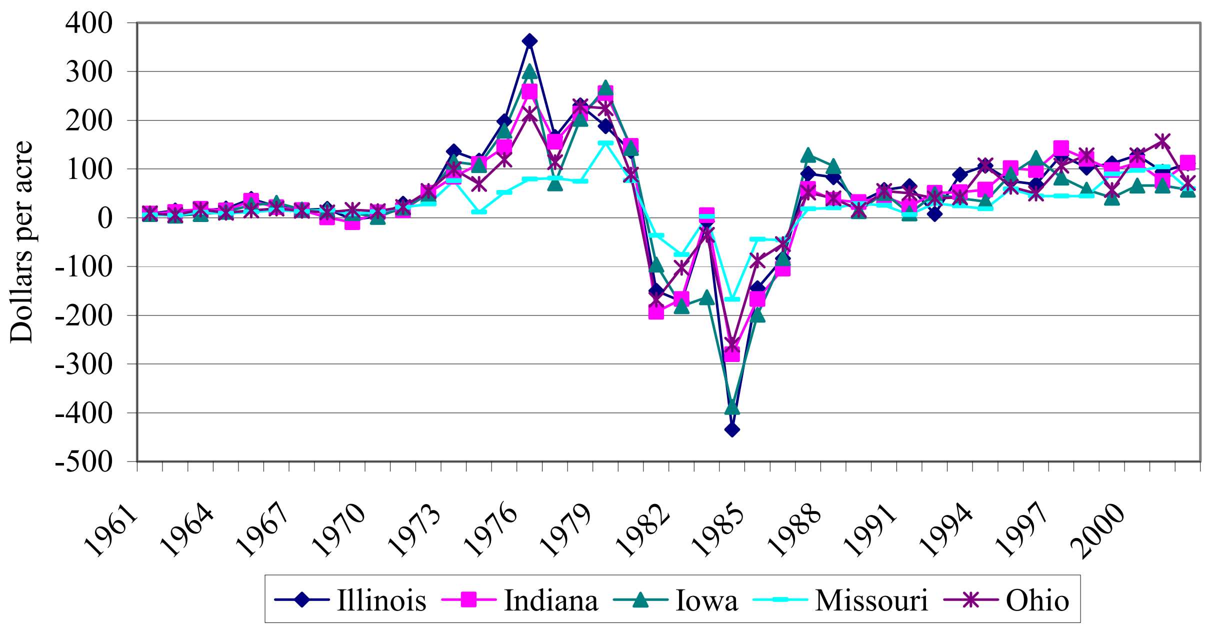

Figure 4-2. Change in farmland values for the Corn Belt states

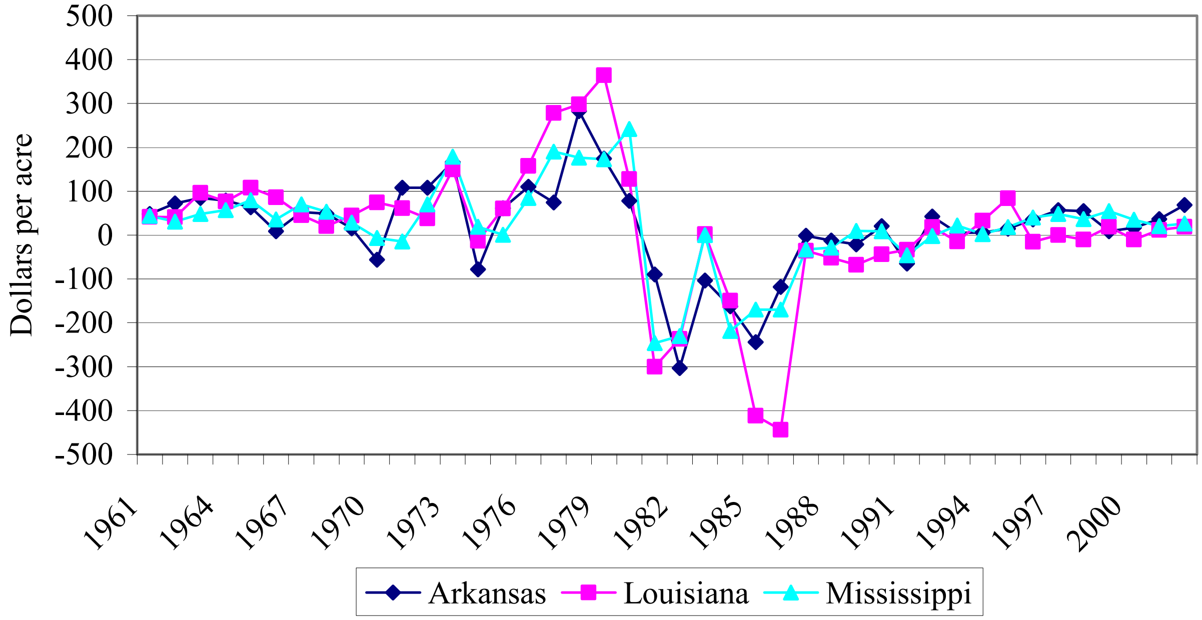

Figure 4-3. Change in farmland values for the Delta states

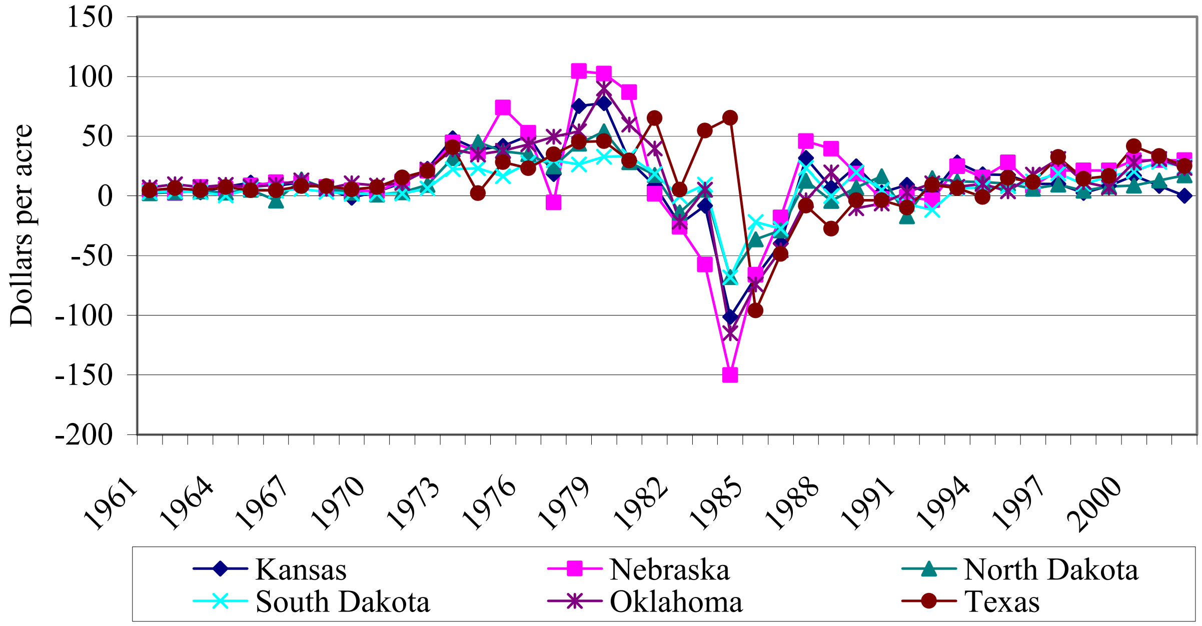

Figure 4-4. Change in farmland values for the Great Plain states

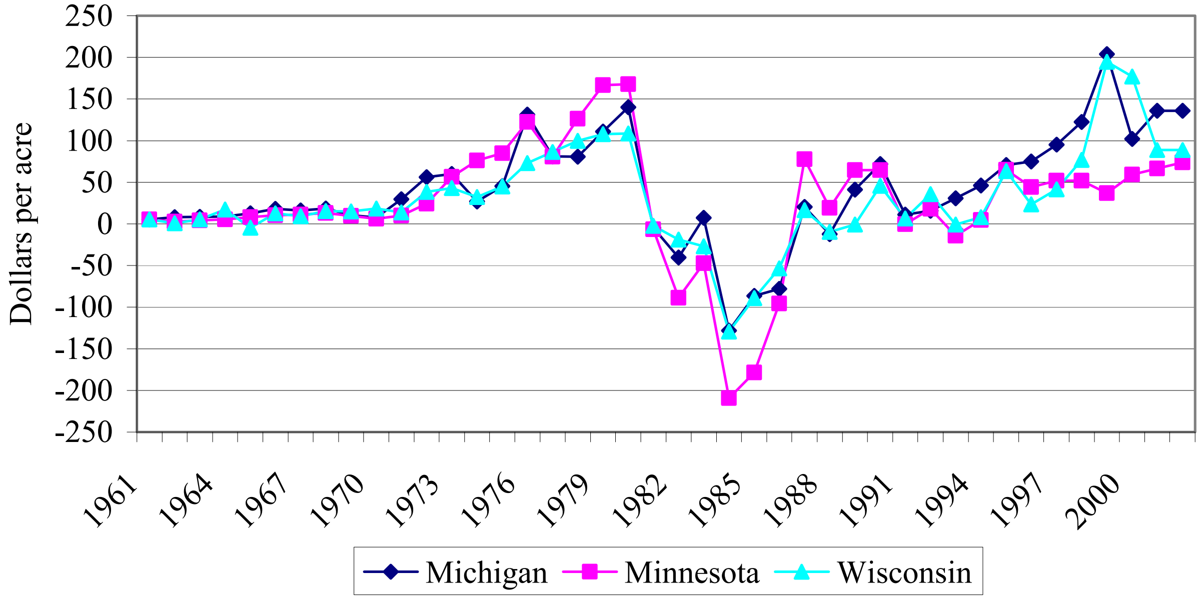

Figure 4-5. Change in farmland values for the Lake states

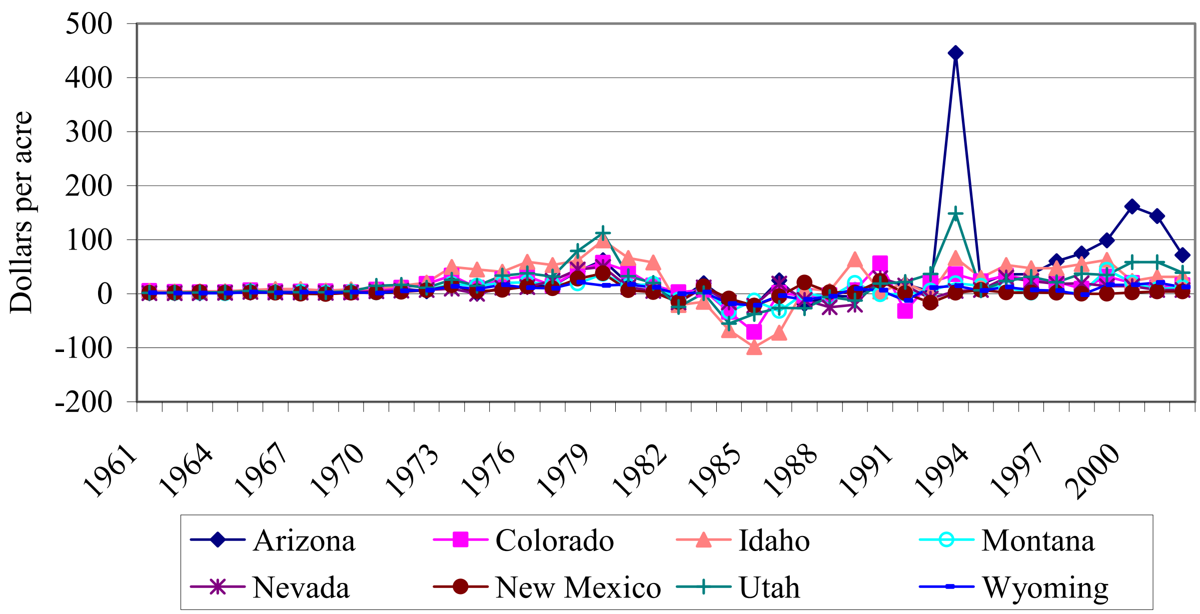

Figure 4-6. Change in farmland values for the Mountain states

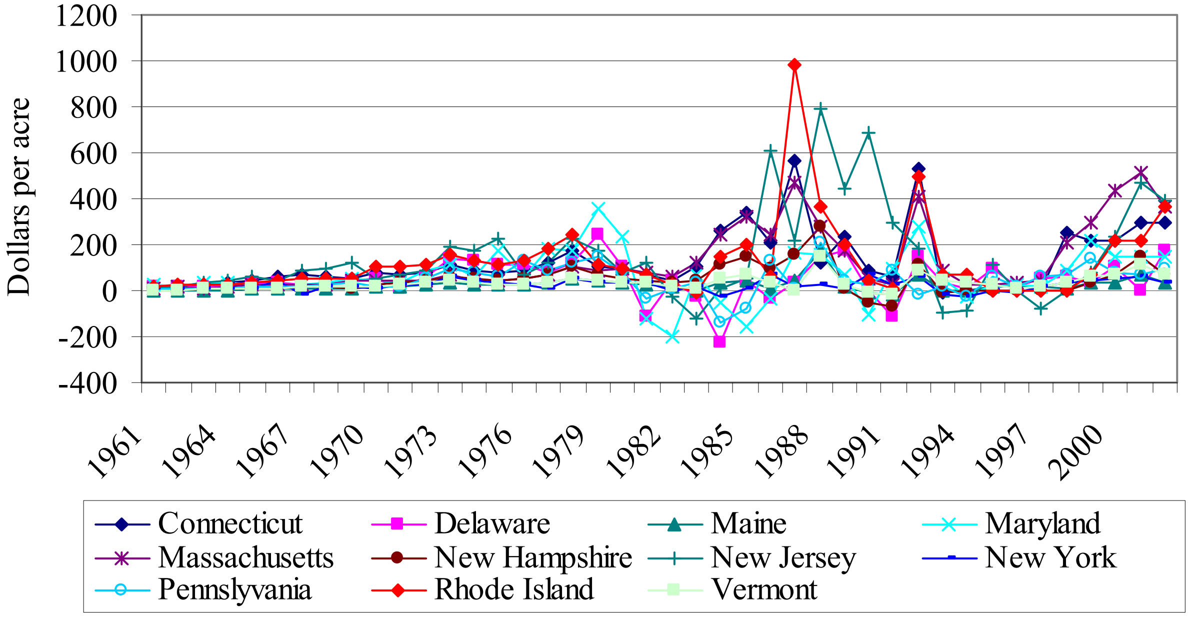

Figure 4-7. Change in farmland values for the Northeast states

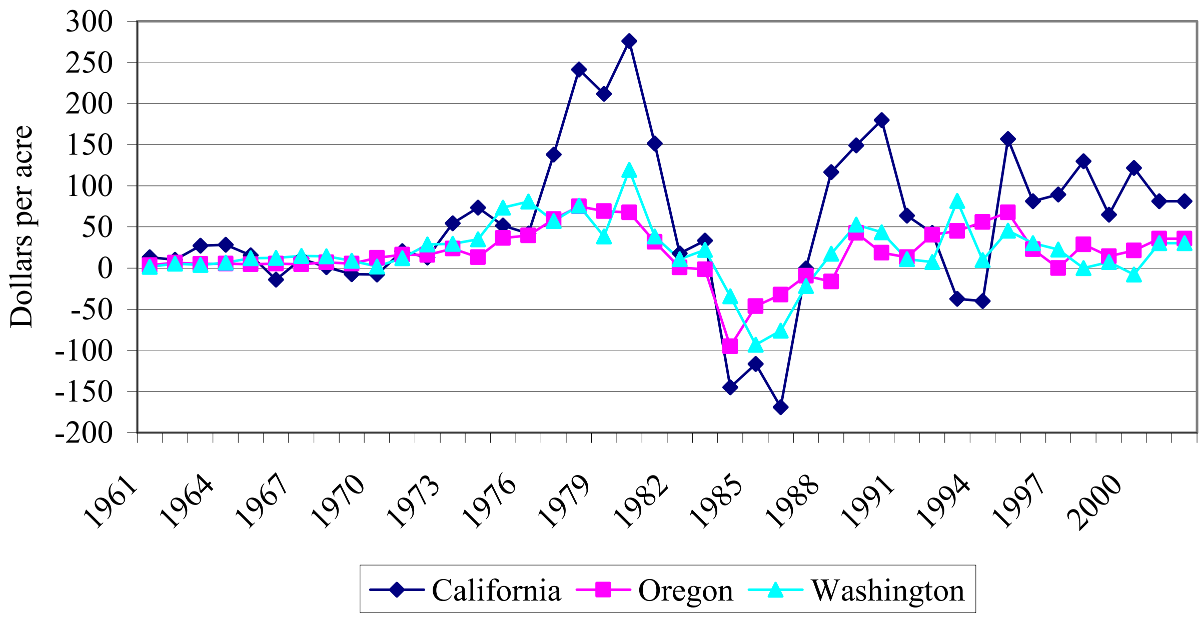

Figure 4-8. Change in farmland values for the Pacific states

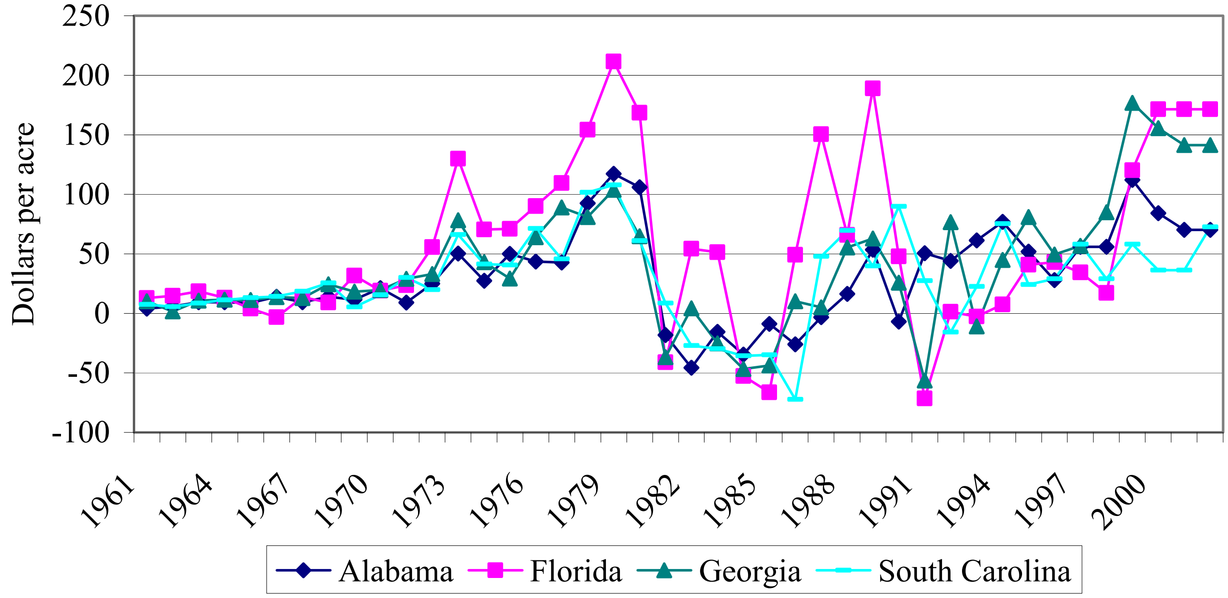

Figure 4-9. Change in farmland values for the Southeast states

Table 4-1. Appalachian states result

Variable	Parameter estimate	Standard error	t-statistic	p-value
α_0	−0.168	10.807	−0.016	0.494
α_1	−0.056	0.080	−0.701	0.242
α_2	0.061	0.011	5.771	0.000
α_3 (KY)	−0.508	10.791	−0.047	0.481
α_4 (TN)	1.923	12.310	0.156	0.438
α_5 (VA)	−0.140	12.259	−0.011	0.495
α_6 (WV)	0.086	12.798	0.007	0.497
δ	0.939	0.011		
β	0.060	0.086		
N = 210				

Table 4-2. Corn Belt states result

Variable	Parameter estimate	Standard error	t-statistic	p-value
α_0	19.499	17.525	1.113	0.133
α_1	−0.543	0.316	−1.717	0.043
α_2	0.071	0.020	3.615	0.000
α_3 (IL)	−13.529	23.407	−0.578	0.282
α_4 (IN)	−2.722	23.020	−0.118	0.453
α_5 (IA)	−1.576	24.489	−0.064	0.474
α_6 (OH)	−3.057	23.066	−0.133	0.447
δ	0.929	0.020		
β	0.584	0.349		
N = 210				

Table 4-3. Delta states result

Variable	Parameter estimate	Standard error	t-statistic	p-value
α_0	3.306	15.068	0.219	0.413
α_1	−0.150	0.240	−0.624	0.266
α_2	0.037	0.028	1.333	0.091
α_3 (AR)	10.922	14.785	0.739	0.230
α_4 (MS)	10.467	13.815	0.758	0.224
δ	0.963	0.028		
β	0.155	0.252		
N = 126				

Table 4-4. Great Plain states results

Variable	Parameter estimate	Standard error	t-statistic	p-value
α_0	0.242	5.472	0.044	0.482
α_1	−0.472	0.195	−2.419	0.008
α_2	0.071	0.019	3.714	0.000
α_3 (KS)	4.162	6.662	0.625	0.266
α_4 (NE)	0.572	6.798	0.084	0.466
α_5 (ND)	−0.073	6.452	−0.011	0.495
α_6 (OK)	−0.354	7.000	−0.051	0.480
α_7 (TX)	−0.460	7.177	−0.064	0.474
δ	0.929	0.019		
β	0.508	0.218		
N = 252				

Table 4-5. Lake states results

Variable	Parameter estimate	Standard error	t-statistic	p-value
α_0	0.163	14.588	0.011	0.496
α_1	−0.486	0.191	−2.551	0.005
α_2	0.110	0.019	5.940	0.000
α_3 (MN)	−11.146	12.858	−0.867	0.193
α_4 (WI)	10.203	14.100	0.723	0.235
δ	0.890	0.019		
β	0.546	0.222		
N = 126				

Table 4-6. Mountain states result

Variable	Parameter estimate	Standard error	t-statistic	p-value
α_0	−1.865	5.707	−0.327	0.372
α_1	−0.571	0.173	−3.296	0.000
α_2	0.103	0.013	8.209	0.000
α_3 (CO)	−2.711	7.035	−0.385	0.350
α_4 (ID)	4.871	8.854	0.550	0.291
α_5 (MT)	−2.140	7.032	−0.304	0.380
α_6 (NV)	0.154	7.031	0.022	0.491
α_7 (NM)	−0.987	7.128	−0.138	0.445
α_8 (UT)	−0.825	6.820	−0.121	0.452
α_9 (WY)	1.280	7.124	0.180	0.429
δ	0.897	0.013		
β	0.637	0.200		
N = 336				

Table 4-7. Northeast states result

Variable	Parameter estimate	Standard error	t-statistic	p-value
α_0	8.676	20.627	0.421	0.337
α_1	0.103	0.065	1.604	0.054
α_2	0.034	0.006	5.605	0.000
α_3 (CT)	−3.469	23.041	−0.151	0.440
α_4 (DE)	−5.109	23.685	−0.216	0.414
α_5 (ME)	2.288	24.870	0.092	0.463
α_6 (MD)	−2.850	24.014	−0.119	0.453
α_7 (MA)	−2.379	23.496	−0.101	0.460
α_8 (NH)	−0.355	24.993	−0.014	0.494
α_9 (NJ)	−2.204	23.982	−0.092	0.463
α_{10} (NY)	0.689	24.768	0.028	0.489
α_{11} (PA)	−6.380	24.306	−0.263	0.396
α_{12} (VT)	9.405	24.744	0.380	0.352
δ	0.966	0.006		
β	−0.107	0.066		
N = 462				

Table 4-8. Pacific states result

Variable	Parameter estimate	Standard error	t-statistic	p-value
α_0	18.803	16.802	1.119	0.132
α_1	−0.337	0.224	−1.507	0.066
α_2	0.067	0.027	2.517	0.006
α_3 (OR)	−19.901	16.794	−1.185	0.118
α_4 (WA)	−11.209	15.045	−0.745	0.228
δ	0.933	0.027		
β	0.361	0.249		
N = 126				

Table 4-9. Southeast states result

Variable	Parameter estimate	Standard error	t-statistic	p-value
α_0	10.841	11.657	0.930	0.176
α_1	−0.280	0.142	−1.969	0.024
α_2	0.078	0.021	3.652	0.000
α_3 (AL)	−3.429	11.492	−0.298	0.383
α_4 (GA)	0.356	11.436	0.031	0.488
α_5 (SC)	−5.252	11.394	−0.461	0.322
δ	0.922	0.021		
β	0.304	0.161		
N = 168				

Table 4-10. Discount rates by region

Region	Short-run discount rate	Long-run discount rate	F-statistic[1]
Appalachian	287.6%	6.3%	102.152
Corn Belt[2]	61.2%	7.4%	1.417
Delta	190.2%	3.8%	11.199
Great Plain	75.1%	7.4%	5.064
Lake	72.2%	11.6%	4.187
Mountain[3]	56.8%	10.9%	3.305
Northeast	−227.0%	3.5%	278.590
Pacific	108.8%	6.9%	6.563
Southeast	124.0%	8.4%	9.900

[1] The critical value of the F-statistic with $(1, \infty)$ degrees of freedom and 5% level of significance is 3.840.
[2] Discount rates are not statistically different from one another at conventional levels
[3] Discount rates are statistically different from one another at the 10% level of significance.

CHAPTER 5
CONCLUSION AND FUTURE WORK

This chapter presents a more thorough interpretation of the empirical results with three main goals. The first goal of this chapter is to foster a greater understanding of the results and offers a comparison to other relevant studies on time discounting while also focusing on the major weaknesses and limitations of the study. Second, a discussion on the importance and intuition of the results is also presented with an emphasis on the practical implications of the results and the major relevance to policy and extension. Finally, suggestions for future research are provided. The dissertation concludes with a summary.

Comparisons and Limitations

The empirical results prompt three key questions regarding the estimates of the short-run and long-run discount rates presented in Table 4-10. First, why are there differences in discount rates within regions? Second, why are there differences in discount rates across regions? Lastly, and most importantly, why are the short-run discount rates so high compared to the long-run discount rates? The first two questions can be addressed rather succinctly while the last one requires more thoughtful consideration.

The first question regarding differences in short-run and long-run discount rates within a specific region relates to the crux of the dissertation regarding time-inconsistency and non-constant discounting. Evidence in numerous fields of economics has found that individuals are not time-consistent in their intertemporal preferences but rather time-inconsistent. This time-inconsistency is the result of two related but distinct phenomena, preference reversals and intra-personal games, as explained in Chapter 1. Time inconsistency implies a non-constant and declining discount rate through time, meaning that discount rates in the short-run will be larger than discount rates in the long-run. Quasi-hyperbolic discounting is a declining discount function and represents one way of modeling time-inconsistent preferences. The question regarding why differences in the short-run and long-run discount rates exist is answered by the presence of time-inconsistent preferences. Chapter 1 presented the reasoning and intuition as to why a landowner might be characterized by time-inconsistency and why quasi-hyperbolic discounting might be present in the land market with a particular emphasis on land conversion models.

The second question pertaining to why the short-run and long-run discount rates differ between regions is best explained by the heterogeneity of the land market, the landowner, and the regional economy. Variables affecting the value of land not accounted for in this analysis will have a direct effect on the discount rate whether such variables are land-specific, landowner-specific, or economy-specific. Hedonic characteristics of the land, such as parcel size, location, and soil quality differ greatly both within and between major agricultural regions, and have been found in a number of studies to directly affect farmland values (Carrion-Flores and Irwin 2004; Taylor and Brester 2005; Livanis et al. 2006). For example, Livanis et al. (2006) estimate a positive affect of median single-family house value on U.S. farmland values.

Landowner-specific characteristics also vary substantially between regions. Barnard and Butcher (1989) show how the demographic characteristics of the landowner, such as age, education, income, and other traits affect the perceived present value of undeveloped land. Since demographic variables affect the perceived present value, the discount rate is also going to differ not only between individuals, but between regions as well. Eisenhauer and Ventura (2006, p.1229), using international survey data, find that hyperbolic discounters tend to be "younger, poorer, less educated, blue-collar, unemployed, individuals from larger cities, and those in southern regions working in agriculture." In a study using survey data from a developing country, Robberstad and Cairns (2007) find that individuals who obtain most of their income from farming will have higher discount rates than individuals whose main income is non-farm related. To the extent these demographic traits exist and differ between regions, differences in the discount rate, particularly the short-run discount rate, are to be expected.

Lastly, the state of the economy will affect intertemporal preferences and the implied discount rate. In an influential study, Lawrance (1991) uses data from the Panel Study of Income Dynamics and finds evidence that time preferences are positively related to household income. In particular, the author concludes that poor households tend to have relatively higher discount rates. In a meta-analytic review of time discounting studies, Percoco and Nijkamp (2007) find that the discount rate is negatively related to the level of per capita GDP implying that as GDP rises on a per capita basis, the discount rate falls. Since both household income and state level GDP differ between the agricultural regions studied in this dissertation, and even between states in each region for that matter, differences between both the short-run and long-run discount rate are to be expected.

This brings us to the third and final question regarding the magnitudes of the short-run discount rates and why they are so stark compared to the long-run discount rates. The results of hypothesis tests imply a formal rejection that the short-run discount rate is equal to the long-run discount rate, a new result in the literature on land values. The results in this dissertation are unique and there are no baseline estimates for which to make exact comparisons. Although one would be hard-pressed to defend the estimated short-run discount rates given in Table 4-10 in actual financial analysis, the presence of large discount rates is not without precedent in the empirical literature on both time-consistent discounting and time-inconsistent discounting.

Important studies on constant discounting in energy consumption and household durables have revealed large exponential discount rates. Hausman (1979), using data on air conditioner purchases, finds personal discount rates ranging from 5% to 89% depending on household income, with higher income households having lower discount rates. Houston (1983), using a survey method on energy appliance demand, finds discount rates in the range of 20% to 25% also depending on income. Gately (1980), using data on refrigerator purchases, finds much higher discount rates ranging from 45% to 300% with most of the discount rates exceeding 100%, depending upon the energy efficiency and brand name of the refrigerator. Using data on military personnel and retirement decisions, Warner and Pleeter (2000) estimate personal discount rates in the range of 0% to 59%, again depending on the individual characteristics.

One of the only known studies to estimate the rate of time preference in an agricultural context is Lence (2000). Using consumption and asset return data for U.S. farmers, he estimates the standard discount factor to be $\delta = 0.962$, implying a long-run discount rate of 3.92%. However, Lence (2000) assumes time-consistency and only examines time preference with standard exponential discounting. While there are no existing studies that examine land values in this context for which to compare estimates, the values of the quasi-hyperbolic discount parameter, β, obtained here in the range of 0.06 to 0.64 (including even one negative value for the Northeast) is lower than many estimates presented in the experimental economics literature, typically calculated between 0.80 and 0.90 (Benzion, Rapoport, and Yagil 1989; Coller and Williams 1999; Eisenhauer and Ventura 2006).

The findings in this dissertation are similar with the few studies that have estimated quasi-hyperbolic time preferences from field data using a structural model. Laibson, Repetto, and Tobacman (2007) use individual level data on credit card borrowing, consumption, income, and retirement savings to estimate the discount factors finding that $\delta = 0.958$ and $\beta = 0.703$, both statistically significant. Their results imply a short-run discount rate of 39.53% and a long-run discount rate of 4.29%. Fang and Silverman (2004) use panel data from the National Longitudinal Survey of Youth (NLSY) on welfare participation for single mothers and estimate how time-inconsistency affects the decision to take-up welfare. The authors estimate the discount factors to be $\delta = 0.875$ and $\beta = 0.338$, implying a short-run discount rate of 121.82% and a long-run discount rate of 12.78%. Paserman (2004) uses data on unemployment spells and job search duration from the NLSY to estimate time preferences. In a sample of low-wage workers his estimates of the discount parameters, $\delta = 0.996$ and $\beta = 0.402$, imply short-run and long-run discount rates of 91.53% and 0.40%, respectively. His findings show the rate of time preference increases as the wage level increases. The high-wage sample in Paserman (2004) yields discount parameter estimates of $\delta = 0.999$ and $\beta = 0.894$, implying a short-run discount rate of 11.31% and a long-run discount rate of 0.10%.

Clearly, the literature offers anecdotal explanations as to why the short-run discount rates stand in such sharp contrast to the long-run discount rates. Given that the primary data set in this dissertation is agricultural land values, the evidence from both Ventura (2006) and Robberstad and Cairns (2007) regarding higher discount rates for agriculture lends additional explanation to the high short-run discount rates that were obtained. Further, to the extent that landowners and farmers have lower than average incomes, higher short-run discount rates may be expected, as described in Paserman (2004). The durable goods and energy demand literature also gave precedent for high discount rates. Since land can be considered a durable good itself, if not an infinitely lived asset, then high discount rates also make sense.

Despite the evidence of high short-run discount rates in the literature, the question remains as to why such high short-run discount rates have been found in this dissertation on farmland values. A simple mathematical explanation is offered first. The rent generated from land will affect the discount factor, and the regions differ greatly in terms of the income generated from agricultural use. Careful reexamination of the parameter estimates in Table 4-1 through Table 4-9 with the estimated discount rates in Table 4-10 reveals that as the estimated coefficient on farmland returns increases in magnitude the value of the short-run discount rate decreases in size. This of course is not coincidence since the relationship is an artifact of the theoretical model. In Equation (3-11), the quasi-hyperbolic discount parameter increases as the estimated coefficient on farmland returns increases. A higher quasi-hyperbolic discount parameter reflects greater individual patience, implying a lower short-run discount rate. When land returns are high, the short-run discount rate is lower, implying a greater level of short-run patience. When land returns are low, the short-run discount rate is high, implying a lower level of short-run patience, or a stronger desire for instantaneous gratification. Generally, land returns have been on an upward trend since 1960, however for many of the regions farmland returns have decreased substantially over the past 10 to 20 years, depending on the region. To the extent returns have fluctuated and fallen, the value of the quasi-hyperbolic parameter and the implied short-run interest rate will be biased upward. Future work should examine more closely the relationship between expected returns from land and the rate of time-preference.

However, more rigorous explanations for the relatively high short-run discount rates stem from the formulation of the net present value model in Chapter 3. The simplistic assumptions made in the theoretical and empirical model regarding risk neutrality, rational expectations, and no inflation are possible explanations for the high short-run discount rates reported in Table 4-

10. First, the presence of inflation will result in an upward bias in the estimated discount rate. Although inflation is not accounted for in the empirical analysis, there is reason to suspect that inflation and expectations of inflation will affect not only the present value of land, but both the short-run and long-run discount rates. Consider the argument outlined in Frederick, Loewenstein, and O'Donoghue (2002) stating that the presence of inflation creates an upward bias in discount rate estimates. The authors reason, quite simply, that a sum of money today is not worth the same sum if inflation is expected, in fact that sum of money will be worth less. In other words, should you expect inflation to occur in the next five years, spending \$500 today will generate more utility from consumption than spending \$500 in the future. Since inflation gives an incentive to value future rewards less than present rewards, the discount rate will be higher. As Frederick, Loewenstein, and O'Donoghue (2002) correctly state, the magnitude of this upward bias in the discount rate will depend on the individual expectations regarding the extent of inflation. In the farmland markets, inflation has been non-constant across the time horizon and as high as 13% in some cases (Moss 2003). Lloyd (1994) argues that land is purchased as a hedge against inflation based on investor perceptions of land as a resilient asset, capable of holding value in real terms amidst inflationary periods.

In fact, there is evidence to suggest that inflation may be the most important factor influencing farmland values. Moss (1997) examines the sensitivity of farmland values to changes in inflation, asset returns, and the cost of capital by employing Theil's (1987) statistical formulation of information. The basic premise of Moss (1997) states that changes in an independent variable that account for more volatility in farmland prices will imply larger fluctuations in farmland prices than an independent variable that accounts for less volatility, where the total amount of information is described in bits. According to the empirical results in

Moss (1997), inflation contributes the most to the explanation of changes in U.S. farmland values. Even more revealing is how inflation contributes to the explanation of farmland prices by region. The Appalachian region had inflation as the largest contribution of information to farmland values while the Northeast region had the lowest contribution of information to farmland values (Moss 1997). The results in Table 4-10 would seem to underscore the importance of inflation in discount rate estimates. The Appalachian region had the highest short-run discount rate, while the Northeast region had a negative discount rate, providing at least anecdotal evidence that inflation has resulted in an upward bias in the estimated discount rates in this dissertation. Further, the information contribution of inflation is far more uniform in the five states that compose the Appalachian region than the eleven states that compose the Northeast region.

As mentioned earlier, the data used in the analysis to obtain the discount rates in Table 4-10 are based on nominal rather than real data and so inflationary affects are present in the data. In fact, this represents an advantage to using nominal data over real data since real data loses the information present in nominal data from inflation. Further, the use of real data involves a debate regarding which deflator to use, the PPI, the CPI, or the PCE index. Unreported results reflected a sensitivity of the discount rates to the choice of deflator used and so nominal data were preferred to detract from a debate on the best method of deflating the data. At the present time, there is no well defined land price deflator and none of the current price deflators seem appropriate for the land market. Regardless, future work should attempt to extract the effects of inflation from the farmland values data and determine the impact on short-run and long-run discount rates.

Second, the presence of risk and uncertainty will also result in an upward bias in the estimated discount rate. Recall that the empirical results obtained in this dissertation and the discount rates presented in Table 4-10 are generated under the assumption of risk neutrality. Frederick, Loewenstein, and O'Donoghue (2002) point out that since a future reward received with some degree of delay is often associated with at least some degree of uncertainty, the exact effect of the rate of time preference on the size of the discount rate is a complicated relationship that is difficult to measure. However, there is evidence in both experimental data and field data to suggest that accounting for risk aversion reduces the size of estimated short-run and long-run discount rates. Using experimental data from the 2000 Bank of Italy Survey of Household Income and Wealth, Eisenhauer and Ventura (2006) find that controlling for risk aversion reduces estimates of the hyperbolic discount rate by several orders of magnitude.

Anderhub et al. (2001) utilize an experiment on college undergraduates to elicit discount rates and examine how risk and time preferences are inter-related. The authors find clear evidence that higher degrees of risk aversion are associated with lower values of the discount factor, which implies a higher discount rate. Hence, the authors find a positive relationship between the value of the risk aversion coefficient and the rate of time preference. Hence, higher risk aversion means heavier discounting, meaning risk averse individuals tend to be more impatient. Anderhub et al. (2001) argue that the heavier discounting seen in more risk averse individuals is the result of the uncertainty that surrounds future payoffs as opposed to immediate payoffs.

Andersen et al. (forthcoming), using experimental data from Denmark, jointly estimate the coefficient of relative risk aversion (CRRA) and the discount rates assuming both a time-consistent and time-inconsistent discount structure. In both cases, joint estimation of risk and time preference results in significantly lower discount rates congruent with market interest rates. Assuming risk neutrality and time-consistency, the authors obtain a discount rate of 25.2%, but when risk aversion is accounted for, the estimated discount rate falls to 10.1%. When time-inconsistent preferences are modeled using a hyperbolic discount factor evidence of declining discount rates are still obtained, but the magnitudes between the short-run and long-run discount rates is substantially softened. Thus, in contrast to Anderhub et al. (2001), who find a positive relationship, Andersen et al. (forthcoming) find a negative relationship between the degree of risk aversion and the rate of time preference. The authors attribute this finding to the fact that Anderhub et al. (2001) uses data on risk attitudes to impute the discount rate over money rather than over utility as in Andersen et al. (forthcoming). Estimated discount rates will be lower when defined over utility than when defined over money (Andersen et al. forthcoming). The high short-run discount rates in this dissertation may be a result of the data, which are based on dollar values of farmland rather than utility.

Using field data, Laibson, Repetto, and Tobacman (2007) estimate several versions of the life-cycle consumption model in which the CRRA is either jointly estimated or imposed on the model. The estimates of β and δ vary substantially in regards to both magnitude and statistical significance depending upon the risk assumption imposed. When the CRRA is jointly estimated the short-run discount rate falls from 39.53% to 14.63% and the long-run discount rate falls from 4.29% to 3.87%, with the estimated CRRA being about 0.22, which is quite low. The authors also impose values of the relative risk aversion coefficient on the estimates, ranging from a CRRA of three to a CRRA of one. As the imposed value of the CRRA falls, the estimated value of both β and δ rise, which implies both lower short-run and long-run discount rates. The results in Laibson, Repetto, and Tobacman (2007) would seem to imply that the greater the level of risk aversion, the lower the rate of time preference, meaning that risk averse individuals are more impatient. This would seem to make sense if future rewards are received with a greater amount of uncertainty than immediate rewards and is in accord with the results in Anderhub et al. (2001).

Farmland markets and farmland values are especially sensitive to risk, and farmland is in general considered a risky investment (Hanson 1995). As explained in Moss, Shonkwiler, and Schmitz (2003), changes in risk affect the value of farmland over time, as evidenced by estimates of the certainty-equivalence parameter in a data set on U.S. farmland returns, interest rates, and values. Both Lence (2000) and Chavas and Thomas (1999) reject the hypothesis of risk neutrality and find evidence of risk aversion in the U.S. farmland market. Antle (1987) finds evidence to suggest that agricultural producers are risk averse with a risk premium as high as 25% of expected returns. The large short-run discount rates presented in Table 4-10 could in fact be the result of not accounting for risk in the analysis. Future work should attempt to incorporate risk in models of farmland values and determine the extent that short-run and long-run discount rates are affected.

Third, and finally, the high short-run discount rates in Table 4-10 may be in part due to the possibly unrealistic assumption of rational expectations. Under rational expectations, landowners are assumed to correctly forecast, on average, future land rents using all relevant economic information without any systematic bias. However, some authors have attributed the short-run failure of NPV models of farmland to be a violation of rational expectations (Lloyd, Rayner, and Orme 1991; Tegene and Kuchler 1991; Engsted 1998). Furthermore, the short-run failure of the NPV model has also been noted in the literature on housing prices with strong rejection of the rational expectations hypothesis (Meese and Wallace 1994; Clayton 1996).

A possible alternative to rational expectations is an adaptive expectations formulation which assumes that landowners would base future expectations on land rents based on past land rents with the possibility of systematic bias due to stochastic economic shocks. Chow (1989) compared both rational and adaptive expectations in a NPV model of stock prices and dividends. Based on the parameters estimates, the NPV under rational expectations are not consistent with the theory. Obtained values of the long-run discount rates, for example, are above 100% when rational expectations is assumed. The inconsistent discount rates persist under rational expectations even when homoskedasticity is corrected for and a time-varying discount factor included in the model. When adaptive expectations is assumed, the obtained long-run discount rates become much more reasonable and congruent with market interest rates. Chow (1989) concludes that when a correct model incorrectly assumes rational expectations, then unreasonable parameter estimates are often the case

There is empirical evidence of atypical long-run discount rates under assumptions of rational expectations in the farmland values literature. Lloyd, Rayner, and Orme (1991) use a structural model similar to the one in this dissertation to obtain values of the long-run discount rate from a reduced-form parameterization of the structural model. The authors examine the NPV model of real farmland values in England and Wales using both rational and adaptive expectations. The rational expectations model uncovers a real long-run discount rate of −37.74% with a rejection of the null hypothesis of a positive real rate of discount. In the authors' adaptive expectations model, the real long run rate of discount is 2.38% and is much more in line with market interest rates.

Tegene and Kuchler (1991) compare the NPV model of U.S. farmland values under both rational and adaptive expectations for the Corn Belt, Lake States, and Northern Plain regions.

The estimated coefficients of land prices and rents in the rational expectations model imply discount rates above 100% and are inconsistent with the rational expectation hypothesis. In the authors' adaptive expectation model, long-run discount rates are found to be less than 7% and estimated parameters are consistent with the adaptive expectations hypothesis. The authors conclude with a strong rejection of rational expectations in favor of adaptive expectations. Promising future work remains in uncovering the relationship between expectation formulations and time preferences.

Importance and Implications

Although the magnitudes of the short-run discount rates presented in Table 4-10 are surprising, the results are not being recommended for use in financial analysis or in forecasting farmland values. As discussed above, the incorporation of inflation, risk, and adaptive expectations is suggested before such a recommendation is even contemplated. The results then are not so much important for the specific magnitudes of the short-run and long-run discount rates presented, but are important for what the differences in short-run and long-run discount rates imply for the land market. In this section, added intuition regarding the nature and importance of the results is offered. The value and practical use of the results are based on what they imply for land-use decision-making, what they offer for explaining the methodological failure of the NPV of farmland, and what they suggest in regards to landowner behavior. The results also have important policy and extension implications.

First, the results are important for their implication and description of land-use decisions and investments. The fundamental interpretation of the large short-run discount rates presented in Table 4-10 reflect the fact that landowners have a tendency to be short-run in their thinking. Such a near-term or short-run dominate way of thinking would tend to result in decisions that sacrifice the future for the sake of the present. For example, suppose a landowner is facing a decision of converting farmland to a more capital intensive use such as residential housing or an ethanol refinery plant with a large one-time monetary gain. The short-run and long-run discount rates obtained would imply that the landowner may be inclined to hastily accept such an offer without full consideration of more remunerative future returns from farmland. In essence, a landowner with a higher short-run discount rate may prefer to sell his land now to an investor for a substantial instant return, rather than be forward-thinking in his behavior and wait 20 years for a more remunerative return.

In a sense, the large short-run discount rates suggest a sort of short-run bandwagon that landowners have a tendency to ride. Recent investments in residential real estate and ethanol refineries have either failed to generate substantial returns or have resulted in financial losses. In some regard, a high short-run discount rate would provide an explanation into the occasional tendency of landowners to make short-sighted decisions regarding land use. For example, the long-run future rewards of grain-based ethanol production is in a precarious state, however, the short-run desire for instant returns may drive the decision of landowners to either plant more corn or to construct an ethanol refinery on their land. The notion of quasi-hyperbolic discounting would seem quite appropriate given the frenzy on biofuels and the ensuing land rush that has accompanied the phenomenon.

A 2006 editorial in *Nature Biotechnology* described the surge of investment in biofuels, which figures in the billions of dollars in the United States, as “irrational exuberance.” However, as of yet, no company has produced and sold ethanol in U.S. on any sort of mass level, raising doubts regarding the success of the current business model (Waltz 2008). Furthermore, the importance of land-use decisions in the bio-energy industry is critical, underscoring the importance of the results in this dissertation. Land is the largest and most valued productive input in ethanol production, and so time preferences regarding the value of land remain an important area of investigation. Given that land used in production of energy cannot be used in the production of food or other uses, the decisions made for every parcel over time are of great importance not only to economists, but to landowners, policy makers, and consumers. Hence, one of the largest contributions of the results in this paper is a numerical description of the impulsiveness that may characterize many land-use decisions.

Second, the results provide an explanation for the significant short-run deviations that occur in the discounted value formulation of farmland values (Falk and Lee 1998; Featherstone and Moss 2003). One explanation for the apparent disconnect between short-run and long-run values is the presence of boom/bust cycles in which farmland values change more dramatically than would be expected in response to an increase or decrease in returns (Schmitz 1995). Of course, the prevailing question remains: what causes boom/bust cycles in farmland values? In addition to transaction costs and time-varying risk premia, alternative explanations include the presence of quasi-rationality or rational bubbles (Featherstone and Baker 1987), market overreaction (Burt 1986), fads (Falk and Lee 1998), and option values and hysteresis (Titman 1985; Turvey 2002).

A possible explanation offered here is the presence of quasi-hyperbolic discounting. The mix of long-run rationality with short-run irrationality makes quasi-hyperbolic discounting an appealing explanation. The quasi-hyperbolic discount factor explicitly models disconnects between the short-run and long-run. Unlike other farm assets, farmland is unique in that approximately 80% of the asset portfolio in U.S. agriculture is accounted for by farmland values (Moss and Schmitz 2003). Unlike assets that have a definite life-span, such as capital equipment that depreciate substantially like tractors, farmland is typically characterized by an infinite horizon. Since the life span of land as an asset is infinite, the choice of the discount factor plays a premier role, and may be subject to the short-run jumps described by quasi-hyperbolic discounting. With quasi-hyperbolic discounting, the short-run bubble nature of farmland values can persist, but equilibrium in the long run can be achieved. Thus, during the life of the asset, especially during boom/bust cycles, the discount rate for farmland may change over time. During periods of economic boom, the rate of time preference decreases as available capital increases, implying more patience. During periods of economic bust, the rate of time preference decreases as borrowing increases to cover financial losses, implying a greater level of impatience.

The results are also important for their description of landowner behavior and, in particular, what they imply for farmland investment and savings. The results also further the Golden Eggs investment hypothesis presented by Laibson (1997). In an agricultural economics framework, the story of the goose that laid the golden egg can be thought of as a farmer who owns a region of land. The land represents the farmer's so-called goose, whose lifespan depends on whether he continues to keep the land in agriculture or convert the land to an urban use. The farmer has two options: one, he can sell the goose to a developer for some immediate sum and thus increase his stock of liquid assets; or two, he can keep the goose in the hopes of a more remunerative return and keep the illiquid asset. The time-inconsistent model presented in Laibson (1997) would suggest that hyperbolic discounters sell the goose and increase the stock of liquid assets to fund immediate consumption in the short-run. This is where the notion of commitment devices come into play. The farmer could alternatively decide to keep the goose, his farmland, in the current period and constrain his future self from developing the land in the next period. This may lend some support to the notion that the Conservation Reserve Program

(CRP) may serve as a commitment device to a farmer or landowner who potentially discounts hyperbolically. The CRP pays billions of dollars annually to landowners and farmers to keep land out of crop-use under 10 to 15 year contracts in order to sustain the land for future use.

Farmland may even serve as a commitment device itself to some landowners. Hyperbolic discounters tend to hold relatively little wealth in liquid assets and hold much more of there wealth portfolio in illiquid assets (Laibson 1997). According to the USDA Farm Balance Sheet published by the Economic Research Service, over $3 trillion of the portfolio (about 80% of the total) is attributed to land. Farmland also represents one of the most illiquid of assets in the farm investment portfolio. This may imply land is a golden egg to the farmer-landowner. In the literature on time-inconsistent preferences and hyperbolic discounting, illiquid assets serve two fundamental roles. The first role is as a commitment device, preventing one's future self from capriciously spending his wealth. The second role is as a golden egg, generating substantial benefits but only after a long period of time has elapsed. Although a less transparent instrument for commitment than other devices, land as an illiquid asset that generates a stream of income can serve as a mechanism to constrain future choices. Further, with an asset such as land, whose sale typically must be initiated a period or more before the actual revenues from the sale are obtained, farmland promises substantial benefits in the long-run but immediate benefits are hard to realize in the short-run. The difficult to sell nature of farmland can be attributed to a variety of factors including transaction costs, information asymmetries, and incomplete markets.

Finally, the results have important extension and policy relevance. The results underline the short-run nature of thinking of many farmers, growers, ranchers, and developers. The high calculated short-run discount rates compared to the low long-run discount rates imply the relative importance of the two time periods to a decision-maker, with the priority being the short-run. If the short-run discount rates suggest a tendency of individuals to sacrifice future returns for immediate gains, then extension efforts should attempt to curve or address this behavior. In essence, extension work must recognize that there is a short-run bandwagon that individuals have a tendency to focus on. Many agricultural investments that offer high short-run returns such as biofuel programs, commodity speculation, and urbanization offer dubious long-run security. Extension efforts should address this behavioral tendency and emphasize the long-run opportunities in postponing or delaying land development.

The greatest potential for policy may come from the design of pre-commitment devices for landowners. Christmas clubs were once a popular way of constraining individuals from spending money so that a stock of liquid cash would be available for the purchase of holiday gifts. Landowners may desire a similar style of commitment device so that their future self is constrained from making decisions against their present self, such as hasty land conversion or commodity speculation. As mentioned, the Conservation Reserve Program may serve as a commitment device for some landowners. However, the efficiency of the CRP is in doubt if landowners are time-inconsistent, resulting in a future decision to drop out of the program for higher monetary gain than the CRP offers.

Gulati and Vercammen (2006) model resource conservation contracts under time-inconsistent preferences. The authors note that commitment and time-inconsistency issues are important in the implementation of the CRP and other similar contracts. Since the CRP pre-determines payment schedules over the length of the contract according to a discounted present value model, problems of landowners dropping out of the contract are common. To address this problem, the authors suggest instituting penalties for dropping out of the CRP or for increasing the payment schedule over time in order to combat the hyperbolic nature of landowner time preferences. Since the results in this dissertation imply that landowners are described by quasi-hyperbolic time preferences, the results in this dissertation would seem to confirm the suggestions made by Gulati and Vercammen (2006).

Future Work

Given the evidence presented in this dissertation, critical attention should be devoted to the investigation of intertemporal preference in the land values literature specifically, and in the agricultural economics literature more generally. In regards to this dissertation, several potential areas for future research are offered. First, NPV models of land values under adaptive expectations should be explored and test for the presence of hyperbolic discounting. Another interesting extension would involve the incorporation of risk into the NPV model and simultaneously estimate both risk and time preference parameters. Such an extension may involve other models than the NPV model used here, such as Euler equations for investment and savings decisions. Also, including a better control of inflation in the NPV model offers an interesting and important area of exploration.

In regards to the general land literature, investigation on how the shape of the discount factor affects the co-movement of land price and land rents, as well as the affect on development and rural land conversion times and intensity are important and interesting questions. How does the timing of rural land conversion differ under hyperbolic time preferences? What does time-inconsistency imply for land taxes, conversion costs, and capital intensity of development efforts? Also, survey methods directed at landowners offer an attractive method of obtaining discount rates and testing for hyperbolic discounting.

There is also a range of interesting questions yet to be examined in the context of potential time-inconsistency and hyperbolic discounting in other research areas as well. Food demand, for example, offers a good opportunity for testing hyperbolic preferences and could also lend itself to experimental methods, which have become recently popular. Policy research on time-inconsistency and resource conservation contracts has just begun. Data on CRP participation offers a viable avenue of potential research. The model and the results in this dissertation could be generalized into a model of land conversion and seek implications on development timing under time-inconsistent preferences.

Indeed, there is no shortage of important and engaging questions to examine under the umbrella of intertemporal preferences. The investigation of non-constant discounting and time-inconsistency is waiting to be uncovered in the agricultural economics profession. It is hoped that this dissertation serves to fuel an enthusiastic interest in the topic.

Summary

This dissertation estimates the parameters of time preference in the land values asset equation, generalizing the standard discount factor to include quasi-hyperbolic discounting. While the present-value model has been used almost exclusively to estimate land values, empirical inquiry has revealed two serious flaws. First, present-value models are not able to explain the presence of rational bubbles and the apparent boom/bust nature of land prices. Second, there are apparent disconnects in the movement between land rents and land prices in the short-run versus the long-run. The poor performance of the PV model to estimate land values in other papers may of course be due to a variety of other potential issues, hyperbolic discounting being just one possibility. Failure of the standard discounting model may be attributed to transaction costs (Chavas and Tomas 1999) or time-varying risk premia in farmland returns (Hanson and Myers 1995). Another possible explanation for the poor performance of the present value model and its failure to stand up to empirical scrutiny may involves a priori assumptions on the shape of the discount factor.

In particular, this dissertation modifies the standard model to incorporate quasi-hyperbolic discounting; a generalized form of exponential discounting that has received considerable but recent attention in the financial and experimental economics literature. Statistically significant evidence of quasi-hyperbolic discounting over standard exponential discounting is uncovered in a dataset of U.S. farmland values and returns for the major agricultural regions of the United States. The results not only suggest a significant quasi-hyperbolic parameter, but significantly different short-run and long-run discount rates in eight out of the nine panel sets examined. The results show that individuals discount land far more heavily in the short-run than the long-run, with obtained short-run discount rates several orders of magnitudes larger than the obtained long-run discount rates.

The short-run discount rates obtained are not important for use in actual financial analysis, but for what they imply about land-use decisions, theoretical models of land values, and for landowner behavior. First, the high short-run discount rates suggest that landowner decisions tend to be dominated by short-run thinking. This may result in possible land investment projects that offer a high instant return, but offer little long-run gain. The short-run discount rates imply land decisions that tend to sacrifice the future for the sake of the present. Second, the presence of quasi-hyperbolic discounting offers an explanation into the apparent short-run and long-run disconnects in NPV models of farmland. Farmland values and returns tend to be well co-integrated in the long-run but not in the short-run. If individuals have a higher short-run discount rate than the long-run, then this might explain why the short-run dynamic relationship tends to break down. Third, the results offer evidence that farmland may acts as the so-called goose that laid the golden egg, with landowners caught in an internal tussle as whether to keep land in farming or to sell a developer for a more capital intensive use. In this case, commitment devices may be a helpful policy tool for the time-inconsistent landowner.

Some limitations to the results apply since the high short-run discount rates may be affected by the simplistic assumptions maintained in the theoretical model. First, individuals were assumed to be risk-neutral. Evidence in the literature suggests that not accounting for risk aversion results in short-run discount rates that are biased upward. Second, rational expectations were assumed, which has been shown to result in unreasonable discount parameter estimates in models of stock prices and farmland values. Third, inflation was not accounted for in this analysis which may also result in an upward bias in both the short-run and long-run discount rates. Although the assumptions made in this dissertation are limiting, they also offer a starting point for the analysis which is congruent with the assumptions made in the farmland values literature. While more complicated assumptions may result in lower discount rates, it is believed that significant differences between the short-run and long-run discount rate would still be uncovered.

Future work should attempt to obtain the time preference parameters under more relaxed assumptions of risk, expectations, and inflation. There is also tremendous potential for future work into time preferences and time inconsistency and other economic models such as land conversion and food demand. It is hoped that this dissertation has not only served to bridge the gap between the literature on intertemporal preferences and agricultural economics, but that it has sparked an interest into further investigation on time inconsistency in the profession.

APPENDIX
PROCEDURE FOR R-CODE

```
# TITLE: Appalachian State Panel OLS & Linear GMM

# RESET ALL WORK
rm(list = ls())

# Call needed libraries
library(lmtest); library(stats); library(tseries)
library(car); library(sandwich); library(systemfit)

# Download CPI Deflator
dta0 <- read.table("Deflators.dta")
cpi <- as.numeric(dta0[2:44,1])
lagcpi <- as.numeric(dta0[3:44,1])

# Download data sets
# Column Order: Y~KY~NC~TN~VA~WV~V~R~I~DV
dta <- read.table("AppalachiaNom.dta")

# Create lagged variables
obs <- nrow(dta)
lagVky <- as.matrix(dta[1:(43-1),7])
lagRky <- as.matrix(dta[1:(43-1),8])
lagVnc <- as.matrix(dta[44:(86-1),7])
lagRnc <- as.matrix(dta[44:(86-1),8])
lagVtn <- as.matrix(dta[87:(129-1),7])
lagRtn <- as.matrix(dta[87:(129-1),8])
lagVva <- as.matrix(dta[130:(172-1),7])
lagRva <- as.matrix(dta[130:(172-1),8])
lagVwv <- as.matrix(dta[173:(215-1),7])
lagRwv <- as.matrix(dta[173:(215-1),8])
lagV <- rbind(lagVky,lagVnc,lagVtn,lagVva,lagVwv)
lagR <- rbind(lagRky,lagRnc,lagRtn,lagRva,lagRwv)

# Define dep var, indep var, & scale
dvky <- as.matrix(dta[2:43,10])
dvnc <- as.matrix(dta[45:86,10])
dvtn <- as.matrix(dta[88:129,10])
dvva <- as.matrix(dta[131:172,10])
dvwv <- as.matrix(dta[174:215,10])
dv <- rbind(dvky,dvnc,dvtn,dvva,dvwv)
n <- nrow(dv)
constant <- as.matrix(seq(length=n,from=1,by=0))
vky <- as.matrix(dta[2:43,7])
vnc <- as.matrix(dta[45:86,7])
```

```
vtn <- as.matrix(dta[88:129,7])
vva <- as.matrix(dta[131:172,7])
vwv <- as.matrix(dta[174:215,7])
v <- rbind(vky,vnc,vtn,vva,vwv)
rky <- as.matrix(dta[2:43,8])
rnc <- as.matrix(dta[45:86,8])
rtn <- as.matrix(dta[88:129,8])
rva <- as.matrix(dta[131:172,8])
rwv <- as.matrix(dta[174:215,8])
r <- rbind(rky,rnc,rtn,rva,rwv)
one <- as.matrix(seq(length=42,from=1,by=0))
zero <- as.matrix(seq(length=42,from=0,by=0))
ky <- rbind(one,zero,zero,zero,zero)
nc <- rbind(zero,one,zero,zero,zero)
tn <- rbind(zero,zero,one,zero,zero)
va <- rbind(zero,zero,zero,one,zero)
wv <- rbind(zero,zero,zero,zero,one)
x <- cbind(constant,r,v,ky,tn,va,wv)
y <- dv

# OLS estimation and test results
ols <- lm(dv~r+v+ky+tn+va+wv)
output <- summary(ols); output
NWvcov <- as.matrix(NeweyWest(ols))
bptest(ols)
        # Null Hypothesis of BP test is homoscedasticity
        # Critical value is Chi-square with alp=.05, dof=2: 5.991
durbin.watson(ols,max.lag=2)
        # Null hypothsis is no autocorrelation (rho=0)
        # If d<dl reject, if d>du do not reject, if du>d>dl inconclusive
        # Critcal value is DW with k=2, n=41: dl=1.449, du=1.549
Box.test(dv, type = c("Ljung-Box"))
        # Null hypothesis is no autocorrelation (rho=0)
        # Critical value is Chi-square with alp=.05, dof=1: 3.841
adf.test(dv)
        # Null hypothesis is nonstationary (unit root)

# Calculate Discount Parameters
coeff <- as.matrix(ols$coefficients)
a1 <- coeff[2,1]; a2 <- coeff[3,1]
a1se <- sqrt(NWvcov[2,2]); a2se <- sqrt(NWvcov[3,3]); a1a2cov <- NWvcov[2,3]
delta <- 1-a2; beta <- -a1/(1-a2)

# Conduct linear hypothsis test on exponential discounting
q <- a2-a1-1
qse <- sqrt(a1se^2+a2se^2+2*a1a2cov)
```

```
exptest <- (q/qse)^2
deltase <- a2se
print("Value of Exponential Factor"); print(cbind(delta,deltase))
print("Exponential Discounting F-test"); print(exptest)
        # This is a two-sided F-test with dof=1,203 and alpha=0.05
        # Null hypothesis is exponential discounting
        # Critical value is 3.84

# Conduct nonlinear hypothesis test on hyperbolic discounting
ga1 <- -1/(1-a2); ga2 <- -a1/((1-a2)^2)
betase <- sqrt((ga1^2)*(a1se^2)+(ga2^2)*(a2se^2)+2*(ga1)*(ga2)*(a1a2cov))
hyptest <- ((beta-1)/betase)^2
print("Value of Quasi-Hyperbolic Factor"); print(cbind(beta,betase))
print("Quasi-Hyperbolic Discounting F-test"); print(hyptest)
        # This is one-sided F-test with dof=1,203 and alpha=0.05
        # Null hypothesis is no hyperbolic discounting
        # Critical value is 3.84

# Define IV matrix and scale
z <- as.matrix(cbind(constant,v,r,ky,tn,va,wv,r^2,lagV,lagR))
k <- ncol(z)

# Define initial weighting matrix
w <- nrow(z)*solve(t(z)%*%z)

# Define GMM function
fr <- function(b){
    (1/n)*t(y-x%*%b)%*%z%*%w%*%((1/n)*t(z)%*%(y-x%*%b)) }

# Define gradient
gfr <- function(b){
    -2*t(y-x%*%b)%*%z%*%w%*%t(z)%*%x }

# Conduct first step GMM
gmm <- optim(c(0,0,0,0,0,0,0),fr,gfr)
sse <- as.numeric(t(y-x%*%gmm$par)%*%(y-x%*%gmm$par)/nrow(y))
shat <- (sse/nrow(z))*(t(z)%*%z)
mhat <- nrow(z)*solve((t(x)%*%z)%*%w%*%(t(z)%*%x))%*%(t(x)%*%z)%*%w
vhat <- mhat%*%shat%*%t(mhat)
print(cbind(gmm$par,sqrt(diag(vhat)/nrow(x)),gmm$par/sqrt(diag(vhat)/nrow(x)),
        1-pnorm(abs(gmm$par/sqrt(diag(vhat)/nrow(x))))))

# Conduct second step GMM
w <- solve(shat)
gmm <- optim(c(0,0,0,0,0,0,0),fr,gfr)
sse <- as.numeric(t(y-x%*%gmm$par)%*%(y-x%*%gmm$par)/nrow(y))
```

```
shat <- (sse/nrow(z))*(t(z)%*%z)
mhat <- nrow(z)*solve((t(x)%*%z)%*%w%*%(t(z)%*%x))%*%(t(x)%*%z)%*%w
vhat <- mhat%*%shat%*%t(mhat)
print(cbind(gmm$par,sqrt(diag(vhat)/nrow(x)),gmm$par/sqrt(diag(vhat)/nrow(x)),
        1-pnorm(abs(gmm$par/sqrt(diag(vhat)/nrow(x))))))

# Overidentifying restrictions / Specification test statistic (J-Test)
Jdof <- ncol(z)-ncol(x)
sse <- as.numeric(t(y-x%*%gmm$par)%*%(y-x%*%gmm$par))
shat <- (sse)*(t(z)%*%z)
print("J-test Degrees of Freedom"); Jdof
jt <- (n^-0.5)*t(y-x%*%gmm$par)%*%z%*%solve(shat)%*%t(z)%*%(y-x%*%gmm$par)
print("Jt Test Statistic"); jt
        # Jt converges to Chi-Square with q-p degrees of freedom
        # The degrees of freedom equal the number of overidentifying restrictions
        # The critical value with alpha=0.05 and q-p=4 is 9.488
        # Rejection indicates problems with the GMM estimator

# Calculate Discount Parameters
coeff <- as.matrix(gmm$par)
a1 <- coeff[2,1]; a2 <- coeff[3,1]
a1se <- sqrt(vhat[2,2]/nrow(x)); a2se <- sqrt(vhat[3,3]/nrow(x)); a1a2cov <- vhat[2,3]/nrow(x)
delta <- 1-a2; beta <- -a1/(1-a2)

# Conduct linear hypothsis test on exponential discounting
q <- a2-a1-1
qse <- sqrt(a1se^2+a2se^2+2*a1a2cov)
exptest <- (q/qse)^2
deltase <- a2se
print("Value of Exponential Factor"); print(cbind(delta,deltase))
print("Exponential Discounting F-test"); print(exptest)
        # This is a two-sided F-test with dof=1,203 and alp=0.05
        # Null hypothesis is exponential discounting
        # Critical value is 3.84

# Conduct nonlinear hypothesis test on hyperbolic discounting
ga1 <- -1/(1-a2); ga2 <- -a1/((1-a2)^2)
betase <- sqrt((ga1^2)*(a1se^2)+(ga2^2)*(a2se^2)+2*(ga1)*(ga2)*(a1a2cov))
hyptest <- ((beta-1)/betase)^2
print("Value of Quasi-Hyperbolic Factor"); print(cbind(beta,betase))
print("Quasi-Hyperbolic Discounting F-test"); print(hyptest)
        # This is one-sided F-test with dof=1,203 and alp=0.05
        # Null hypothesis is no hyperbolic discounting
        # Critical value is 3.84

# END PROGRAM
```

```
# TITLE: Cornbelt States Panel OLS & Linear GMM

# RESET ALL WORK
rm(list = ls())

# Call needed libraries
library(lmtest); library(stats); library(tseries)
library(car); library(sandwich); library(systemfit)

# Download CPI Deflator
dta0 <- read.table("Deflators.dta")
cpi <- as.numeric(dta0[2:44,1])
lagcpi <- as.numeric(dta0[3:44,1])

# Download data sets
# Column Order: Y~IL~IN~IA~MO~OH~V~R~I~DV
dta <- read.table("CornbeltNom.dta")

# Create lagged variables
obs <- nrow(dta)
lagVil <- as.matrix(dta[1:(43-1),7])
lagRil <- as.matrix(dta[1:(43-1),8])
lagVin <- as.matrix(dta[44:(86-1),7])
lagRin <- as.matrix(dta[44:(86-1),8])
lagVia <- as.matrix(dta[87:(129-1),7])
lagRia <- as.matrix(dta[87:(129-1),8])
lagVmo <- as.matrix(dta[130:(172-1),7])
lagRmo <- as.matrix(dta[130:(172-1),8])
lagVoh <- as.matrix(dta[173:(215-1),7])
lagRoh <- as.matrix(dta[173:(215-1),8])
lagV <- rbind(lagVil,lagVin,lagVia,lagVmo,lagVoh)
lagR <- rbind(lagRil,lagRin,lagRia,lagRmo,lagRoh)

# Define dep var, indep var, & scale
dvil <- as.matrix(dta[2:43,10])
dvin <- as.matrix(dta[45:86,10])
dvia <- as.matrix(dta[88:129,10])
dvmo <- as.matrix(dta[131:172,10])
dvoh <- as.matrix(dta[174:215,10])
dv <- rbind(dvil,dvin,dvia,dvmo,dvoh)
n <- nrow(dv)
constant <- as.matrix(seq(length=n,from=1,by=0))
vil <- as.matrix(dta[2:43,7])
vin <- as.matrix(dta[45:86,7])
via <- as.matrix(dta[88:129,7])
vmo <- as.matrix(dta[131:172,7])
```

```
voh <- as.matrix(dta[174:215,7])
v <- rbind(vil,vin,via,vmo,voh)
ril <- as.matrix(dta[2:43,8])
rin <- as.matrix(dta[45:86,8])
ria <- as.matrix(dta[88:129,8])
rmo <- as.matrix(dta[131:172,8])
roh <- as.matrix(dta[174:215,8])
r <- rbind(ril,rin,ria,rmo,roh)
one <- as.matrix(seq(length=42,from=1,by=0))
zero <- as.matrix(seq(length=42,from=0,by=0))
il <- rbind(one,zero,zero,zero,zero)
inn <- rbind(zero,one,zero,zero,zero)
ia <- rbind(zero,zero,one,zero,zero)
mo <- rbind(zero,zero,zero,one,zero)
oh <- rbind(zero,zero,zero,zero,one)
x <- cbind(constant,r,v,il,inn,ia,oh)
y <- dv

# OLS estimation and test results
ols <- lm(dv~r+v+il+inn+ia+oh)
output <- summary(ols); output
NWvcov <- as.matrix(NeweyWest(ols))
bptest(ols)
        # Null Hypothesis of BP test is homoscedasticity
        # Critical value is Chi-square with alp=.05, dof=2: 5.991
durbin.watson(ols,max.lag=2)
        # Null hypothsis is no autocorrelation (rho=0)
        # If d<dl reject, if d>du do not reject, if du>d>dl inconclusive
        # Critcal value is DW with k=2, n=41: dl=1.449, du=1.549
Box.test(dv, type = c("Ljung-Box"))
        # Null hypothesis is no autocorrelation (rho=0)
        # Critical value is Chi-square with alp=.05, dof=1: 3.841
adf.test(dv)
        # Null hypothesis is nonstationary (unit root)

# Calculate Discount Parameters
coeff <- as.matrix(ols$coefficients)
a1 <- coeff[2,1]; a2 <- coeff[3,1]
a1se <- sqrt(NWvcov[2,2]); a2se <- sqrt(NWvcov[3,3]); a1a2cov <- NWvcov[2,3]
delta <- 1-a2; beta <- -a1/(1-a2)

# Conduct linear hypothsis test on exponential discounting
q <- a2-a1-1
qse <- sqrt(a1se^2+a2se^2+2*a1a2cov)
exptest <- (q/qse)^2
deltase <- a2se
```

```
print("Value of Exponential Factor"); print(cbind(delta,deltase))
print("Exponential Discounting F-test"); print(exptest)
        # This is a two-sided F-test with dof=1,203 and alpha=0.05
        # Null hypothesis is exponential discounting
        # Critical value is 3.84

# Conduct nonlinear hypothesis test on hyperbolic discounting
ga1 <- -1/(1-a2); ga2 <- -a1/((1-a2)^2)
betase <- sqrt((ga1^2)*(a1se^2)+(ga2^2)*(a2se^2)+2*(ga1)*(ga2)*(a1a2cov))
hyptest <- ((beta-1)/betase)^2
print("Value of Quasi-Hyperbolic Factor"); print(cbind(beta,betase))
print("Quasi-Hyperbolic Discounting F-test"); print(hyptest)
        # This is one-sided F-test with dof=1,203 and alpha=0.05
        # Null hypothesis is no hyperbolic discounting
        # Critical value is 3.84

# Define IV matrix and scale
z <- as.matrix(cbind(constant,v,r,il,inn,ia,oh,r^2,v^2,lagV,lagR))
k <- ncol(z)

# Define initial weighting matrix
w <- nrow(z)*solve(t(z)%*%z)

# Define GMM function
fr <- function(b){
    (1/n)*t(y-x%*%b)%*%z%*%w%*%((1/n)*t(z)%*%(y-x%*%b)) }

# Define gradient
gfr <- function(b){
    -2*t(y-x%*%b)%*%z%*%w%*%t(z)%*%x }

# Conduct first step GMM
gmm <- optim(c(0,0,0,0,0,0,0),fr,gfr)
sse <- as.numeric(t(y-x%*%gmm$par)%*%(y-x%*%gmm$par)/nrow(y))
shat <- (sse/nrow(z))*(t(z)%*%z)
mhat <- nrow(z)*solve((t(x)%*%z)%*%w%*%(t(z)%*%x))%*%(t(x)%*%z)%*%w
vhat <- mhat%*%shat%*%t(mhat)
print(cbind(gmm$par,sqrt(diag(vhat)/nrow(x)),gmm$par/sqrt(diag(vhat)/nrow(x)),
        1-pnorm(abs(gmm$par/sqrt(diag(vhat)/nrow(x))))))

# Conduct second step GMM
w <- solve(shat)
gmm <- optim(c(0,0,0,0,0,0,0),fr,gfr)
sse <- as.numeric(t(y-x%*%gmm$par)%*%(y-x%*%gmm$par)/nrow(y))
shat <- (sse/nrow(z))*(t(z)%*%z)
mhat <- nrow(z)*solve((t(x)%*%z)%*%w%*%(t(z)%*%x))%*%(t(x)%*%z)%*%w
```

```
vhat <- mhat%*%shat%*%t(mhat)
print(cbind(gmm$par,sqrt(diag(vhat)/nrow(x)),gmm$par/sqrt(diag(vhat)/nrow(x)),
        1-pnorm(abs(gmm$par/sqrt(diag(vhat)/nrow(x))))))

# Overidentifying restrictions / Specification test statistic (J-Test)
Jdof <- ncol(z)-ncol(x)
sse <- as.numeric(t(y-x%*%gmm$par)%*%(y-x%*%gmm$par))
shat <- (sse)*(t(z)%*%z)
print("J-test Degrees of Freedom"); Jdof
jt <- (n^-0.5)*t(y-x%*%gmm$par)%*%z%*%solve(shat)%*%t(z)%*%(y-x%*%gmm$par)
print("Jt Test Statistic"); jt
        # Jt converges to Chi-Square with q-p degrees of freedom
        # The degrees of freedom equal the number of overidentifying restrictions
        # The critical value with alpha=0.05 and q-p=4 is 9.488
        # Rejection indicates problems with the GMM estimator

# Calculate Discount Parameters
coeff <- as.matrix(gmm$par)
a1 <- coeff[2,1]; a2 <- coeff[3,1]
a1se <- sqrt(vhat[2,2]/nrow(x)); a2se <- sqrt(vhat[3,3]/nrow(x)); a1a2cov <- vhat[2,3]/nrow(x)
delta <- 1-a2; beta <- -a1/(1-a2)

# Conduct linear hypothsis test on exponential discounting
q <- a2-a1-1
qse <- sqrt(a1se^2+a2se^2+2*a1a2cov)
exptest <- (q/qse)^2
deltase <- a2se
print("Value of Exponential Factor"); print(cbind(delta,deltase))
print("Exponential Discounting F-test"); print(exptest)
        # This is a two-sided F-test with dof=1,203 and alp=0.05
        # Null hypothesis is exponential discounting
        # Critical value is 3.84

# Conduct nonlinear hypothesis test on hyperbolic discounting
ga1 <- -1/(1-a2); ga2 <- -a1/((1-a2)^2)
betase <- sqrt((ga1^2)*(a1se^2)+(ga2^2)*(a2se^2)+2*(ga1)*(ga2)*(a1a2cov))
hyptest <- ((beta-1)/betase)^2
print("Value of Quasi-Hyperbolic Factor"); print(cbind(beta,betase))
print("Quasi-Hyperbolic Discounting F-test"); print(hyptest)
        # This is one-sided F-test with dof=1,203 and alp=0.05
        # Null hypothesis is no hyperbolic discounting
        # Critical value is 3.84

# END PROGRAM
```

```
# TITLE: Delta States Panel OLS & Linear GMM
# Last Modified: 02/22/2008

# RESET ALL WORK
rm(list = ls())

# Call needed libraries
library(lmtest); library(stats); library(tseries)
library(car); library(sandwich); library(systemfit)

# Download data sets
# Column Order: Y~AR~LA~MS~V~R~I~DV
dta <- read.table("DeltaNom.dta")

# Create lagged variables
obs <- nrow(dta)
lagVar <- as.matrix(dta[1:(43-1),5])
lagRar <- as.matrix(dta[1:(43-1),6])
lagVla <- as.matrix(dta[44:(86-1),5])
lagRla <- as.matrix(dta[44:(86-1),6])
lagVms <- as.matrix(dta[87:(129-1),5])
lagRms <- as.matrix(dta[87:(129-1),6])
lagV <- rbind(lagVar,lagVla,lagVms)
lagR <- rbind(lagVar,lagVla,lagVms)

# Define dep var, indep var, & scale
dvar <- as.matrix(dta[2:43,8])
dvla <- as.matrix(dta[45:86,8])
dvms <- as.matrix(dta[88:129,8])
dv <- rbind(dvar,dvla,dvms)
n <- nrow(dv)
constant <- as.matrix(seq(length=n,from=1,by=0))
var <- as.matrix(dta[2:43,5])
vla <- as.matrix(dta[45:86,5])
vms <- as.matrix(dta[88:129,5])
v <- rbind(var,vla,vms)
rar <- as.matrix(dta[2:43,6])
rla <- as.matrix(dta[45:86,6])
rms <- as.matrix(dta[88:129,6])
r <- rbind(rar,rla,rms)
one <- as.matrix(seq(length=42,from=1,by=0))
zero <- as.matrix(seq(length=42,from=0,by=0))
ar <- rbind(one,zero,zero)
la <- rbind(zero,one,zero)
ms <- rbind(zero,zero,one)
x <- cbind(constant,r,v,ar,ms)
```

```
y <- dv

# OLS estimation and test results
ols <- lm(dv~r+v+ar+ms)
output <- summary(ols); output
NWvcov <- as.matrix(NeweyWest(ols))
bptest(ols)
	# Null Hypothesis of BP test is homoscedasticity
	# Critical value is Chi-square with alp=.05, dof=2: 5.991
durbin.watson(ols,max.lag=2)
	# Null hypothsis is no autocorrelation (rho=0)
	# If d<dl reject, if d>du do not reject, if du>d>dl inconclusive
	# Critcal value is DW with k=2, n=41: dl=1.449, du=1.549
Box.test(dv, type = c("Ljung-Box"))
	# Null hypothesis is no autocorrelation (rho=0)
	# Critical value is Chi-square with alp=.05, dof=1: 3.841
adf.test(dv)
	# Null hypothesis is nonstationary (unit root)

# Calculate Discount Parameters
coeff <- as.matrix(ols$coefficients)
a1 <- coeff[2,1]; a2 <- coeff[3,1]
a1se <- sqrt(NWvcov[2,2]); a2se <- sqrt(NWvcov[3,3]); a1a2cov <- NWvcov[2,3]
delta <- 1-a2; beta <- -a1/(1-a2)

# Conduct linear hypothsis test on exponential discounting
q <- a2-a1-1
qse <- sqrt(a1se^2+a2se^2+2*a1a2cov)
exptest <- (q/qse)^2
deltase <- a2se
print("Value of Exponential Factor"); print(cbind(delta,deltase))
print("Exponential Discounting F-test"); print(exptest)
	# This is a two-sided F-test with dof=1,121 and alpha=0.05
	# Null hypothesis is exponential discounting
	# Critical value is 3.92

# Conduct nonlinear hypothesis test on hyperbolic discounting
ga1 <- -1/(1-a2); ga2 <- -a1/((1-a2)^2)
betase <- sqrt((ga1^2)*(a1se^2)+(ga2^2)*(a2se^2)+2*(ga1)*(ga2)*(a1a2cov))
hyptest <- ((beta-1)/betase)^2
print("Value of Quasi-Hyperbolic Factor"); print(cbind(beta,betase))
print("Quasi-Hyperbolic Discounting F-test"); print(hyptest)
	# This is one-sided F-test with dof=1,121 and alpha=0.05
	# Null hypothesis is no hyperbolic discounting
	# Critical value is 3.92
```

```
# Define IV matrix and scale
z <- as.matrix(cbind(constant,v,r,ar,ms,v^2,r^2,lagV))
k <- ncol(z)

# Define initial weighting matrix
w <- nrow(z)*solve(t(z)%*%z)

# Define GMM function
fr <- function(b){
      (1/n)*t(y-x%*%b)%*%z%*%w%*%((1/n)*t(z)%*%(y-x%*%b)) }

# Define gradient
gfr <- function(b){
      -2*t(y-x%*%b)%*%z%*%w%*%t(z)%*%x }

# Conduct first step GMM
gmm <- optim(c(0,0,0,0,0),fr,gfr)
sse <- as.numeric(t(y-x%*%gmm$par)%*%(y-x%*%gmm$par)/nrow(y))
shat <- (sse/nrow(z))*(t(z)%*%z)
mhat <- nrow(z)*solve((t(x)%*%z)%*%w%*%(t(z)%*%x))%*%(t(x)%*%z)%*%w
vhat <- mhat%*%shat%*%t(mhat)
print(cbind(gmm$par,sqrt(diag(vhat)/nrow(x)),gmm$par/sqrt(diag(vhat)/nrow(x)),
          1-pnorm(abs(gmm$par/sqrt(diag(vhat)/nrow(x))))))

# Conduct second step GMM
w <- solve(shat)
gmm <- optim(c(0,0,0,0,0),fr,gfr)
sse <- as.numeric(t(y-x%*%gmm$par)%*%(y-x%*%gmm$par)/nrow(y))
shat <- (sse/nrow(z))*(t(z)%*%z)
mhat <- nrow(z)*solve((t(x)%*%z)%*%w%*%(t(z)%*%x))%*%(t(x)%*%z)%*%w
vhat <- mhat%*%shat%*%t(mhat)
print(cbind(gmm$par,sqrt(diag(vhat)/nrow(x)),gmm$par/sqrt(diag(vhat)/nrow(x)),
          1-pnorm(abs(gmm$par/sqrt(diag(vhat)/nrow(x))))))

# Overidentifying restrictions / Specification test statistic (J-Test)
Jdof <- ncol(z)-ncol(x)
sse <- as.numeric(t(y-x%*%gmm$par)%*%(y-x%*%gmm$par))
shat <- (sse)*(t(z)%*%z)
print("J-test Degrees of Freedom"); Jdof
jt <- (n^-0.5)*t(y-x%*%gmm$par)%*%z%*%solve(shat)%*%t(z)%*%(y-x%*%gmm$par)
print("Jt Test Statistic"); jt
          # Jt converges to Chi-Square with q-p degrees of freedom
          # The degrees of freedom equal the number of overidentifying restrictions
          # The critical value with alpha=0.05 and q-p=4 is 9.488
          # Rejection indicates problems with the GMM estimator
```

```
# Calculate Discount Parameters
coeff <- as.matrix(gmm$par)
a1 <- coeff[2,1]; a2 <- coeff[3,1]
a1se <- sqrt(vhat[2,2]/nrow(x)); a2se <- sqrt(vhat[3,3]/nrow(x)); a1a2cov <- vhat[2,3]/nrow(x)
delta <- 1-a2; beta <- -a1/(1-a2)

# Conduct linear hypothsis test on exponential discounting
q <- a2-a1-1
qse <- sqrt(a1se^2+a2se^2+2*a1a2cov)
exptest <- (q/qse)^2
deltase <- a2se
print("Value of Exponential Factor"); print(cbind(delta,deltase))
print("Exponential Discounting F-test"); print(exptest)
        # This is a two-sided F-test with dof=1,121 and alp=0.05
        # Null hypothesis is exponential discounting
        # Critical value is 3.92

# Conduct nonlinear hypothesis test on hyperbolic discounting
ga1 <- -1/(1-a2); ga2 <- -a1/((1-a2)^2)
betase <- sqrt((ga1^2)*(a1se^2)+(ga2^2)*(a2se^2)+2*(ga1)*(ga2)*(a1a2cov))
hyptest <- ((beta-1)/betase)^2
print("Value of Quasi-Hyperbolic Factor"); print(cbind(beta,betase))
print("Quasi-Hyperbolic Discounting F-test"); print(hyptest)
        # This is one-sided F-test with dof=1,121 and alp=0.05
        # Null hypothesis is no hyperbolic discounting
        # Critical value is 3.92

# END PROGRAM

# TITLE: Plain States Panel OLS & Linear GMM
# Last Modified: 02/26/2008

# RESET ALL WORK
rm(list = ls())

# Call needed libraries
library(lmtest); library(stats); library(tseries)
library(car); library(sandwich); library(systemfit)

# Download CPI Deflator
dta0 <- read.table("Deflators.dta")
cpi <- as.numeric(dta0[2:44,1])
lagcpi <- as.numeric(dta0[3:44,1])

# Download data sets
# Column Order: Y~KS~NE~ND~OK~SD~TX~V~R~I~DV
```

```
dta <- read.table("PlainsNom.dta")

# Create lagged variables
obs <- nrow(dta)
lagVks <- as.matrix(dta[1:(43-1),8])
lagRks <- as.matrix(dta[1:(43-1),9])
lagVne <- as.matrix(dta[44:(86-1),8])
lagRne <- as.matrix(dta[44:(86-1),9])
lagVnd <- as.matrix(dta[87:(129-1),8])
lagRnd <- as.matrix(dta[87:(129-1),9])
lagVok <- as.matrix(dta[130:(172-1),8])
lagRok <- as.matrix(dta[130:(172-1),9])
lagVsd <- as.matrix(dta[173:(215-1),8])
lagRsd <- as.matrix(dta[173:(215-1),9])
lagVtx <- as.matrix(dta[216:(258-1),8])
lagRtx <- as.matrix(dta[216:(258-1),9])
lagV <- rbind(lagVks,lagVne,lagVnd,lagVok,lagVsd,lagVtx)
lagR <- rbind(lagRks,lagRne,lagRnd,lagRok,lagRsd,lagRtx)

# Define dep var, indep var, & scale
dvks <- as.matrix(dta[2:43,11])
dvne <- as.matrix(dta[45:86,11])
dvnd <- as.matrix(dta[88:129,11])
dvok <- as.matrix(dta[131:172,11])
dvsd <- as.matrix(dta[174:215,11])
dvtx <- as.matrix(dta[217:258,11])
dv <- rbind(dvks,dvne,dvnd,dvok,dvsd,dvtx)
n <- nrow(dv)
constant <- as.matrix(seq(length=n,from=1,by=0))
vks <- as.matrix(dta[2:43,8])
vne <- as.matrix(dta[45:86,8])
vnd <- as.matrix(dta[88:129,8])
vok <- as.matrix(dta[131:172,8])
vsd <- as.matrix(dta[174:215,8])
vtx <- as.matrix(dta[217:258,8])
v <- rbind(vks,vne,vnd,vok,vsd,vtx)
rks <- as.matrix(dta[2:43,9])
rne <- as.matrix(dta[45:86,9])
rnd <- as.matrix(dta[88:129,9])
rok <- as.matrix(dta[131:172,9])
rsd <- as.matrix(dta[174:215,9])
rtx <- as.matrix(dta[217:258,9])
r <- rbind(rks,rne,rnd,rok,rsd,rtx)
one <- as.matrix(seq(length=42,from=1,by=0))
zero <- as.matrix(seq(length=42,from=0,by=0))
ks <- rbind(one,zero,zero,zero,zero,zero)
```

```
ne <- rbind(zero,one,zero,zero,zero,zero)
nd <- rbind(zero,zero,one,zero,zero,zero)
ok <- rbind(zero,zero,zero,one,zero,zero)
sd <- rbind(zero,zero,zero,zero,one,zero)
tx <- rbind(zero,zero,zero,zero,zero,one)
x <- cbind(constant,r,v,ks,ne,nd,ok,tx)
y <- dv

# OLS estimation and test results
ols <- lm(dv~r+v+ks+ne+nd+ok+tx)
output <- summary(ols); output
NWvcov <- as.matrix(NeweyWest(ols))
bptest(ols)
        # Null Hypothesis of BP test is homoscedasticity
        # Critical value is Chi-square with alp=.05, dof=2: 5.991
durbin.watson(ols,max.lag=2)
        # Null hypothsis is no autocorrelation (rho=0)
        # If d<dl reject, if d>du do not reject, if du>d>dl inconclusive
        # Critcal value is DW with k=2, n=41: dl=1.449, du=1.549
Box.test(dv, type = c("Ljung-Box"))
        # Null hypothesis is no autocorrelation (rho=0)
        # Critical value is Chi-square with alp=.05, dof=1: 3.841
adf.test(dv)
        # Null hypothesis is nonstationary (unit root)

# Calculate Discount Parameters
coeff <- as.matrix(ols$coefficients)
a1 <- coeff[2,1]; a2 <- coeff[3,1]
a1se <- sqrt(NWvcov[2,2]); a2se <- sqrt(NWvcov[3,3]); a1a2cov <- NWvcov[2,3]
delta <- 1-a2; beta <- -a1/(1-a2)

# Conduct linear hypothsis test on exponential discounting
q <- a2-a1-1
qse <- sqrt(a1se^2+a2se^2+2*a1a2cov)
exptest <- (q/qse)^2
print("Value of Exponential Factor"); print(delta)
print("Exponential Discounting F-test"); print(exptest)
        # This is a two-sided F-test with dof=1,244
        # Null hypothesis is exponential discounting
        # Critical value is 3.84 (alp=0.05) & 2.70 (alp=0.10)

# Conduct nonlinear hypothesis test on hyperbolic discounting
ga1 <- -1/(1-a2); ga2 <- -a1/((1-a2)^2)
betase <- sqrt((ga1^2)*(a1se^2)+(ga2^2)*(a2se^2)+2*(ga1)*(ga2)*(a1a2cov))
hyptest <- ((beta-1)/betase)^2
print("Value of Quasi-Hyperbolic Factor"); print(cbind(beta,betase))
```

```
print("Quasi-Hyperbolic Discounting F-test"); print(hyptest)
        # This is one-sided F-test with dof=1,244
        # Null hypothesis is no hyperbolic discounting
        # Critical value is 3.84 (alp=0.05) & 2.70 (alp=0.10)

# Define IV matrix and scale
z <- as.matrix(cbind(constant,v,r,ks,ne,nd,ok,tx,v^2,r^2,lagV,lagR))
k <- ncol(z)

# Define initial weighting matrix
w <- nrow(z)*solve(t(z)%*%z)

# Define GMM function
fr <- function(b){
    (1/n)*t(y-x%*%b)%*%z%*%w%*%((1/n)*t(z)%*%(y-x%*%b)) }

# Define gradient
gfr <- function(b){
    -2*t(y-x%*%b)%*%z%*%w%*%t(z)%*%x }

# Conduct first step GMM
gmm <- optim(c(0,0,0,0,0,0,0,0),fr,gfr)
sse <- as.numeric(t(y-x%*%gmm$par)%*%(y-x%*%gmm$par)/nrow(y))
shat <- (sse/nrow(z))*(t(z)%*%z)
mhat <- nrow(z)*solve((t(x)%*%z)%*%w%*%(t(z)%*%x))%*%(t(x)%*%z)%*%w
vhat <- mhat%*%shat%*%t(mhat)
print(cbind(gmm$par,sqrt(diag(vhat)/nrow(x)),gmm$par/sqrt(diag(vhat)/nrow(x)),
        1-pnorm(abs(gmm$par/sqrt(diag(vhat)/nrow(x))))))

# Conduct second step GMM
w <- solve(shat)
gmm <- optim(c(0,0,0,0,0,0,0,0),fr,gfr)
sse <- as.numeric(t(y-x%*%gmm$par)%*%(y-x%*%gmm$par)/nrow(y))
shat <- (sse/nrow(z))*(t(z)%*%z)
mhat <- nrow(z)*solve((t(x)%*%z)%*%w%*%(t(z)%*%x))%*%(t(x)%*%z)%*%w
vhat <- mhat%*%shat%*%t(mhat)
print(cbind(gmm$par,sqrt(diag(vhat)/nrow(x)),gmm$par/sqrt(diag(vhat)/nrow(x)),
        1-pnorm(abs(gmm$par/sqrt(diag(vhat)/nrow(x))))))

# Overidentifying restrictions / Specification test statistic (J-Test)
Jdof <- ncol(z)-ncol(x)
sse <- as.numeric(t(y-x%*%gmm$par)%*%(y-x%*%gmm$par))
shat <- (sse)*(t(z)%*%z)
print("J-test Degrees of Freedom"); Jdof
jt <- (n^-0.5)*t(y-x%*%gmm$par)%*%z%*%solve(shat)%*%t(z)%*%(y-x%*%gmm$par)
print("Jt Test Statistic"); jt
```

```
	# Jt converges to Chi-Square with q-p degrees of freedom
	# The degrees of freedom equal the number of overidentifying restrictions
	# The critical value with alpha=0.05 and q-p=4 is 9.488
	# Rejection indicates problems with the GMM estimator

# Calculate Discount Parameters
coeff <- as.matrix(gmm$par)
a1 <- coeff[2,1]; a2 <- coeff[3,1]
a1se <- sqrt(vhat[2,2]/nrow(x)); a2se <- sqrt(vhat[3,3]/nrow(x)); a1a2cov <- vhat[2,3]/nrow(x)
delta <- 1-a2; beta <- -a1/(1-a2)

# Conduct linear hypothsis test on exponential discounting
q <- a2-a1-1
qse <- sqrt(a1se^2+a2se^2+2*a1a2cov)
exptest <- (q/qse)^2
deltase <- a2se
print("Value of Exponential Factor"); print(cbind(delta,deltase))
print("Exponential Discounting F-test"); print(exptest)
	# This is a two-sided F-test with dof=1,244
	# Null hypothesis is exponential discounting
	# Critical value is 3.84 (alp=0.05) & 2.70 (alp=0.10)

# Conduct nonlinear hypothesis test on hyperbolic discounting
ga1 <- -1/(1-a2); ga2 <- -a1/((1-a2)^2)
betase <- sqrt((ga1^2)*(a1se^2)+(ga2^2)*(a2se^2)+2*(ga1)*(ga2)*(a1a2cov))
hyptest <- ((beta-1)/betase)^2
print("Value of Quasi-Hyperbolic Factor"); print(cbind(beta,betase))
print("Quasi-Hyperbolic Discounting F-test"); print(hyptest)
	# This is one-sided F-test with dof=1,244
	# Null hypothesis is no hyperbolic discounting
	# Critical value is 3.84 (alp=0.05) & 2.70 (alp=0.10)

# END PROGRAM

# TITLE: Lake States Panel OLS & Linear GMM

# RESET ALL WORK
rm(list = ls())

# Call needed libraries
library(lmtest); library(stats); library(tseries)
library(car); library(sandwich); library(systemfit)

# Download CPI Deflator
dta0 <- read.table("Deflators.dta")
cpi <- as.numeric(dta0[2:44,1])
```

```
lagcpi <- as.numeric(dta0[3:44,1])

# Download data sets
# Column Order: Y~MI~MN~WI~V~R~I~DV
dta <- read.table("LakeNom.dta")

# Create lagged variables
obs <- nrow(dta)
lagVmi <- as.matrix(dta[1:(43-1),5])
lagRmi <- as.matrix(dta[1:(43-1),6])
lagVmn <- as.matrix(dta[44:(86-1),5])
lagRmn <- as.matrix(dta[44:(86-1),6])
lagVwi <- as.matrix(dta[87:(129-1),5])
lagRwi <- as.matrix(dta[87:(129-1),6])
lagV <- rbind(lagVmi,lagVmn,lagVwi)
lagR <- rbind(lagVmi,lagVmn,lagVwi)

# Define dep var, indep var, & scale
dvmi <- as.matrix(dta[2:43,8])
dvmn <- as.matrix(dta[45:86,8])
dvwi <- as.matrix(dta[88:129,8])
dv <- rbind(dvmi,dvmn,dvwi)
n <- nrow(dv)
constant <- as.matrix(seq(length=n,from=1,by=0))
vmi <- as.matrix(dta[2:43,5])
vmn <- as.matrix(dta[45:86,5])
vwi <- as.matrix(dta[88:129,5])
v <- rbind(vmi,vmn,vwi)
rmi <- as.matrix(dta[2:43,6])
rmn <- as.matrix(dta[45:86,6])
rwi <- as.matrix(dta[88:129,6])
r <- rbind(rmi,rmn,rwi)
one <- as.matrix(seq(length=42,from=1,by=0))
zero <- as.matrix(seq(length=42,from=0,by=0))
mi <- rbind(one,zero,zero)
mn <- rbind(zero,one,zero)
wi <- rbind(zero,zero,one)
x <- cbind(constant,r,v,mn,wi)
y <- dv

# OLS estimation and test results
ols <- lm(dv~r+v+mn+wi)
output <- summary(ols); output
NWvcov <- as.matrix(NeweyWest(ols))
bptest(ols)
        # Null Hypothesis of BP test is homoscedasticity
```

```
        # Critical value is Chi-square with alp=.05, dof=2: 5.991
durbin.watson(ols,max.lag=2)
        # Null hypothsis is no autocorrelation (rho=0)
        # If d<dl reject, if d>du do not reject, if du>d>dl inconclusive
        # Critcal value is DW with k=2, n=41: dl=1.449, du=1.549
Box.test(dv, type = c("Ljung-Box"))
        # Null hypothesis is no autocorrelation (rho=0)
        # Critical value is Chi-square with alp=.05, dof=1: 3.841
adf.test(dv)
        # Null hypothesis is nonstationary (unit root)

# Calculate Discount Parameters
coeff <- as.matrix(ols$coefficients)
a1 <- coeff[2,1]; a2 <- coeff[3,1]
a1se <- sqrt(NWvcov[2,2]); a2se <- sqrt(NWvcov[3,3]); a1a2cov <- NWvcov[2,3]
delta <- 1-a2; beta <- -a1/(1-a2)

# Conduct linear hypothsis test on exponential discounting
q <- a2-a1-1
qse <- sqrt(a1se^2+a2se^2+2*a1a2cov)
exptest <- (q/qse)^2
deltase <- a2se
print("Value of Exponential Factor"); print(cbind(delta,deltase))
print("Exponential Discounting F-test"); print(exptest)
        # This is a two-sided F-test with dof=1,121 and alpha=0.05
        # Null hypothesis is exponential discounting
        # Critical value is 3.92

# Conduct nonlinear hypothesis test on hyperbolic discounting
ga1 <- -1/(1-a2); ga2 <- -a1/((1-a2)^2)
betase <- sqrt((ga1^2)*(a1se^2)+(ga2^2)*(a2se^2)+2*(ga1)*(ga2)*(a1a2cov))
hyptest <- ((beta-1)/betase)^2
print("Value of Quasi-Hyperbolic Factor"); print(cbind(beta,betase))
print("Quasi-Hyperbolic Discounting F-test"); print(hyptest)
        # This is one-sided F-test with dof=1,121 and alpha=0.05
        # Null hypothesis is no hyperbolic discounting
        # Critical value is 3.92

# Define IV matrix and scale
z <- as.matrix(cbind(constant,v,r,mn,wi,v^2,r^2,lagV))
k <- ncol(z)

# Define initial weighting matrix
w <- nrow(z)*solve(t(z)%*%z)

# Define GMM function
```

```
fr <- function(b){
     (1/n)*t(y-x%*%b)%*%z%*%w%*%((1/n)*t(z)%*%(y-x%*%b)) }

# Define gradient
gfr <- function(b){
     -2*t(y-x%*%b)%*%z%*%w%*%t(z)%*%x }

# Conduct first step GMM
gmm <- optim(c(0,0,0,0,0),fr,gfr)
sse <- as.numeric(t(y-x%*%gmm$par)%*%(y-x%*%gmm$par)/nrow(y))
shat <- (sse/nrow(z))*(t(z)%*%z)
mhat <- nrow(z)*solve((t(x)%*%z)%*%w%*%(t(z)%*%x))%*%(t(x)%*%z)%*%w
vhat <- mhat%*%shat%*%t(mhat)
print(cbind(gmm$par,sqrt(diag(vhat)/nrow(x)),gmm$par/sqrt(diag(vhat)/nrow(x)),
        1-pnorm(abs(gmm$par/sqrt(diag(vhat)/nrow(x))))))

# Conduct second step GMM
w <- solve(shat)
gmm <- optim(c(0,0,0,0,0),fr,gfr)
sse <- as.numeric(t(y-x%*%gmm$par)%*%(y-x%*%gmm$par)/nrow(y))
shat <- (sse/nrow(z))*(t(z)%*%z)
mhat <- nrow(z)*solve((t(x)%*%z)%*%w%*%(t(z)%*%x))%*%(t(x)%*%z)%*%w
vhat <- mhat%*%shat%*%t(mhat)
print(cbind(gmm$par,sqrt(diag(vhat)/nrow(x)),gmm$par/sqrt(diag(vhat)/nrow(x)),
        1-pnorm(abs(gmm$par/sqrt(diag(vhat)/nrow(x))))))

# Overidentifying restrictions / Specification test statistic (J-Test)
Jdof <- ncol(z)-ncol(x)
sse <- as.numeric(t(y-x%*%gmm$par)%*%(y-x%*%gmm$par))
shat <- (sse)*(t(z)%*%z)
print("J-test Degrees of Freedom"); Jdof
jt <- (n^-0.5)*t(y-x%*%gmm$par)%*%z%*%solve(shat)%*%t(z)%*%(y-x%*%gmm$par)
print("Jt Test Statistic"); jt
        # Jt converges to Chi-Square with q-p degrees of freedom
        # The degrees of freedom equal the number of overidentifying restrictions
        # The critical value with alpha=0.05 and q-p=4 is 9.488
        # Rejection indicates problems with the GMM estimator

# Calculate Discount Parameters
coeff <- as.matrix(gmm$par)
a1 <- coeff[2,1]; a2 <- coeff[3,1]
a1se <- sqrt(vhat[2,2]/nrow(x)); a2se <- sqrt(vhat[3,3]/nrow(x)); a1a2cov <- vhat[2,3]/nrow(x)
delta <- 1-a2; beta <- -a1/(1-a2)

# Conduct linear hypothsis test on exponential discounting
q <- a2-a1-1
```

```
qse <- sqrt(a1se^2+a2se^2+2*a1a2cov)
exptest <- (q/qse)^2
deltase <- a2se
print("Value of Exponential Factor"); print(cbind(delta,deltase))
print("Exponential Discounting F-test"); print(exptest)
        # This is a two-sided F-test with dof=1,121 and alp=0.05
        # Null hypothesis is exponential discounting
        # Critical value is 3.92

# Conduct nonlinear hypothesis test on hyperbolic discounting
ga1 <- -1/(1-a2); ga2 <- -a1/((1-a2)^2)
betase <- sqrt((ga1^2)*(a1se^2)+(ga2^2)*(a2se^2)+2*(ga1)*(ga2)*(a1a2cov))
hyptest <- ((beta-1)/betase)^2
print("Value of Quasi-Hyperbolic Factor"); print(cbind(beta,betase))
print("Quasi-Hyperbolic Discounting F-test"); print(hyptest)
        # This is one-sided F-test with dof=1,121 and alp=0.05
        # Null hypothesis is no hyperbolic discounting
        # Critical value is 3.92

# END PROGRAM

# TITLE: Mountain States Panel OLS & Linear GMM

# RESET ALL WORK
rm(list = ls())

# Call needed libraries
library(lmtest); library(stats); library(tseries)
library(car); library(sandwich); library(systemfit)

# Download CPI Deflator
dta0 <- read.table("Deflators.dta")
cpi <- as.numeric(dta0[2:44,1])
lagcpi <- as.numeric(dta0[3:44,1])

# Download data sets
# Column Order: Y~AZ~CO~ID~MT~NV~NM~UT~WY~V~R~I~DV
dta <- read.table("MountainNom.dta")

# Create lagged variables
obs <- nrow(dta)
lagVaz <- as.matrix(dta[1:(43-1),10])
lagRaz <- as.matrix(dta[1:(43-1),11])
lagVco <- as.matrix(dta[44:(86-1),10])
lagRco <- as.matrix(dta[44:(86-1),11])
lagVid <- as.matrix(dta[87:(129-1),10])
```

```
lagRid <- as.matrix(dta[87:(129-1),11])
lagVmt <- as.matrix(dta[130:(172-1),10])
lagRmt <- as.matrix(dta[130:(172-1),11])
lagVnv <- as.matrix(dta[173:(215-1),10])
lagRnv <- as.matrix(dta[173:(215-1),11])
lagVnm <- as.matrix(dta[216:(258-1),10])
lagRnm <- as.matrix(dta[216:(258-1),11])
lagVut <- as.matrix(dta[259:(301-1),10])
lagRut <- as.matrix(dta[259:(301-1),11])
lagVwy <- as.matrix(dta[302:(344-1),10])
lagRwy <- as.matrix(dta[302:(344-1),11])
lagV <- rbind(lagVaz,lagVco,lagVid,lagVmt,lagVnv,lagVnm,lagVut,lagVwy)
lagR <- rbind(lagRaz,lagRco,lagRid,lagRmt,lagRnv,lagRnm,lagRut,lagRwy)

# Define dep var, indep var, & scale
dvaz <- as.matrix(dta[2:43,13])
dvco <- as.matrix(dta[45:86,13])
dvid <- as.matrix(dta[88:129,13])
dvmt <- as.matrix(dta[131:172,13])
dvnv <- as.matrix(dta[174:215,13])
dvnm <- as.matrix(dta[217:258,13])
dvut <- as.matrix(dta[260:301,13])
dvwy <- as.matrix(dta[303:344,13])
dv <- rbind(dvaz,dvco,dvid,dvmt,dvnv,dvnm,dvut,dvwy)
n <- nrow(dv)
constant <- as.matrix(seq(length=n,from=1,by=0))
vaz <- as.matrix(dta[2:43,10])
vco <- as.matrix(dta[45:86,10])
vid <- as.matrix(dta[88:129,10])
vmt <- as.matrix(dta[131:172,10])
vnv <- as.matrix(dta[174:215,10])
vnm <- as.matrix(dta[217:258,10])
vut <- as.matrix(dta[260:301,10])
vwy <- as.matrix(dta[303:344,10])
v <- rbind(vaz,vco,vid,vmt,vnv,vnm,vut,vwy)
raz <- as.matrix(dta[2:43,11])
rco <- as.matrix(dta[45:86,11])
rid <- as.matrix(dta[88:129,11])
rmt <- as.matrix(dta[131:172,11])
rnv <- as.matrix(dta[174:215,11])
rnm <- as.matrix(dta[217:258,11])
rut <- as.matrix(dta[260:301,11])
rwy <- as.matrix(dta[303:344,11])
r <- rbind(raz,rco,rid,rmt,rnv,rnm,rut,rwy)
one <- as.matrix(seq(length=42,from=1,by=0))
zero <- as.matrix(seq(length=42,from=0,by=0))
```

```
az <- rbind(one,zero,zero,zero,zero,zero,zero,zero)
co <- rbind(zero,one,zero,zero,zero,zero,zero,zero)
id <- rbind(zero,zero,one,zero,zero,zero,zero,zero)
mt <- rbind(zero,zero,zero,one,zero,zero,zero,zero)
nv <- rbind(zero,zero,zero,zero,one,zero,zero,zero)
nm <- rbind(zero,zero,zero,zero,zero,one,zero,zero)
ut <- rbind(zero,zero,zero,zero,zero,zero,one,zero)
wy <- rbind(zero,zero,zero,zero,zero,zero,zero,one)
x <- cbind(constant,r,v,co,id,mt,nv,nm,ut,wy)
y <- dv

# OLS estimation and test results
ols <- lm(dv~r+v+co+id+mt+nv+nm+ut+wy)
output <- summary(ols); output
NWvcov <- as.matrix(NeweyWest(ols))
bptest(ols)
	# Null Hypothesis of BP test is homoscedasticity
	# Critical value is Chi-square with alp=.05, dof=2: 5.991
durbin.watson(ols,max.lag=2)
	# Null hypothsis is no autocorrelation (rho=0)
	# If d<dl reject, if d>du do not reject, if du>d>dl inconclusive
	# Critcal value is DW with k=2, n=41: dl=1.449, du=1.549
Box.test(dv, type = c("Ljung-Box"))
	# Null hypothesis is no autocorrelation (rho=0)
	# Critical value is Chi-square with alp=.05, dof=1: 3.841
adf.test(dv)
	# Null hypothesis is nonstationary (unit root)

# Calculate Discount Parameters
coeff <- as.matrix(ols$coefficients)
a1 <- coeff[2,1]; a2 <- coeff[3,1]
a1se <- sqrt(NWvcov[2,2]); a2se <- sqrt(NWvcov[3,3]); a1a2cov <- NWvcov[2,3]
delta <- 1-a2; beta <- -a1/(1-a2)

# Conduct linear hypothsis test on exponential discounting
q <- a2-a1-1
qse <- sqrt(a1se^2+a2se^2+2*a1a2cov)
exptest <- (q/qse)^2
deltase <- a2se
print("Value of Exponential Factor"); print(cbind(delta,deltase))
print("Exponential Discounting F-test"); print(exptest)
	# This is a two-sided F-test with dof=1,203 and alpha=0.05
	# Null hypothesis is exponential discounting
	# Critical value is 3.84

# Conduct nonlinear hypothesis test on hyperbolic discounting
```

```
ga1 <- -1/(1-a2); ga2 <- -a1/((1-a2)^2)
betase <- sqrt((ga1^2)*(a1se^2)+(ga2^2)*(a2se^2)+2*(ga1)*(ga2)*(a1a2cov))
hyptest <- ((beta-1)/betase)^2
print("Value of Quasi-Hyperbolic Factor"); print(cbind(beta,betase))
print("Quasi-Hyperbolic Discounting F-test"); print(hyptest)
        # This is one-sided F-test with dof=1,203 and alpha=0.05
        # Null hypothesis is no hyperbolic discounting
        # Critical value is 3.84

# Define IV matrix and scale
z <- as.matrix(cbind(constant,v,r,co,id,mt,nv,nm,ut,wy,r^2,v^2,lagV,lagR))
k <- ncol(z)

# Define initial weighting matrix
w <- nrow(z)*solve(t(z)%*%z)

# Define GMM function
fr <- function(b){
    (1/n)*t(y-x%*%b)%*%z%*%w%*%((1/n)*t(z)%*%(y-x%*%b)) }

# Define gradient
gfr <- function(b){
    -2*t(y-x%*%b)%*%z%*%w%*%t(z)%*%x }

# Conduct first step GMM
gmm <- optim(c(0,0,0,0,0,0,0,0,0,0),fr,gfr)
sse <- as.numeric(t(y-x%*%gmm$par)%*%(y-x%*%gmm$par)/nrow(y))
shat <- (sse/nrow(z))*(t(z)%*%z)
mhat <- nrow(z)*solve((t(x)%*%z)%*%w%*%(t(z)%*%x))%*%(t(x)%*%z)%*%w
vhat <- mhat%*%shat%*%t(mhat)
print(cbind(gmm$par,sqrt(diag(vhat)/nrow(x)),gmm$par/sqrt(diag(vhat)/nrow(x)),
        1-pnorm(abs(gmm$par/sqrt(diag(vhat)/nrow(x))))))

# Conduct second step GMM
w <- solve(shat)
gmm <- optim(c(0,0,0,0,0,0,0,0,0,0),fr,gfr)
sse <- as.numeric(t(y-x%*%gmm$par)%*%(y-x%*%gmm$par)/nrow(y))
shat <- (sse/nrow(z))*(t(z)%*%z)
mhat <- nrow(z)*solve((t(x)%*%z)%*%w%*%(t(z)%*%x))%*%(t(x)%*%z)%*%w
vhat <- mhat%*%shat%*%t(mhat)
print(cbind(gmm$par,sqrt(diag(vhat)/nrow(x)),gmm$par/sqrt(diag(vhat)/nrow(x)),
        1-pnorm(abs(gmm$par/sqrt(diag(vhat)/nrow(x))))))

# Overidentifying restrictions / Specification test statistic (J-Test)
Jdof <- ncol(z)-ncol(x)
sse <- as.numeric(t(y-x%*%gmm$par)%*%(y-x%*%gmm$par))
```

```
shat <- (sse)*(t(z)%*%z)
print("J-test Degrees of Freedom"); Jdof
jt <- (n^-0.5)*t(y-x%*%gmm$par)%*%z%*%solve(shat)%*%t(z)%*%(y-x%*%gmm$par)
print("Jt Test Statistic"); jt
        # Jt converges to Chi-Square with q-p degrees of freedom
        # The degrees of freedom equal the number of overidentifying restrictions
        # The critical value with alpha=0.05 and q-p=4 is 9.488
        # Rejection indicates problems with the GMM estimator

# Calculate Discount Parameters
coeff <- as.matrix(gmm$par)
a1 <- coeff[2,1]; a2 <- coeff[3,1]
a1se <- sqrt(vhat[2,2]/nrow(x)); a2se <- sqrt(vhat[3,3]/nrow(x)); a1a2cov <- vhat[2,3]/nrow(x)
delta <- 1-a2; beta <- -a1/(1-a2)

# Conduct linear hypothsis test on exponential discounting
q <- a2-a1-1
qse <- sqrt(a1se^2+a2se^2+2*a1a2cov)
exptest <- (q/qse)^2
deltase <- a2se
print("Value of Exponential Factor"); print(cbind(delta,deltase))
print("Exponential Discounting F-test"); print(exptest)
        # This is a two-sided F-test with dof=1,203 and alp=0.05
        # Null hypothesis is exponential discounting
        # Critical value is 3.84

# Conduct nonlinear hypothesis test on hyperbolic discounting
ga1 <- -1/(1-a2); ga2 <- -a1/((1-a2)^2)
betase <- sqrt((ga1^2)*(a1se^2)+(ga2^2)*(a2se^2)+2*(ga1)*(ga2)*(a1a2cov))
hyptest <- ((beta-1)/betase)^2
print("Value of Quasi-Hyperbolic Factor"); print(cbind(beta,betase))
print("Quasi-Hyperbolic Discounting F-test"); print(hyptest)
        # This is one-sided F-test with dof=1,203 and alp=0.05
        # Null hypothesis is no hyperbolic discounting
        # Critical value is 3.84

# END PROGRAM

# TITLE: Northeast States Panel OLS & Linear GMM

# RESET ALL WORK
rm(list = ls())

# Call needed libraries
library(lmtest); library(stats); library(tseries)
library(car); library(sandwich); library(systemfit)
```

```
# Download CPI Deflator
dta0 <- read.table("Deflators.dta")
cpi <- as.numeric(dta0[2:44,1])
lagcpi <- as.numeric(dta0[3:44,1])

# Download data sets
# Column Order: Y~CT~DE~ME~MD~MA~NH~NJ~NY~PA~RI~VT~V~R~I~DV
dta <- read.table("NortheastNom.dta")

# Create lagged variables
obs <- nrow(dta)
lagVct <- as.matrix(dta[1:(43-1),13])
lagRct <- as.matrix(dta[1:(43-1),14])
lagVde <- as.matrix(dta[44:(86-1),13])
lagRde <- as.matrix(dta[44:(86-1),14])
lagVme <- as.matrix(dta[87:(129-1),13])
lagRme <- as.matrix(dta[87:(129-1),14])
lagVmd <- as.matrix(dta[130:(172-1),13])
lagRmd <- as.matrix(dta[130:(172-1),14])
lagVma <- as.matrix(dta[173:(215-1),13])
lagRma <- as.matrix(dta[173:(215-1),14])
lagVnh <- as.matrix(dta[216:(258-1),13])
lagRnh <- as.matrix(dta[216:(258-1),14])
lagVnj <- as.matrix(dta[259:(301-1),13])
lagRnj <- as.matrix(dta[259:(301-1),14])
lagVny <- as.matrix(dta[302:(344-1),13])
lagRny <- as.matrix(dta[302:(344-1),14])
lagVpa <- as.matrix(dta[345:(387-1),13])
lagRpa <- as.matrix(dta[345:(387-1),14])
lagVri <- as.matrix(dta[388:(430-1),13])
lagRri <- as.matrix(dta[388:(430-1),14])
lagVvt <- as.matrix(dta[431:(473-1),13])
lagRvt <- as.matrix(dta[431:(473-1),14])
lagV <-
rbind(lagVct,lagVde,lagVme,lagVmd,lagVma,lagVnh,lagVnj,lagVny,lagVpa,lagVri,lagVvt)
lagR <-
rbind(lagRct,lagRde,lagRme,lagRmd,lagRma,lagRnh,lagRnj,lagRny,lagRpa,lagRri,lagRvt)

# Define dep var, indep var, & scale
dvct <- as.matrix(dta[2:43,16])
dvde <- as.matrix(dta[45:86,16])
dvme <- as.matrix(dta[88:129,16])
dvmd <- as.matrix(dta[131:172,16])
dvma <- as.matrix(dta[174:215,16])
dvnh <- as.matrix(dta[217:258,16])
```

```
dvnj <- as.matrix(dta[260:301,16])
dvny <- as.matrix(dta[303:344,16])
dvpa <- as.matrix(dta[346:387,16])
dvri <- as.matrix(dta[389:430,16])
dvvt <- as.matrix(dta[432:473,16])
dv <- rbind(dvct,dvde,dvme,dvmd,dvma,dvnh,dvnj,dvny,dvpa,dvri,dvvt)
n <- nrow(dv)
constant <- as.matrix(seq(length=n,from=1,by=0))
vct <- as.matrix(dta[2:43,13])
vde <- as.matrix(dta[45:86,13])
vme <- as.matrix(dta[88:129,13])
vmd <- as.matrix(dta[131:172,13])
vma <- as.matrix(dta[174:215,13])
vnh <- as.matrix(dta[217:258,13])
vnj <- as.matrix(dta[260:301,13])
vny <- as.matrix(dta[303:344,13])
vpa <- as.matrix(dta[346:387,13])
vri <- as.matrix(dta[389:430,13])
vvt <- as.matrix(dta[432:473,13])
v <- rbind(vct,vde,vme,vmd,vma,vnh,vnj,vny,vpa,vri,vvt)
rct <- as.matrix(dta[2:43,14])
rde <- as.matrix(dta[45:86,14])
rme <- as.matrix(dta[88:129,14])
rmd <- as.matrix(dta[131:172,14])
rma <- as.matrix(dta[174:215,14])
rnh <- as.matrix(dta[217:258,14])
rnj <- as.matrix(dta[260:301,14])
rny <- as.matrix(dta[303:344,14])
rpa <- as.matrix(dta[346:387,14])
rri <- as.matrix(dta[389:430,14])
rvt <- as.matrix(dta[432:473,14])
r <- rbind(rct,rde,rme,rmd,rma,rnh,rnj,rny,rpa,rri,rvt)
one <- as.matrix(seq(length=42,from=1,by=0))
zero <- as.matrix(seq(length=42,from=0,by=0))
ct <- rbind(one,zero,zero,zero,zero,zero,zero,zero,zero,zero,zero)
de <- rbind(zero,one,zero,zero,zero,zero,zero,zero,zero,zero,zero)
me <- rbind(zero,zero,one,zero,zero,zero,zero,zero,zero,zero,zero)
md <- rbind(zero,zero,zero,one,zero,zero,zero,zero,zero,zero,zero)
ma <- rbind(zero,zero,zero,zero,one,zero,zero,zero,zero,zero,zero)
nh <- rbind(zero,zero,zero,zero,zero,one,zero,zero,zero,zero,zero)
nj <- rbind(zero,zero,zero,zero,zero,zero,one,zero,zero,zero,zero)
ny <- rbind(zero,zero,zero,zero,zero,zero,zero,one,zero,zero,zero)
pa <- rbind(zero,zero,zero,zero,zero,zero,zero,zero,one,zero,zero)
ri <- rbind(zero,zero,zero,zero,zero,zero,zero,zero,zero,one,zero)
vt <- rbind(zero,zero,zero,zero,zero,zero,zero,zero,zero,zero,one)
x <- cbind(constant,r,v,ct,de,me,md,ma,nh,nj,ny,pa,vt)
```

```
y <- dv

# OLS estimation and test results
ols <- lm(dv~r+v+ct+de+me+md+ma+nh+nj+ny+pa+vt)
output <- summary(ols); output
NWvcov <- as.matrix(NeweyWest(ols))
bptest(ols)
        # Null Hypothesis of BP test is homoscedasticity
        # Critical value is Chi-square with alp=.05, dof=2: 5.991
durbin.watson(ols,max.lag=2)
        # Null hypothsis is no autocorrelation (rho=0)
        # If d<dl reject, if d>du do not reject, if du>d>dl inconclusive
        # Critcal value is DW with k=2, n=41: dl=1.449, du=1.549
Box.test(dv, type = c("Ljung-Box"))
        # Null hypothesis is no autocorrelation (rho=0)
        # Critical value is Chi-square with alp=.05, dof=1: 3.841
adf.test(dv)
        # Null hypothesis is nonstationary (unit root)

# Calculate Discount Parameters
coeff <- as.matrix(ols$coefficients)
a1 <- coeff[2,1]; a2 <- coeff[3,1]
a1se <- sqrt(NWvcov[2,2]); a2se <- sqrt(NWvcov[3,3]); a1a2cov <- NWvcov[2,3]
delta <- 1-a2; beta <- -a1/(1-a2)

# Conduct linear hypothsis test on exponential discounting
q <- a2-a1-1
qse <- sqrt(a1se^2+a2se^2+2*a1a2cov)
exptest <- (q/qse)^2
deltase <- a2se
print("Value of Exponential Factor"); print(cbind(delta,deltase))
print("Exponential Discounting F-test"); print(exptest)
        # This is a two-sided F-test with dof=1,203 and alpha=0.05
        # Null hypothesis is exponential discounting
        # Critical value is 3.84

# Conduct nonlinear hypothesis test on hyperbolic discounting
ga1 <- -1/(1-a2); ga2 <- -a1/((1-a2)^2)
betase <- sqrt((ga1^2)*(a1se^2)+(ga2^2)*(a2se^2)+2*(ga1)*(ga2)*(a1a2cov))
hyptest <- ((beta-1)/betase)^2
print("Value of Quasi-Hyperbolic Factor"); print(cbind(beta,betase))
print("Quasi-Hyperbolic Discounting F-test"); print(hyptest)
        # This is one-sided F-test with dof=1,203 and alpha=0.05
        # Null hypothesis is no hyperbolic discounting
        # Critical value is 3.84
```

```
# Define IV matrix and scale
z <- as.matrix(cbind(constant,r,v,ct,de,me,md,ma,nh,nj,ny,pa,vt,r^2,lagR,lagV))
k <- ncol(z)

# Define initial weighting matrix
w <- nrow(z)*solve(t(z)%*%z)

# Define GMM function
fr <- function(b){
     (1/n)*t(y-x%*%b)%*%z%*%w%*%((1/n)*t(z)%*%(y-x%*%b)) }

# Define gradient
gfr <- function(b){
     -2*t(y-x%*%b)%*%z%*%w%*%t(z)%*%x }

# Conduct first step GMM
gmm <- optim(c(0,0,0,0,0,0,0,0,0,0,0,0,0),fr,gfr)
sse <- as.numeric(t(y-x%*%gmm$par)%*%(y-x%*%gmm$par)/nrow(y))
shat <- (sse/nrow(z))*(t(z)%*%z)
mhat <- nrow(z)*solve((t(x)%*%z)%*%w%*%(t(z)%*%x))%*%(t(x)%*%z)%*%w
vhat <- mhat%*%shat%*%t(mhat)
print(cbind(gmm$par,sqrt(diag(vhat)/nrow(x)),gmm$par/sqrt(diag(vhat)/nrow(x)),
          1-pnorm(abs(gmm$par/sqrt(diag(vhat)/nrow(x))))))

# Conduct second step GMM
w <- solve(shat)
gmm <- optim(c(0,0,0,0,0,0,0,0,0,0,0,0,0),fr,gfr)
sse <- as.numeric(t(y-x%*%gmm$par)%*%(y-x%*%gmm$par)/nrow(y))
shat <- (sse/nrow(z))*(t(z)%*%z)
mhat <- nrow(z)*solve((t(x)%*%z)%*%w%*%(t(z)%*%x))%*%(t(x)%*%z)%*%w
vhat <- mhat%*%shat%*%t(mhat)
print(cbind(gmm$par,sqrt(diag(vhat)/nrow(x)),gmm$par/sqrt(diag(vhat)/nrow(x)),
          1-pnorm(abs(gmm$par/sqrt(diag(vhat)/nrow(x))))))

# Overidentifying restrictions / Specification test statistic (J-Test)
Jdof <- ncol(z)-ncol(x)
sse <- as.numeric(t(y-x%*%gmm$par)%*%(y-x%*%gmm$par))
shat <- (sse)*(t(z)%*%z)
print("J-test Degrees of Freedom"); Jdof
jt <- (n^-0.5)*t(y-x%*%gmm$par)%*%z%*%solve(shat)%*%t(z)%*%(y-x%*%gmm$par)
print("Jt Test Statistic"); jt
          # Jt converges to Chi-Square with q-p degrees of freedom
          # The degrees of freedom equal the number of overidentifying restrictions
          # The critical value with alpha=0.05 and q-p=4 is 9.488
          # Rejection indicates problems with the GMM estimator
```

```
# Calculate Discount Parameters
coeff <- as.matrix(gmm$par)
a1 <- coeff[2,1]; a2 <- coeff[3,1]
a1se <- sqrt(vhat[2,2]/nrow(x)); a2se <- sqrt(vhat[3,3]/nrow(x)); a1a2cov <- vhat[2,3]/nrow(x)
delta <- 1-a2; beta <- -a1/(1-a2)

# Conduct linear hypothsis test on exponential discounting
q <- a2-a1-1
qse <- sqrt(a1se^2+a2se^2+2*a1a2cov)
exptest <- (q/qse)^2
deltase <- a2se
print("Value of Exponential Factor"); print(cbind(delta,deltase))
print("Exponential Discounting F-test"); print(exptest)
	# This is a two-sided F-test with dof=1,203 and alp=0.05
	# Null hypothesis is exponential discounting
	# Critical value is 3.84

# Conduct nonlinear hypothesis test on hyperbolic discounting
ga1 <- -1/(1-a2); ga2 <- -a1/((1-a2)^2)
betase <- sqrt((ga1^2)*(a1se^2)+(ga2^2)*(a2se^2)+2*(ga1)*(ga2)*(a1a2cov))
hyptest <- ((beta-1)/betase)^2
print("Value of Quasi-Hyperbolic Factor"); print(cbind(beta,betase))
print("Quasi-Hyperbolic Discounting F-test"); print(hyptest)
	# This is one-sided F-test with dof=1,203 and alp=0.05
	# Null hypothesis is no hyperbolic discounting
	# Critical value is 3.84

# END PROGRAM

# TITLE: Pacific States Panel OLS & Linear GMM

# RESET ALL WORK
rm(list = ls())

# Call needed libraries
library(lmtest); library(stats); library(tseries)
library(car); library(sandwich); library(systemfit)

# Download CPI Deflator
dta0 <- read.table("Deflators.dta")
cpi <- as.numeric(dta0[2:44,1])
lagcpi <- as.numeric(dta0[3:44,1])

# Download data sets
# Column Order: Y~CA~OR~WA~V~R~I~DV
dta <- read.table("PacificNom.dta")
```

```
# Create lagged variables
obs <- nrow(dta)
lagVca <- as.matrix(dta[1:(43-1),5])
lagRca <- as.matrix(dta[1:(43-1),6])
lagVor <- as.matrix(dta[44:(86-1),5])
lagRor <- as.matrix(dta[44:(86-1),6])
lagVwa <- as.matrix(dta[87:(129-1),5])
lagRwa <- as.matrix(dta[87:(129-1),6])
lagV <- rbind(lagVca,lagVor,lagVwa)
lagR <- rbind(lagVca,lagVor,lagVwa)

# Define dep var, indep var, & scale
dvca <- as.matrix(dta[2:43,8])
dvor <- as.matrix(dta[45:86,8])
dvwa <- as.matrix(dta[88:129,8])
dv <- rbind(dvca,dvor,dvwa)
n <- nrow(dv)
constant <- as.matrix(seq(length=n,from=1,by=0))
vca <- as.matrix(dta[2:43,5])
vor <- as.matrix(dta[45:86,5])
vwa <- as.matrix(dta[88:129,5])
v <- rbind(vca,vor,vwa)
rca <- as.matrix(dta[2:43,6])
ror <- as.matrix(dta[45:86,6])
rwa <- as.matrix(dta[88:129,6])
r <- rbind(rca,ror,rwa)
one <- as.matrix(seq(length=42,from=1,by=0))
zero <- as.matrix(seq(length=42,from=0,by=0))
ca <- rbind(one,zero,zero)
or <- rbind(zero,one,zero)
wa <- rbind(zero,zero,one)
x <- cbind(constant,r,v,or,wa)
y <- dv

# OLS estimation and test results
ols <- lm(dv~r+v+or+wa)
output <- summary(ols); output
NWvcov <- as.matrix(NeweyWest(ols))
bptest(ols)
        # Null Hypothesis of BP test is homoscedasticity
        # Critical value is Chi-square with alp=.05, dof=2: 5.991
durbin.watson(ols,max.lag=2)
        # Null hypothsis is no autocorrelation (rho=0)
        # If d<dl reject, if d>du do not reject, if du>d>dl inconclusive
        # Critcal value is DW with k=2, n=41: dl=1.449, du=1.549
```

```
Box.test(dv, type = c("Ljung-Box"))
        # Null hypothesis is no autocorrelation (rho=0)
        # Critical value is Chi-square with alp=.05, dof=1: 3.841
adf.test(dv)
        # Null hypothesis is nonstationary (unit root)

# Calculate Discount Parameters
coeff <- as.matrix(ols$coefficients)
a1 <- coeff[2,1]; a2 <- coeff[3,1]
a1se <- sqrt(NWvcov[2,2]); a2se <- sqrt(NWvcov[3,3]); a1a2cov <- NWvcov[2,3]
delta <- 1-a2; beta <- -a1/(1-a2)

# Conduct linear hypothsis test on exponential discounting
q <- a2-a1-1
qse <- sqrt(a1se^2+a2se^2+2*a1a2cov)
exptest <- (q/qse)^2
deltase <- a2se
print("Value of Exponential Factor"); print(cbind(delta,deltase))
print("Exponential Discounting F-test"); print(exptest)
        # This is a two-sided F-test with dof=1,121 and alpha=0.05
        # Null hypothesis is exponential discounting
        # Critical value is 3.92

# Conduct nonlinear hypothesis test on hyperbolic discounting
ga1 <- -1/(1-a2); ga2 <- -a1/((1-a2)^2)
betase <- sqrt((ga1^2)*(a1se^2)+(ga2^2)*(a2se^2)+2*(ga1)*(ga2)*(a1a2cov))
hyptest <- ((beta-1)/betase)^2
print("Value of Quasi-Hyperbolic Factor"); print(cbind(beta,betase))
print("Quasi-Hyperbolic Discounting F-test"); print(hyptest)
        # This is one-sided F-test with dof=1,121 and alpha=0.05
        # Null hypothesis is no hyperbolic discounting
        # Critical value is 3.92

# Define IV matrix and scale
z <- as.matrix(cbind(constant,v,r,or,wa,r^2,lagR))
k <- ncol(z)

# Define initial weighting matrix
w <- nrow(z)*solve(t(z)%*%z)

# Define GMM function
fr <- function(b){
     (1/n)*t(y-x%*%b)%*%z%*%w%*%((1/n)*t(z)%*%(y-x%*%b)) }

# Define gradient
gfr <- function(b){
```

```
    -2*t(y-x%*%b)%*%z%*%w%*%t(z)%*%x }

# Conduct first step GMM
gmm <- optim(c(0,0,0,0,0),fr,gfr)
sse <- as.numeric(t(y-x%*%gmm$par)%*%(y-x%*%gmm$par)/nrow(y))
shat <- (sse/nrow(z))*(t(z)%*%z)
mhat <- nrow(z)*solve((t(x)%*%z)%*%w%*%(t(z)%*%x))%*%(t(x)%*%z)%*%w
vhat <- mhat%*%shat%*%t(mhat)
print(cbind(gmm$par,sqrt(diag(vhat)/nrow(x)),gmm$par/sqrt(diag(vhat)/nrow(x)),
        1-pnorm(abs(gmm$par/sqrt(diag(vhat)/nrow(x))))))

# Conduct second step GMM
w <- solve(shat)
gmm <- optim(c(0,0,0,0,0),fr,gfr)
sse <- as.numeric(t(y-x%*%gmm$par)%*%(y-x%*%gmm$par)/nrow(y))
shat <- (sse/nrow(z))*(t(z)%*%z)
mhat <- nrow(z)*solve((t(x)%*%z)%*%w%*%(t(z)%*%x))%*%(t(x)%*%z)%*%w
vhat <- mhat%*%shat%*%t(mhat)
print(cbind(gmm$par,sqrt(diag(vhat)/nrow(x)),gmm$par/sqrt(diag(vhat)/nrow(x)),
        1-pnorm(abs(gmm$par/sqrt(diag(vhat)/nrow(x))))))

# Overidentifying restrictions / Specification test statistic (J-Test)
Jdof <- ncol(z)-ncol(x)
sse <- as.numeric(t(y-x%*%gmm$par)%*%(y-x%*%gmm$par))
shat <- (sse)*(t(z)%*%z)
print("J-test Degrees of Freedom"); Jdof
jt <- (n^-0.5)*t(y-x%*%gmm$par)%*%z%*%solve(shat)%*%t(z)%*%(y-x%*%gmm$par)
print("Jt Test Statistic"); jt
        # Jt converges to Chi-Square with q-p degrees of freedom
        # The degrees of freedom equal the number of overidentifying restrictions
        # The critical value with alpha=0.05 and q-p=4 is 9.488
        # Rejection indicates problems with the GMM estimator

# Calculate Discount Parameters
coeff <- as.matrix(gmm$par)
a1 <- coeff[2,1]; a2 <- coeff[3,1]
a1se <- sqrt(vhat[2,2]/nrow(x)); a2se <- sqrt(vhat[3,3]/nrow(x)); a1a2cov <- vhat[2,3]/nrow(x)
delta <- 1-a2; beta <- -a1/(1-a2)

# Conduct linear hypothsis test on exponential discounting
q <- a2-a1-1
qse <- sqrt(a1se^2+a2se^2+2*a1a2cov)
exptest <- (q/qse)^2
deltase <- a2se
print("Value of Exponential Factor"); print(cbind(delta,deltase))
print("Exponential Discounting F-test"); print(exptest)
```

```
	# This is a two-sided F-test with dof=1,121 and alp=0.05
	# Null hypothesis is exponential discounting
	# Critical value is 3.92

# Conduct nonlinear hypothesis test on hyperbolic discounting
ga1 <- -1/(1-a2); ga2 <- -a1/((1-a2)^2)
betase <- sqrt((ga1^2)*(a1se^2)+(ga2^2)*(a2se^2)+2*(ga1)*(ga2)*(a1a2cov))
hyptest <- ((beta-1)/betase)^2
print("Value of Quasi-Hyperbolic Factor"); print(cbind(beta,betase))
print("Quasi-Hyperbolic Discounting F-test"); print(hyptest)
	# This is one-sided F-test with dof=1,121 and alp=0.05
	# Null hypothesis is no hyperbolic discounting
	# Critical value is 3.92

# END PROGRAM

# TITLE: Southeast Panel OLS & Linear GMM

# RESET ALL WORK
rm(list = ls())

# Call needed libraries
library(lmtest); library(stats); library(tseries)
library(car); library(sandwich); library(systemfit)

# Download CPI Deflator
dta0 <- read.table("Deflators.dta")
cpi <- as.numeric(dta0[2:44,1])
lagcpi <- as.numeric(dta0[3:44,1])

# Download data sets
# Column Order: Y~AL~FL~GA~SC~V~R~I~DV
dta <- read.table("SoutheastNom.dta")

# Create lagged variables
obs <- nrow(dta)
lagVal <- as.matrix(dta[1:(43-1),6])
lagRal <- as.matrix(dta[1:(43-1),7])
lagVfl <- as.matrix(dta[44:(86-1),6])
lagRfl <- as.matrix(dta[44:(86-1),7])
lagVga <- as.matrix(dta[87:(129-1),6])
lagRga <- as.matrix(dta[87:(129-1),7])
lagVsc <- as.matrix(dta[130:(172-1),6])
lagRsc <- as.matrix(dta[130:(172-1),7])
lagV <- rbind(lagVal,lagVfl,lagVga,lagVsc)
lagR <- rbind(lagRal,lagRfl,lagRga,lagRsc)
```

```
# Define dep var, indep var, & scale
dval <- as.matrix(dta[2:43,9])
dvfl <- as.matrix(dta[45:86,9])
dvga <- as.matrix(dta[88:129,9])
dvsc <- as.matrix(dta[131:172,9])
dv <- rbind(dval,dvfl,dvga,dvsc)
n <- nrow(dv)
constant <- as.matrix(seq(length=n,from=1,by=0))
val <- as.matrix(dta[2:43,6])
vfl <- as.matrix(dta[45:86,6])
vga <- as.matrix(dta[88:129,6])
vsc <- as.matrix(dta[131:172,6])
v <- rbind(val,vfl,vga,vsc)
ral <- as.matrix(dta[2:43,7])
rfl <- as.matrix(dta[45:86,7])
rga <- as.matrix(dta[88:129,7])
rsc <- as.matrix(dta[131:172,7])
r <- rbind(ral,rfl,rga,rsc)
one <- as.matrix(seq(length=42,from=1,by=0))
zero <- as.matrix(seq(length=42,from=0,by=0))
al <- rbind(one,zero,zero,zero)
fl <- rbind(zero,one,zero,zero)
ga <- rbind(zero,zero,one,zero)
sc <- rbind(zero,zero,zero,one)
x <- cbind(constant,r,v,al,ga,sc)
y <- dv

# OLS estimation and test results
ols <- lm(dv~r+v+al+ga+sc)
output <- summary(ols); output
NWvcov <- as.matrix(NeweyWest(ols))
bptest(ols)
        # Null Hypothesis of BP test is homoscedasticity
        # Critical value is Chi-square with alp=.05, dof=2: 5.991
durbin.watson(ols,max.lag=2)
        # Null hypothsis is no autocorrelation (rho=0)
        # If d<dl reject, if d>du do not reject, if du>d>dl inconclusive
        # Critcal value is DW with k=2, n=41: dl=1.449, du=1.549
Box.test(dv, type = c("Ljung-Box"))
        # Null hypothesis is no autocorrelation (rho=0)
        # Critical value is Chi-square with alp=.05, dof=1: 3.841
adf.test(dv)
        # Null hypothesis is nonstationary (unit root)

# Calculate Discount Parameters
```

```
coeff <- as.matrix(ols$coefficients)
a1 <- coeff[2,1]; a2 <- coeff[3,1]
a1se <- sqrt(NWvcov[2,2]); a2se <- sqrt(NWvcov[3,3]); a1a2cov <- NWvcov[2,3]
delta <- 1-a2; beta <- -a1/(1-a2)

# Conduct linear hypothsis test on exponential discounting
q <- a2-a1-1
qse <- sqrt(a1se^2+a2se^2+2*a1a2cov)
exptest <- (q/qse)^2
print("Value of Exponential Factor"); print(delta)
print("Exponential Discounting F-test"); print(exptest)
        # This is a two-sided F-test with dof=1,162 and alpha=0.05
        # Null hypothesis is exponential discounting
        # Critical value is 3.84

# Conduct nonlinear hypothesis test on hyperbolic discounting
ga1 <- -1/(1-a2); ga2 <- -a1/((1-a2)^2)
betase <- sqrt((ga1^2)*(a1se^2)+(ga2^2)*(a2se^2)+2*(ga1)*(ga2)*(a1a2cov))
hyptest <- ((beta-1)/betase)^2
print("Value of Quasi-Hyperbolic Factor"); print(cbind(beta,betase))
print("Quasi-Hyperbolic Discounting F-test"); print(hyptest)
        # This is one-sided F-test with dof=1,162 and alpha=0.05
        # Null hypothesis is no hyperbolic discounting
        # Critical value is 3.84

# Define IV matrix and scale
z <- as.matrix(cbind(constant,v,r,ga,al,sc,v^2,r^2,lagV,lagR))
k <- ncol(z)

# Define initial weighting matrix
w <- nrow(z)*solve(t(z)%*%z)

# Define GMM function
fr <- function(b){
    (1/n)*t(y-x%*%b)%*%z%*%w%*%((1/n)*t(z)%*%(y-x%*%b)) }

# Define gradient
gfr <- function(b){
    -2*t(y-x%*%b)%*%z%*%w%*%t(z)%*%x }

# Conduct first step GMM
gmm <- optim(c(0,0,0,0,0,0),fr,gfr)
sse <- as.numeric(t(y-x%*%gmm$par)%*%(y-x%*%gmm$par)/nrow(y))
shat <- (sse/nrow(z))*(t(z)%*%z)
mhat <- nrow(z)*solve((t(x)%*%z)%*%w%*%(t(z)%*%x))%*%(t(x)%*%z)%*%w
vhat <- mhat%*%shat%*%t(mhat)
```

```
print(cbind(gmm$par,sqrt(diag(vhat)/nrow(x)),gmm$par/sqrt(diag(vhat)/nrow(x)),
        1-pnorm(abs(gmm$par/sqrt(diag(vhat)/nrow(x))))))

# Conduct second step GMM
w <- solve(shat)
gmm <- optim(c(0,0,0,0,0,0),fr,gfr)
sse <- as.numeric(t(y-x%*%gmm$par)%*%(y-x%*%gmm$par)/nrow(y))
shat <- (sse/nrow(z))*(t(z)%*%z)
mhat <- nrow(z)*solve((t(x)%*%z)%*%w%*%(t(z)%*%x))%*%(t(x)%*%z)%*%w
vhat <- mhat%*%shat%*%t(mhat)
print(cbind(gmm$par,sqrt(diag(vhat)/nrow(x)),gmm$par/sqrt(diag(vhat)/nrow(x)),
        1-pnorm(abs(gmm$par/sqrt(diag(vhat)/nrow(x))))))

# Overidentifying restrictions / Specification test statistic (J-Test)
Jdof <- ncol(z)-ncol(x)
sse <- as.numeric(t(y-x%*%gmm$par)%*%(y-x%*%gmm$par))
shat <- (sse)*(t(z)%*%z)
print("J-test Degrees of Freedom"); Jdof
jt <- (n^-0.5)*t(y-x%*%gmm$par)%*%z%*%solve(shat)%*%t(z)%*%(y-x%*%gmm$par)
print("Jt Test Statistic"); jt
        # Jt converges to Chi-Square with q-p degrees of freedom
        # The degrees of freedom equal the number of overidentifying restrictions
        # The critical value with alpha=0.05 and q-p=4 is 9.488
        # Rejection indicates problems with the GMM estimator

# Calculate Discount Parameters
coeff <- as.matrix(gmm$par)
a1 <- coeff[2,1]; a2 <- coeff[3,1]
a1se <- sqrt(vhat[2,2]/nrow(x)); a2se <- sqrt(vhat[3,3]/nrow(x)); a1a2cov <- vhat[2,3]/nrow(x)
delta <- 1-a2; beta <- -a1/(1-a2)

# Conduct linear hypothsis test on exponential discounting
q <- a2-a1-1
qse <- sqrt(a1se^2+a2se^2+2*a1a2cov)
exptest <- (q/qse)^2
deltase <- a2se
print("Value of Exponential Factor"); print(cbind(delta,deltase))
print("Exponential Discounting F-test"); print(exptest)
        # This is a two-sided F-test with dof=1,162 and alp=0.05
        # Null hypothesis is exponential discounting
        # Critical value is 3.84

# Conduct nonlinear hypothesis test on hyperbolic discounting
ga1 <- -1/(1-a2); ga2 <- -a1/((1-a2)^2)
betase <- sqrt((ga1^2)*(a1se^2)+(ga2^2)*(a2se^2)+2*(ga1)*(ga2)*(a1a2cov))
hyptest <- ((beta-1)/betase)^2
```

```
print("Value of Quasi-Hyperbolic Factor"); print(cbind(beta,betase))
print("Quasi-Hyperbolic Discounting F-test"); print(hyptest)
	# This is one-sided F-test with dof=1,162 and alp=0.05
	# Null hypothesis is no hyperbolic discounting
	# Critical value is 3.84

# END PROGRAM
```

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BIOGRAPHICAL SKETCH

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Matthew was born in Providence, Rhode Island and later moved to Florida where he began his college career. After graduating from with his Bachelor of Science degree in health services administration, he was admitted to graduate studies in the applied economics program, where he also minored in statistical computing. In fall 2004, he came to the University of Florida and began his doctoral degree in food and resource economics. His major fields of interest are applied microeconomic theory and applied econometrics with a research emphasis in production theory, environmental economics, urban and regional economics, risk and uncertainty, and health economics.