The impact of down-zoning on land values
A theoretical approach

Paul D. Gottlieb
Department of Agricultural, Food, and Resource Economics,
Rutgers University, New Brunswick, New Jersey, USA, and
Adesoji Adelaja
Land Policy Institute, Michigan State University,
East Lansing, Michigan, USA

Abstract
Purpose – This paper aims to build a mathematical model to determine the price of an acre of developable land, whether it is part of a large open tract (farm) or a smaller residential parcel that can legally be subdivided. The primary purpose of the model is to explore the effect of various minimum lot size regulations on the price of these two types of vacant land. The study also attempts to explain apparently conflicting findings that have recently appeared in empirical studies of “down-zoning” in the states of Maryland and New Jersey.

Design/methodology/approach – The mathematical model of land value is based on principles of asset valuation under uncertainty at various locations within a metropolitan area. The price of an acre of land is modeled as the present value of a stream of indirect utility to homeowners, and economic rents to farmers, developers or landlords, depending on an endogenous date of development. The cases of New Jersey and Maryland are compared using parameterized simulations, with minimum lot size allowed to vary.

Findings – The simulations reconcile earlier empirical studies on Maryland and New Jersey. The observed absence of any price effect of down-zoning in rural Maryland appears to be caused by the fact that development is not imminent there. In New Jersey, development is imminent virtually everywhere, and a high proportion of today’s vacant land value is due to its development potential. This means that down-zoning will typically lead to dramatic declines in vacant land value in New Jersey.

Research limitations/implications – The study relies on state averages, so its results should not be applied to particular parcels in Maryland or New Jersey. The study incorporates uncertainty in expected developer profits, but not in future political decisions.

Practical implications – By clarifying the context in which zoning changes will or will not lead to decline in a landowner’s asset value, the study can inform legal and political debates over re-zonings in the USA. Included in these debates is the claim that some re-zonings violate the “takings” clause of the USA constitution.

Originality/value – The majority of papers on this subject are empirical, using a hedonic or an appraisal methodology. This paper provides a coherent theoretical model of per-acre land prices under different levels of zoning restriction. It can be used for simulation or prediction with relatively few input parameters.

Keywords United States of America, Land, Modelling, Asset valuation

Paper type Research paper

This research was supported by state and federal funds appropriated to the New Jersey and Michigan Agricultural Experiment Stations and to the Rutgers and Michigan State University Extension Services under the Hatch and McIntyre-Stennis Acts. The research was also supported by a grant to the Land Policy Institute from the W.K. Kellogg Foundation under the People and Land Prosperity program.
1. Introduction
Down-zoning is defined as the use of the police power to reduce development density on vacant land by increasing the minimum lot size on which homes can legally be built. In many communities where down-zoning has been proposed, it has been controversial. Farmers who own developable land often argue that down-zoning violates their property rights, robs them of equity, compromises the long-term viability of their farm operations and reduces their retirement income by restricting development. Environmentalists, planners and homeowners frequently argue that down-zoning is needed to protect environmental resources and rural character, and that the costs to individuals are small in relation to the social benefits[1] (see e.g. Shupe, 2004; Chiala, 2006; Cecil County Commissioners, 2006).

This debate between local stakeholders hinges, in part, on assumptions about the impact that down-zoning will have on the price of vacant land. Intuitively, down-zoning should reduce present-day land prices because it eliminates certain development rights. This negative effect on price should vary systematically with the parcel's development potential: the greater this potential today, the greater the potential loss of equity from the removal of development rights. On the other hand, down-zoning could increase the price of vacant land because it provides a higher level of amenity and fiscal protections to the neighborhood within which the developable parcel sits. These offsetting effects of large-lot zoning have been much discussed in the literature, but it remains difficult to separate them or to predict the net effect of down-zoning on land prices in particular contexts (Pogodzinski and Sass, 1991; Peterson, 1974; Spalatro and Provencher, 2001; Henneberry and Barrows, 1990).

This article focuses on precisely these property value effects. More specifically, it analyzes down-zoning's effects on the per-acre land values of large landowners (labeled "farmers" here for convenience), and non-farm homeowners, providing a theoretical framework that has been hinted at in much of the literature, but which has not been formalized. A major application of the model is a prediction of down-zoning's price effect as a function of the development component of current land value; or equivalently, a parcel's location on a spectrum of urban to rural. The theoretical framework is illustrated with parameterized simulations of rural land prices in the states of New Jersey and Maryland. The development component of agricultural land price in these two states is taken from the work of Plantinga et al. (2002).

Although clearly not representative of all rural America, these two states were recently the subject of empirical studies on down-zoning that came to radically different conclusions (Eiggen et al., 2003; Samuels, 2004). In a critical review of those two studies, Michael et al. (2006) focused on methodological issues. In contrast, the present work uses principles of finance to provide a plausible explanation for the different price effects of down-zoning found in New Jersey and Maryland. The present work succeeds in explaining and reconciling the two earlier findings without passing judgment on methodology. We suspect that the different degree of development pressure in New Jersey and Maryland generates systematically different price effects of down-zoning, the measurement of which is robust to differences in empirical methodology or quality of the data.

2. Past literature on zoning's price effects
Most studies of the land value effects of zoning look at land use classifications rather than at lot-size restrictions (Henneberry and Barrows, 1990; Brownstone and DeVany, 1991; Grieson and White, 1989). The few that look at lot-size restrictions tend to focus
on residential properties and ignore undeveloped land (Peterson, 1974; Jud, 1980; Dowall and Landis, 1989), thus failing to address the main concern of farmers. Furthermore, with the notable exception of White (1988), none of these studies uses a formal economic model to develop hypotheses on the price effects of lot-size regulations.

Two theoretical models of the impact of minimum lot size on land and housing markets may be found in M. White (1975) and Grieson and J. White (1981). Both articles present models of a regional housing market in which housing is produced using land and capital as inputs, and households have a fixed budget to spend on housing and other goods. In M. White’s model, the per-acre price of residential land is assumed to fall as the minimum lot size increases because some households exit the market, effectively shifting the demand curve for size-restricted land to the left [2]. In contrast, Grieson and J. White (1981) argue that the demand response, and hence the impact on land price, is ambiguous. This argument is mirrored in more recent work by Irwin et al. (2003).

These works are valuable for analyzing minimum lot-size zoning in a traditional supply and demand framework and for considering impacts on an entire region’s housing market. The theoretical model presented below is quite different. It uses a finance/capitalization model to explore the likely effects on landowners of the loss of an option, as well as possible changes in the expected value of different options, in an asset market characterized by uncertainty.

One advantage of this approach is that it explicitly models the fact that future willingness-to-pay for homes on various lot sizes is unknown: when bidding on a vacant parcel, developers must make an educated guess about the stream of residential rents it will return. One possible shortcoming of our approach is that it does not formally consider the zoning actions of other municipalities in a state or region, or the combined effect of many local regulations on the regional housing market. Hence the present study should be regarded as complementing, rather than replacing, works such as M. White (1975), Moss (1977), Grieson and J. White (1981) and Pollakowski and Wachtter (1990).

2.1 Implicit theoretical frameworks made explicit
The model presented below highlights two broad dichotomies that are found throughout the zoning impact literature. The first is the dichotomy between the impact of zoning restrictions on the value of development rights associated with the parcel being studied and the externality effects of zoning restrictions that are imposed elsewhere (including on the parcel’s immediate neighbors, which are assumed to be in the same zone). This distinction has been widely discussed and analyzed in empirical studies, including those conducted in rural areas (Pogodzinski and Sass, 1991; Peterson, 1974; Grieson and White, 1989; Spalatro and Provencher, 2001; Henneberry and Barrows, 1990).

The second dichotomy is that between the impact of zoning restrictions on large landowners, speculators and farmers on the one hand; and small owner-occupiers on the other. The empirical literature has been somewhat less effective at addressing this second dichotomy, largely because individual papers tend to measure zoning’s effects on either developed or undeveloped land, but not both together (a good example of this separation is the pioneering pair of papers written by George Peterson (1974, 1978). In contrast, the theoretical model below analyzes developed and undeveloped property in a single unified framework. This is done for good reason: The politics of local
down-zoning typically pit farmers and developers (i.e. holders of large tracts of developable land) against ordinary homeowners with smaller lots (Fischel, 1985; Vogel and Swanson, 1989; Adelaja and Gottlieb, 2009).

While it is reasonable to expect that large landowners and small owner-occupiers will have different economic interests, the model also highlights similarities between the two types of landowners that have previously been overlooked. An integrated model may help delineate the motives of certain hybrid groups that are becoming increasingly important in some parts of the country. One such group is the so-called “hobby farmer,” who owns a large amount of open space, but prefers to use the land for personal consumption rather than for market exchange in the form of agricultural production or real estate development.

3. Theoretical model
The model developed in this section draws heavily on the work of Capozza and Helsley (1990) and subsequent works employing those authors’ foundational model of land valuation on the metropolitan fringe (Schmitz and Just, 2003; Plantinga and Miller, 2001; Plantinga et al., 2002). In this standard model, the price of an acre of developable land in agriculture is equal to the present value of expected profits from farming until the land is converted to residential use, plus the present value of net residential rents received thereafter. The date of conversion to residential use is a choice variable chosen to maximize the present value of the entire stream of earnings. Conversion to residential use takes place as soon as the present value of development-related rents exceeds the present value of agricultural profits and the option value of waiting to develop at a still later date. The usual assumption that residential development is irreversible is made, and the date of conversion is denoted as \( t^* \).

In the present model, all homeowners retain the right to subdivide their property to the extent permitted by law. Every homeowner is therefore a potential developer, just like farmers and speculators. On the other side of the coin, every farmer derives utility from his homestead as an owner-occupier (Henneberry and Barrows, 1990), cares about the aesthetics of the neighborhood (both before and after the decision to develop), and cares about the net fiscal costs of developments elsewhere in the municipality.

Formally, the per-acre price of a farmer’s land holdings at time \( t \) may be specified as

\[
P_t^f = \max_{p} \{ H_{t-\infty}^f + A_{t-\infty} + D_{t-\infty}^f \} \tag{1}\]

and the per-acre price of the homeowner’s total land holdings at time \( t \) as

\[
P_t^H = \max_{p} \{ H_t^H + D_t^H \} \tag{2}\]

where \( t^* \) is a decision variable chosen to maximize the quantity in brackets. \( H_{t-\infty} \) is a discounted stream of imputed rent derived by the owner from living on the site, \( D_{t-\infty} \) is the discounted stream of net profits from future development and \( A_{t-\infty} \) is a discounted stream of agricultural profits. The presence of \( H_{t-\infty} \) and \( D_{t-\infty} \) in both equations highlights similarities in the incentives facing both types of landowner. Conceptually, it can be argued that the only difference between the farmer and the homeowner at time \( t \) is that the farmer’s 500-acre “backyard” has a feasible economic use beyond the provision of amenity benefits to the farm family, while the homeowner
cannot use a half-acre backyard the same way (which is not to say that he/she would want to even if he/she could). This economic use is captured by the term \( A_{\text{c,lot}} \).

Let \( \alpha \) be a zoning restrictiveness parameter that is equal to 0 when the minimum lot size throughout the community is the smallest one feasible for a single-family dwelling (e.g. a tenth of an acre), which will be denoted \( l_{\text{min}} \). The parameter \( \alpha \) will be equal to 1 when the minimum lot size corresponds to an estate that is so large that only farmers or very affluent residents could have any use for it (e.g. 40 acres), denoted \( l_{\text{max}} \). The lot sizes of parcels that have already been subdivided are grandfathered.

It is expected that \( \partial H / \partial \alpha > 0 \) for both groups because large-lot zoning improves neighborhood aesthetics and provides spillover benefits to the current household, farmers and non-farmers alike. It reduces the likelihood that new development will exceed the capacity of municipal infrastructure systems or cause increased traffic, flooding or environmental problems. Because many public services are consumed in equal quantities but are paid for with a tax on home value, large-lot zoning also reduces the likelihood that incumbent residents will cross-subsidize the public services of newcomers (Hamilton, 1976)[3]. One might also expect that \( \partial H^F / \partial \alpha > \partial H^F / \partial \alpha \) because farmers’ larger landholdings insulate them to some extent from the disamenity effects of neighborhood development, at least before date of development at \( t^* \). By definition, farmers own a large expanse of private open space.

Next consider \( A_{\text{c,lot}} \), the discounted stream of agricultural profits in (1). It is expected that \( \partial A / \partial \alpha > 0 \) because large-lot zoning in the vicinity of the farm will increase the predictability of farming, reduce future right-to-farm conflicts, and help create critical mass in agricultural support services (Henneberry and Barrows, 1990; Libby, 2003; Lynch and Carpenter, 2003).

Finally, consider the future stream of profits from development for both types of landowner. This may be expressed as follows:

\[
D_{t^{*} \rightarrow \infty} = \int_{s=t^{*}}^{\infty} \delta_s \pi_s \, ds
\]

(3)

where \( \delta_s \) is a discount factor and \( \pi_s \) is expected net profits, or rents, from development, both calculated at time \( s \). Because \( \pi_s \) is an expected value driven by uncertainties in the housing market, it is actually a sum of the payoffs expected for each possible lot size multiplied by probabilities, as follows:

\[
\pi_s = \int_{l=0}^{l_{\text{max}}} p_l \pi_{s,l}
\]

(4)

where \( l \) is a continuous lot-size variable, and \( l_{\text{min}} \) and \( l_{\text{max}} \) are the limits on feasible residential lot size defined above, \( p_l \) is the probability that a given lot size \( l \) will be the most profitable lot size at time \( t^* \) and will therefore be chosen by the developer at that time. As written, Equation (4) therefore describes expected development profit at time \( s \) if there is no lot-size constraint imposed by the government.

Down-zoning can be expected to have two offsetting effects in (4). On the one hand, \( \partial \pi_{s,l} / \partial \alpha > 0 \) for the same reason that \( \partial H / \partial \alpha > 0 \) for existing residents. Future homebuyers or tenants will benefit from the externality control that a higher \( \alpha \) brings about, and they should be willing to pay a per-acre premium for access to a community with more restrictive zoning. This assertion holds all else equal, including the size of the homebuyer’s own lot.
But an increase in \( \alpha \) also increases the probability that the most profitable lot size at time \( t^* \) will be prohibited by law, so that \( \pi_t \) will turn out to be the result of a constrained rather than a true optimum. This is the main effect that the opponents of down-zoning focus on: it is the loss of an option. This option has economic value today, even though the most profitable lot size is uncertain and could turn out to be permitted even under more restrictive zoning.

The constraint imposed by down-zoning can be expressed by modifying Equation (4) as follows:

For farmland,

\[
\pi_s = \int_{l = \text{min}}^{l_{\alpha \text{max}}} p_l \tilde{\pi}_d \, dl + \int_{l = l_{\alpha}}^{l_{\text{max}}} p_l \pi_d \, dl
\]  

(5)

where \( l_{\alpha} = l_{\text{max}} - (1 - \alpha)(l_{\text{max}} - l_{\text{min}}) \) is the actual lot size associated with a given \( \alpha \).

Equation (6) splits the integral shown in (4) into two parts. The addend on the right is the portion of expected profit for all possible futures where \( \alpha \) does not bind. The addend on the left is the portion of expected profit for all possible futures where the lot-size constraint is binding. When \( \alpha = 0 \), (5) reduces to (4). When \( \alpha > 0 \), profits associated with possible optima to the left of the regulatory constraint are written \( \tilde{\pi}_d \) to show that they are constrained.

For homeowners there are two constraints, one regulatory and one physical. The homeowner's current lot size \( (l_{\text{exist}}) \) puts an upper bound on the lot size that can be offered to future homebuyers if the homeowner acts as a developer (Peterson, 1974). Expected per-acre homeowner profits at time \( s \) are written as follows:

If \( l_{\alpha} < l_{\text{exist}} - l_{\alpha} \), then

\[
\pi_s = \int_{l = \text{min}}^{l_{\alpha \text{max}}} p_l \tilde{\pi}_d \, dl + \int_{l = l_{\alpha}}^{l_{\text{exist}} - l_{\alpha}} p_l \pi_d \, dl + \int_{l = l_{\text{exist}} - l_{\alpha}}^{l_{\text{max}}} p_l \tilde{\pi}_d \, dl
\]  

(6a)

If \( l_{\alpha} > l_{\text{exist}} - l_{\alpha} \), then \( \pi_s = 0 \)  

(6b)

The expression in (6a) is divided into three parts. When the most profitable future lot size is below regulatory minimum \( l_{\alpha} \), only the regulatory minimum can be brought to market: profits are constrained \( (\tilde{\pi}_d) \). Unconstrained profits are only available between \( l_{\alpha} \) and \( l_{\text{exist}} - l_{\alpha} \). This is because the creation of a new lot between \( l_{\text{exist}} - l_{\alpha} \) and \( l_{\text{exist}} \) would automatically create a remainder lot smaller than the legal minimum. \( l_{\text{exist}} - l_{\alpha} \) becomes the largest lot the homeowner can create by subdividing, and alternative futures with optimal lot sizes above this level once again generate constrained profits \( (\tilde{\pi}_d) \). Expression (6b) handles the case where the legal minimum is above the feasible maximum: expected profits must be zero[4]. It follows that expression (6a) can be used only when \( l_{\alpha} < l_{\text{exist}} - l_{\alpha} \), as shown.

3.1 Developer expectations

Expressions (5) and (6) help determine \( D_{r \rightarrow \infty} \), the development value component of the land-price equations in (1) and (2). Both expressions incorporate developers' expectations on the future of the real estate market, through the terms \( p_l \) and \( \pi_d \). Recall that \( p_l \) is the probability that a particular lot size will be the most profitable in future.
One may restate this as the probability that there will exist a full range of per-acre profits by lot size, denoted by function \( f(s, l) \), that has a global maximum occurring at the \( l \) associated with a given \( p \). This optimal lot size will be denoted \( \hat{l} \) in the following discussion of \( f(s, l) \).

To obtain a functional form for \( f(s, l) \), consider the cost curves of a developer for homes with different lot sizes. Housing inputs are largely sold by competitive price-taking firms and, consistent with economic theory, the marginal cost curve for the residential developer is positively sloped. Furthermore, the total land area available for development in a given location is assumed to be fixed. As lot size increases, average and marginal homebuilding costs may increase for two reasons:

1. Economies of scale associated with building more homes on a given property at higher densities.
2. Higher expected on-site infrastructure costs per dwelling unit on large lots, following the so-called "cost of sprawl" argument.

This second effect is mitigated by an important technological factor: the discontinuous changeover from public sewer lines to individual septic tanks when lot sizes become large enough to support the latter. For present purposes, we assume that the average and marginal cost curves are at best identical across delivered lot sizes, or else increase slightly with increased lot size.

Consider the possibility that local developers in many markets are non-price-takers who operate in relatively non-competitive markets and face downward sloping demand and marginal revenue curves (Turnbull, 1988; Somerville, 1999). With no control over costs and similar cost functions across their portfolio of products by lot size, prices and expected profits for each product will depend on demand conditions. The demand curve is impacted by several shift factors, including tastes and preferences and prices of complementary and competitive products. The distributions of these shifters with respect to lot size are likely to be near-normal or at least bell shaped[5]. Therefore, equilibrium prices and expected profits are expected to follow this same pattern, rising and then falling with increasing lot size. The lot-size/profitability function is therefore assumed to be bell-shaped with the logical constraint that \( l > 0 \).

A simple functional form for future per-acre profits by lot size that meets these two conditions is the log normal

\[
f(s, l) = f[s, \phi(l, \mu)]
\]  

where \( l \) is a lot size, \( s \) is a time variable and \( \phi(l, \mu) \) is log normal function

\[
\frac{1}{l(1/\mu)\sqrt{2\pi}} \exp\left(-\frac{[\ln l - \mu]^2}{2(1/\mu)^2}\right)
\]

with parameter \( \mu[6] \).

Figure 1 supports the argument that this log normal function is a reasonable assumption for expected developer profits by lot size in the unconstrained case. It compares the log normal to a "naïve" profit function, which is constrained to equal the log normal at its optimum (a half-acre in this case), but is otherwise constructed so that per-acre profits are proportional to the number of housing units built on each acre. It seems reasonable that the true function of expected profit per acre will bear at least
some resemblance to the naïve function. It would not, however, rise asymptotically with infinitely smaller lot sizes; nor would it fall quite as sharply as the naïve curve at larger lot sizes, because of the large and positive income elasticity of demand for private open space (Cheshire and Sheppard, 1998). This is exactly what Figure 1 shows.

To develop a realistic and calculable expression for \( f(s, l) \), consider the term \( \pi_d \) in (5) and (6), which represents unconstrained profit for alternative optimal lot sizes. A simplifying assumption is that \( \pi_d \) is the same regardless of which lot size is expected to be the most profitable in the future. This is equivalent to saying, reasonably, that maximum profit in the residential real estate market will be set by overall market conditions. In a given residential neighborhood, profits that are optimal on grounds of market demand will also be an increasing function of the neighborhood zoning parameter \( \alpha \), reflecting land rents attributable to zoning’s amenity and fiscal safeguards. Thus we can drop subscript \( l \) in \( \pi_d \) and write expected profit at any unconstrained optimum lot size as \( \pi(s, \alpha) \).

Equation (7) may now be re-written in terms of \( \pi(s, \alpha) \) and all suboptimal profits related to it. If \( \phi(l^*, \mu) \) is the value of a parameterized log normal function evaluated at its global optimum \( l^* \), then per-acre profits at this optimum will equal \( \pi(s, \alpha) \), while profits at any point \( l \) away from this optimum will equal \( \pi(s, \alpha) \times \phi(l, \mu) / \phi(l^*, \mu) \). The resulting \( f(s, l) \) function holds for all \( l \), including \( l = l^* \):

\[
f(s, l) = \pi(s, \alpha) \times \frac{\phi(l, \mu)}{\phi(l^*, \mu)}
\]  

Equation (8) is a general expression for a single “profile” of expected future profits by lot size. There will be a whole family of such profiles, each with a different optimum \( l^* \), which is determined entirely by parameter \( \mu \) of the log normal. Meanwhile, the term \( p_l \) in (4) through (6) denotes the probability that a particular profit profile – that is, a unique pair of \( \mu \) and \( l^* \) – will prevail in the future.

The actual \( p_l \) considered to be the largest according to today’s developers is unknown, and must be a matter for sensitivity testing. If we posit a single consensus forecast of profits by lot size, however, it is reasonable to argue that the \( p_l \) will be
distributed according to this consensus forecast. The higher the expected profit of a
given lot size, the higher the likelihood that it will be at the pinnacle of the profit profile
that actually prevails in the future − i.e. that it will be the optimum. Therefore we can
draw each \( p_i \) from the same log normal probability density function that underlies \( f(s, l) \),
setting \( \mu \) to achieve whichever consensus optimum we wish to use for our simulation:

\[
p_i = \frac{\phi(l, \mu_c)}{\int_{\mu_{min}}^{\mu_{max}} \phi(l, \mu_c) \, dl} \quad \forall i
\]

(9)

where \( \mu_c \) is the log normal parameter associated with the consensus forecast to be used
for a given simulation run.

All that remains if we are to calculate simulated values for expected development
profit in (5) and (6) is to develop expressions for \( \pi_{dl} \), \( \hat{\pi}_{dl} \) and \( \bar{\pi}_{dl} \). This is a
straightforward matter of applying the relevant domain constraint to whichever profit profile,
\( f(s, l) \), is associated with the alternative future that has probability \( p_i \). The
following payoffs are substituted into (5) and (6):

\[
\begin{align*}
\pi_{dl} &= \pi(s, \alpha) & \text{unconstrained optimal profit (see below)} \\
\hat{\pi}_{dl} &= f(s, l_o) & \text{profit constrained by minimum lot-size zoning} \\
\bar{\pi}_{dl} &= f(s, l_{exist} - l_o) & \text{profit subject to the physical constraint, as well as } \alpha
\end{align*}
\]

(10a, 10b, 10c)

Equations (1) through (10) describe a theoretically grounded, calculable model of
today's land price as a function of minimum lot-size zoning. It utilizes a whole family of
log normals, one of which is considered most likely based on \( p_i \) that themselves follow a
log normal. This approach is shown schematically in Figure 2. A simpler technique

![Figure 2. Schematic representation of expected profit model with consensus optimum at 3 acres and minimum lot-size constraint at 4 acres.](image)

Let MLS = 4.
would assume a single profile of expected profits by lot size, the "consensus" expectation, expressed as a log normal. The problem with that technique, however, is that it leads to the prediction that down-zoning has no effect on expected profits (and therefore no effect on the development component of land price) whenever the regulatory constraint lies below the expected optimum. Such a technique would ignore down-zoning's effect on the value of the option to develop over a range of smaller lot sizes.

Equations (3) through (10) specify the determinants of development value, \( D(\alpha) \), in land price Equations (1) and (2). More specifically, (8) is substituted into (10); (10) and (9) into (5) and (6); (5) or (6) into (3); and (3) into (2) and (1). Given a discount rate and reasonable parameters for functions \( \pi(s, \alpha) \), \( H(\alpha) \) and \( A(\alpha) \), it is possible to use (1) through (10) to develop a set of simulated predictions of current vacant land price as a function of \( \alpha \).

4. Parameterization and simulation analysis

The theoretical model specified in Equations (1) through (10) was programmed into Mathematica[7]. Today's price of an acre of vacant land for the typical farmer and owner-occupier was then calculated by simulation and graphed for selected \( \alpha \in \{0.0, 0.01\} \), corresponding to possible lot-size restrictions between one-tenth of an acre and 40 acres. To put the results in a real-world context, per-acre agricultural profits and indicators of development pressure were collected for the states of New Jersey and Maryland. These states were chosen because they are the sites of two recent empirical studies that found very different land-price effects from down-zoning (Etgen, 2003; Samuels, 2004). The present study helps explain these divergent findings as a result of contextual economic factors that can be specified within a unified model of rural land prices.

The actual economic characteristics of rural New Jersey and Maryland are used in the simulations to the greatest possible extent. Indeed, the only input parameters to the simulation model not drawn from the research literature or from public data sources are those that generate \( p_0 \) and those that determine the structure of \( H(\alpha) \) and \( A(\alpha) \). The expected resistance that an ordinary homeowner would have to subdividing her own lot was modeled by assuming an opportunity cost of development roughly three times that of farmers. Because they are not readily available in the literature, all but the last of these parameters were subjected to sensitivity testing, as reported below. This sensitivity testing allows us to put reasonable boundaries around the price effects of down-zoning in particular agricultural and development contexts.

4.1 Modeling the trend in unconstrained profit

Functions \( \pi(s, \alpha) \), \( H(\alpha) \) and \( A(\alpha) \) require not only the specification of parameters, but also of functional forms. \( \pi(s, \alpha) \) is the function that describes the upward trend in unconstrained profit (rent) in the local real estate market, regardless of which lot size turns out to be the best choice for developers. The urban economics literature suggests that when there is urbanization at the fringe, locational rents will follow a sigmoidal, or log-logistic shape as a function of time (Northam, 1975, pp. 207-8; Hoover, 1968). This can be verified using data on rents from the decennial census. Figure 3 graphs median gross rents from the decennial census for the seven most development-intensive states listed in Plantinga et al (2002). A sigmoidal time trend is readily apparent in Figure 3.

Using a standard log-logistic function, the time trend portion of \( \pi(s, \alpha) \) was specified as \( c/1 + e^{-ms} \) where \( s \) is the time variable in years, \( c \) is the ultimate ceiling of the log-logistic function for any state, \( m \) determines the slope of the log-logistic and \( g \)
determines the location of the entire function along the time axis, and therefore how close or far any state is from maximum urbanization at a given time in history. Parameter $c$ was set at $\$15,000$, which is roughly the annualized per-acre rent ceiling for all states in Figure 3 assuming two rental units per acre and subtracting 25 percent for annualized structure costs [8]. Parameter $m$ was set so that the near-linear portion of the model log-logistic curve has the same slope as the mean of the seven states in Figure 3 over the period 1950-1990. Parameter $g$ was selected to replicate the empirical findings on the percentage of agricultural land price attributable to development potential in New Jersey and Maryland, as reported in Plantinga et al. (2002). This required running the entire land value model of (1) through (10) with fixed $\alpha$ and varying $g$. For each state, the parameter $g$ that reproduced Plantinga’s estimate of $D_t^F / A_t - 1 + D_t^F$ was then selected for all subsequent simulation runs.

4.2 Neighborhood effects of large-lot zoning

The functional forms for the annual flows of rent used to calculate $H^F(\alpha)$, $H^F(u)$ and $A(\alpha)$ are assumed to be logarithmic to account for positive but diminishing returns with rising $\alpha$ (see Table I for details). The y-intercept for annual components of $A(\alpha)$ is taken from the 1997 Census of Agriculture for each state and remains constant over time, following the reasoning in Plantinga et al. (2002). The y-intercept for $H^F(\alpha)$ and $H^F(u)$ at time zero is based on an indirect utility interpretation of $\pi(\delta, \alpha)$ for a single housing unit at $\alpha = 0$. This means that $H^F(\alpha)$ and $H^F(u)$ vary with $g$, reflecting location rents in rural communities customized to each state’s level of urbanization, i.e. accessibility to non-agricultural jobs. Like expected developer profits, the annual component of $H^F(\alpha)$ and $H^F(u)$ then rises to the multi-state rent ceiling of Figure 3 over time.

Because homeowners with developable land are assumed to have the same amenity preferences as future homebuyers, $H^F(\alpha)$ is used to add a “zoning-amenity effect” to expected unconstrained development profit $\pi(\delta, \alpha)$. $\pi(\delta, \alpha)$ becomes $c/1 + \delta^{z_{\text{ms}}} +$
<table>
<thead>
<tr>
<th>State</th>
<th>Fig. 4 NJ</th>
<th>Fig. 5 MD</th>
<th>Fig. 6 NJ</th>
<th>Fig. 7 MD</th>
<th>Fig. 8 NJ</th>
<th>Fig. 9 MD</th>
<th>Fig. 10 NJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>( g )</td>
<td>5.2</td>
<td>8.1</td>
<td>5.2</td>
<td>8.1</td>
<td>5.2</td>
<td>8.1</td>
<td>5.2</td>
</tr>
<tr>
<td>( a )</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>60</td>
</tr>
<tr>
<td>( b )</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>200</td>
</tr>
<tr>
<td>Agricultural profits</td>
<td>w + y*(log10[MLS] + 1)</td>
<td>224</td>
<td>224</td>
<td>92</td>
<td>224</td>
<td>92</td>
<td>224</td>
</tr>
<tr>
<td></td>
<td>w*</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>120</td>
</tr>
<tr>
<td>Trend in optimal development profits</td>
<td>( c(1 + e^{0.05} - e^{0.05}) )</td>
<td>15,000</td>
<td>15,000</td>
<td>15,000</td>
<td>15,000</td>
<td>15,000</td>
<td>15,000</td>
</tr>
<tr>
<td>( c )</td>
<td>–</td>
<td>–</td>
<td>15,000</td>
<td>15,000</td>
<td>15,000</td>
<td>15,000</td>
<td>15,000</td>
</tr>
<tr>
<td>( m )</td>
<td>–</td>
<td>–</td>
<td>0.063</td>
<td>0.063</td>
<td>0.063</td>
<td>0.063</td>
<td>0.063</td>
</tr>
<tr>
<td>Consensus developer optimum</td>
<td>lot size</td>
<td>–</td>
<td>0.5</td>
<td>0.5</td>
<td>3</td>
<td>3</td>
<td>0.5</td>
</tr>
<tr>
<td>( \mu_c )</td>
<td>–</td>
<td>–</td>
<td>0.81</td>
<td>0.81</td>
<td>1.53</td>
<td>1.53</td>
<td>0.81</td>
</tr>
<tr>
<td>Discount rate</td>
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<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Source: 1997 Agricultural Census (inflated to 2000 dollars)
\[ n \times (H^*(a) - H^*(0)) \], where \( n \) is the number of units that can be built per-acre at the unconstrained optimum lot size[9].

Although intercepts for \( H^*(\alpha) \), \( H^*(a) \) and \( A(\alpha) \) can be derived from public data sources, the impact of \( \alpha \) on household utility or agricultural profits (i.e. the slope parameter) is not generally available. Because the literature does not provide guidance on the logarithmic slope parameters, all three functions are shown graphically in Figure 4, with functions and parameters listed in Table 1. The functions in Figure 4 look reasonable on their face, but they will also be altered as part of a sensitivity analysis, as shown in Figure 10.

4.3 Endogenous date of development
Because farmers and homeowners are assumed to develop their vacant land as soon as expected development profits exceed opportunity costs, the actual date of development \( t^* \) in (1) and (2) is a function of expected development and agricultural profits in each year. It is therefore endogenous to \( \alpha \) (Plantinga et al., 2002; Capozza and Helsley, 1989). Mathematica is flexible enough to handle this endogeneity. For each simulated level of \( \alpha \), \( t^* \) for farmers is calculated as the time \( s \) that solves the equation \( \tau_S = \text{annual agricultural profit} \); while \( t^* \) for homeowners is calculated as the time \( s \) that solves the equation \( \tau_S = 3 \times \text{annual agricultural profit} \). This simply means that the opportunity cost of subdividing land owned by non-farm homeowners is three times that of farmers, reflecting a strong resistance to infill development on personal utility grounds[10]. The value of making \( t^* \) endogenous, as in Plantinga et al. (2002), is that one can explore directly the impact of large-lot zoning on date of development \( t^* \). This policy-relevant impact has been the subject of mixed results in the literature (Carrion-Flores and Irwin, 2004; Irwin et al., 2003).

5. Simulation results
Figures 6 through 10 show the impact of lot-size restrictions on the per-acre price of developable land for farmers and homeowners, omitting the homeowner utility term, \( H_{r \rightarrow \infty} \) found in (1) and (2). This is done largely because farmers occupy one unit on

![Figure 4. Single year impact of minimum lot size (alpha) on per-acre agricultural profits and household indirect utility: base case](image-url)

\[ \text{Agricultural profits per acre } A(a) \]
\[ \text{Homeowner personal utility per unit } H^*(a) \]
\[ \text{Farmer personal utility per unit } H(a) \]

<table>
<thead>
<tr>
<th>MLS</th>
<th>Alpha</th>
<th>MLS</th>
<th>Alpha</th>
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<th>Alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01</td>
<td>0</td>
<td>20</td>
<td>0.5</td>
<td>40</td>
<td>1</td>
</tr>
</tbody>
</table>
estates of many different sizes: $H_{t,\infty}$ cannot easily be standardized per acre[11]. For this reason, $H_{t,\infty}$ as a function of $\alpha$ is graphed separately from the development and agricultural components of per-acre land price. Figure 5 shows the resulting picture for farmers and owner-occupiers in Maryland only. It is essentially a present value version of the picture shown in Figure 4 for annual returns. It does not vary much between the two states; its lesson is simply that the effect of minimum lot-size protection on today's willingness-to-pay for a housing site can be substantial. The simulation model effectively transfers this zoning-amenity effect to each unit projected to be built by the developer on vacant land, with the developer capturing the rents.

Figures 6 and 7 depict today's price per acre of developable land when the most profitable future lot size is expected to be half an acre. It can be seen that the impact of

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The impact of down-zoning on land values

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Figure 5.
Present value of personal indirect utility by minimum lot size: Maryland

Figure 6.
New Jersey vacant land price by MLS: developer optimum at 0.5 acre
Figure 7. Maryland vacant land price by MLS: developer optimum at 0.5 acre

Figure 8. New Jersey vacant land price by MLS: developer optimum at 3 acres

Figure 9. Maryland vacant land price by MLS: developer optimum at 3 acres (no homeowner infill development takes place)
increased lot-size restrictions on ordinary homeowners is largely to eliminate all profit potential as soon as the restriction exceeds current lot size (assumed to be two acres in every simulation shown here). While the reason for this “falling off the cliff” effect is obvious, it has important political implications. Figures 6 and 7 suggest that ordinary homeowners have nothing to lose from down-zoning over a wide range of lot sizes[12]. Instead, these residents will experience mostly personal utility gains of the kind depicted in Figure 5.

Perhaps the more interesting finding relates to the per-acre price of vacant farmland. According to Figure 6, New Jersey farmland will sustain a price drop of 58 percent when the minimum lot size increases from a half-acre to 20 acres. This decline in value is less dramatic than those found in the Samuels (2004) appraisal-based report, which were generally in the 60 percent range for smaller down-zonings, like 2 acres to 10. The simulated effect of Figure 6 nevertheless bears a family resemblance to the price effects identified in that earlier report.

If the simulation results reproduce past empirical findings on New Jersey, the same can also be said for Maryland. Figure 7 shows a decline in Maryland farmland value when lot-size restrictions move from 2 to 8 acres, followed by a slight increase thereafter. In Maryland, however, all of the changes in expected land price over the set of zoning choices likely to characterize rural areas move within a range of only about 8 percent of the per-acre land price. Because of the curve's U-shape, a change in minimum lot size from 5 to 16 acres, for example, leaves land price virtually unchanged. It should be no surprise, then, that the 2003 study on the price effects of down-zoning in Maryland, using a controversial before-after comparison technique, emerged with a conclusion of “no effect” (Eugen, 2003; Michael et al., 2006). Interestingly, another study conducted in Maryland failed to find a statistically significant price effect for easement purchase, a policy that also eliminates development options (Nickerson and Lynch, 2001). Figures 8 and 9 report the results of a sensitivity test for one of the most important input parameters to the simulation model: developer consensus on optimal future lot size. Figures 8 and 9 set this expected optimum at three acres. It is difficult to imagine a consensus market optimum that would be much larger. The results are virtually identical to Figures 6 and 7.
vacant land price increases up to a range of lot-size restrictions, about 3-5 acres, that is still smaller than many of today's down-zoning proposals in agricultural zones. In the range of most agricultural down-zoning proposals, roughly 8-40 acres, the per-acre price of farmland plummeted in New Jersey, but rises in Maryland at a rate that is barely perceptible. Homeowner subdivision profits disappear with increasing restrictions, as before. They are non-existent in Maryland because urban rents never lift expected profits above homeowners' psychic opportunity costs, using our assumptions.

It is still necessary to prove that the difference in the price effect of zoning between New Jersey and Maryland is attributable to New Jersey's higher development potential. This can be done by running a control simulation in which New Jersey agricultural profits are combined with Maryland's urbanization parameter, \( g = 8.1 \). This exercise was done for optimal free market lot sizes of one-half and three acres. The results look much like the Maryland results in Figures 7 and 9, proving that imminence of development is the key contextual parameter determining the price effect of such zoning [13].

Figure 10 presents a sensitivity test for the other uncertain parameters, those that measure the effect of \( \alpha \) on amenity/fiscal rents and agricultural profits. The functions remain logarithmic, but the three slope parameters are quadrupled for purposes of this test (see Table I for details). Only the New Jersey half-acre optimum case is shown, because the goal is to see if the algebraic sign on the land-price effect is reversed when the beneficial effects of down-zoning are assumed to be much larger than in the base case. (In Maryland, a stronger amenity effect would only increase the magnitude of the price increase already predicted.)

Because of Figure 4's assumption of diminishing returns from increased lot-size restriction, the effect of this change in parameters occurs at the lowest ranges of \( \alpha \). In Figure 10 the positive price benefits of an increase in minimum lot size from one-tenth to two acres is highly significant in dollar terms (close to +50 percent and over \$6,000 per acre). After this point, however, the per-acre price falls by 50 percent as before. Because agricultural down-zonings typically move to lot-size minima of ten acres or more from a starting point at two or three, the full wealth effect is likely to be felt in New Jersey, even if the assumed farming and amenity/fiscal benefits of lot-size restrictions are quadrupled.

4.4 Effect of down-zoning on date of development

Other things equal, the amenity/fiscal effect of increased \( \alpha \) should hasten time of development \( t^* \), while the effect on agricultural profits and development options should cause the date of conversion to be delayed. In both New Jersey and Maryland, \( t^* \) appears to be driven largely by the change in expected development profit with increased \( \alpha \). For increases in \( \alpha \) below the expected optimum (which developers presumably favor), residential development becomes relatively more attractive and \( t^* \) falls in both states. For increases in \( \alpha \) above the expected optimum, residential development becomes relatively less attractive and \( t^* \) rises in both states. Even though in Maryland the agricultural profit effect dominates the development option effect at higher \( \alpha \), the effect on \( t^* \) remains the same, because both of these effects lead to a prediction of delayed development. The actual values of \( t^* \) for different \( \alpha \) range from a low of 13 years in New Jersey and 25 years in Maryland to figures exceeding 100 years in both states. It follows that down-zoning to lot sizes of ten, 20 or 40 would indeed have rural preservation effects, regardless of its distributional effects. Although reasonable, these results are not directly comparable to the theoretical discussions.
found in studies such as Irwin et al. (2003), due to the present study's omission of the irreversibility risk factor (see below).

6. Conclusion and extensions

In sharp contrast to debates in courtrooms and town councils about whether down-zoning reduces property value or not, and by how much, the present study shows that the land-price effects of down-zoning are extremely context specific. More specifically, when development is impending and comprises the lion's share of today's land price, down-zoning will lead to a significant loss of value. This is, of course, eminently reasonable when you think about it. Somewhat less intuitive is the finding that a state like Maryland, which is rural and quiescent only when compared to New Jersey, sits on that portion of the development spectrum that might actually see modest price gains from agricultural zoning. The findings stated here are robust to reasonable differences in the lot size expected to deliver maximum profit to the developer, and to differences in the amenity and agricultural effects of lot-size restrictions.

The findings on New Jersey and Maryland have a clear policy implication as well: If you must down-zone, do it early. Unfortunately, local political systems are not particularly farsighted. Down-zoning becomes an attractive option precisely when the need for preservation is perceived as urgent, and when land prices have risen to the point where the purchase of development rights seems out of reach (Adelaja, 2006). This is also the time when the wipeout effect on farmers is likely to be most significant.

A second finding of the study is that under reasonable assumptions, land prices tend to increase when lot-size restrictions are raised to the level of the expected market optimum, or even slightly beyond it. For a variety of reasons extremely high densities are not necessarily preferred by multi-product developers, while the amenity protection conferred by minimum lot-size zoning provides them with a net gain. This explanation for the ubiquity of MLS zoning in suburban America stands alongside, and complements, explanations based on exclusionary, environmental or fiscal motives (Ihlafeldt, 2004; Bogart, 1993).

Several research tasks remain to be performed. The model can be formally validated using real-world price data. These are often difficult to acquire, because transactions involving farmland are fewer, are infrequent in particular towns, and are not always conducted at arms-length. One important goal of the validation exercise would be to use the model for parcels sitting at different distances from the central city, rather than the present study's comparison of statewide rural averages. The results presented here should not be interpreted as saying that all down-zoning in New Jersey is bad for landowners' wealth and all down-zoning in Maryland is good. In fact, the variance in development potential within each state could easily exceed the variance between them. With additional validation, the model could, of course, be used for prediction, even at the parcel level.

The model presented here is grounded in principles of real estate finance and urban economics, but there are potential improvements on the theory side as well. First, the model uses the simplest possible assumptions about decision-making under uncertainty. The use of expected value implies that developers are risk neutral. The model does not include the effect of increased lot-size restrictions on the option value of waiting, which is especially important if real estate development is seen as irreversible. The greater the uncertainty in future market conditions, the greater the option value of waiting to develop; the higher will be $r^*$, other things equal.
Whatever else it does, a large increase in the minimum permitted lot size is likely to reduce developer uncertainty by taking a whole range of development options "off the table." Some authors have argued, therefore, that down-zoning reduces the option value of waiting and therefore hastens development, even if it does not necessarily increase prices (Irwin et al., 2003). Whether this effect is sufficiently large to offset the present study's finding of delayed development at higher minimum lot sizes remains an open question.

There is an additional stochasticity that could be modeled as well, and that is the idea that today's zoning regime is not fixed, but might also vary in the future according to yet another set of probabilistic expectations. In the extreme, some argue that developer lobbying determines zoning in any case, so that the whole notion of a binding constraint is meaningless (Wallace, 1988; Logan and Molotch, 1987).

In its extreme form, this argument is contradicted by everyday observation, as well as by research on the power and stamina of the "anti-growth coalition" (Vogel and Swanson, 1989; Pfeffer and Lapping, 1994). Furthermore, a simulation model that is based on a bidding algorithm that exists inside a developer's head should not to be so complicated that it becomes unrealistic on cognitive grounds. Nevertheless, these extensions are worth pursuing; they may ultimately serve to inform, rather than replicate, the decision algorithms used by private sector actors.

Notes


2. There is no supply side effect, M. White argues, because land remains in fixed supply and any land with a smaller legal minimum is regarded as a perfect substitute for land with a larger minimum via the process of assembly.

3. Following the argument of Hamilton (1976), this fiscal motivation for large-lot zoning has often been felt to be pre-eminent, or different in kind from other socio-economic, fiscal or environmental motives. But Thomas Bogart (1993) showed that all of these motives are observationally equivalent. Thus the rent/capitalization effect in which we are interested can be combined into a single function like that shown in Figure 5.

4. Note also that if $l^* > l_{\text{est}}$, then the middle integral in (6a) is undefined. The case where $l_{\text{est}} < l^*$ is subsumed in this case and need not be considered separately.

5. The distribution of income in any metropolitan area is bell-shaped and lot size is a normal good (Cheshire and Sheppard, 1998). Therefore the demand for homes is expected to rise and then fall with increasing lot size. In fact, all three primary shifters of demand (income, tastes and the availability of substitutes and complements) are expected to have bell-shaped distributions with respect to residential lot size.

6. This is the standard log normal with $\sigma = 1/\mu$, giving a function that has only one parameter while retaining a theoretically reasonable shape. An additional justification for the log normal is its common use in the analysis of probabilistic investment returns that are bounded by zero, like the future price of a stock.

7. The mathematical model is not programmed verbatim in one sense: discounted payment streams are calculated as summations over a 100-year time horizon to avoid indefinite integrals and reduce computer processing time.

8. These assumptions for converting reported per-unit rents into per-acre rents may seem arbitrary. The $15,000 annual rent ceiling associated with complete urbanization applies equally to all scenarios, however, and should not affect the comparisons in which we are ultimately interested. Note that Figure 2 cannot show time-rent trajectories that are truly unconfined, since the seven states undoubtedly employed zoning regulations over this period. "Government-free" land rent data are not available,
9. Note that $H(a)$ and $\pi_t(a)$ determine each other recursively, not simultaneously. $\pi_t(0)$ can be calculated without knowledge of $H(a)$. $\pi_t(0)$ determines only the y-intercept of $H'0$; this intercept drops out of the amenity adjustment factor for developer profits in any case.

10. Although it is easily observed that infill development occurs much later than the initial development of greenfield sites even in the face of strong market demand, this psychic opportunity cost on the part of homeowners is not available in the literature. Homeowner opportunity cost equal to three times agricultural profit represents another assumption that could be subject to sensitivity testing if infill development should become a primary focus of the research.

11. Another difficulty in the interpretation of $H_{L-x}$ is that farmers may or may not move off the property at time $t$. If they do not, their personal holdings could become so small that they are no longer insulated from neighborhood disamenities, as assumed in Figure 4.

12. This analysis assumes that down-zoning typically occurs throughout a large zone in each town that includes both open farmland and existing subdivisions. In our experience this is generally not the case. In many cases, only agricultural and environmental reserve areas are subject to significant increases in minimum lot size. This real-world observation strengthens the argument presented here on the politics of down-zoning. Non-farm homeowners simply exempt themselves from any increased lot-size requirement that would apply to their own developable lots. In short, they have the power to benefit from the improved communitywide amenities conferred by downzoning without paying a price in lost development opportunities.

13. Results available upon request.

References
Cecil County, Maryland (2006), Minutes of the Board of County Commissioners Meeting held on April 11, available at: www.ccgov.org/uploads/Commissioners/minutes/041106.htm (accessed 1 April 2008).


About the authors

Paul D. Gottlieb is an Associate Professor in the Department of Agricultural, Food and Resource Economics, Rutgers, The State University of New Jersey, New Brunswick, New Jersey. Paul D. Gottlieb is the corresponding author and can be contacted at: gottlieb@aesop.rutgers.edu.

Adesoji Adelaja is a John A. Hannah Distinguished Professor in Land Policy and Director of the Land Policy Institute, Michigan State University, East Lansing, Michigan, USA.