WHAT CAN BE (AND WHAT HAS BEEN) LEARNED FROM GENERAL EQUILIBRIUM SIMULATION MODELS OF SCHOOL FINANCE?

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INTRODUCTION

An analysis of the choices parents make regarding their children's education is more complex and challenging than the analyses of many other kinds of choices economists typically study. This is true for at least four reasons: First, parental choices regarding their children's education involve judgments about school production functions that economists do not yet understand well. Second, access to primary and secondary public schools is typically linked to residential location -- giving rise to tradeoffs between schooling, housing quality and other local amenities. Third, the existence of private schools provides an alternative to a public system that is linked to residential housing markets. And fourth, households face different credit constraints given incomplete credit markets that generally do not permit borrowing against human capital investments.

With this complexity in mind, public policy makers must come to terms not only with the ways in which policy changes alter the incentives for *individual* households, but they must also determine whether the changes in individual household behavior *aggregate* to produce the outcomes intended by the policy or whether changes in individual behavior are likely to have unintended consequences. This involves considerably more than simply "adding up" what an analysis of individual household responses suggests because changes in individual household behavior can combine to fundamentally alter the economic environment in which individual decisions are made. For instance, the connection of housing markets to public schools implies that fundamental changes in school finance policy may alter relative housing prices which in turn changes the trade-offs individuals face between house quality and public school quality or between public and private schools. Or, to the extent that peer effects are important components of school production functions, the decision by some parents to change from one school to another may fundamentally alter school quality in both schools – thus causing other parents to rethink their decisions. And policy changes may alter incentives for schools as household decisions combine to create more or less competitive environments. A complete analysis of the impact of different types of school finance policies is therefore complicated by the interdependencies between individual choices and the overall economic environment.

In response to the need for new tools to aid in the analysis of these complex issues, and helped by the vastly increased computing resources available to researchers, new simulation-based research approaches have emerged in the last several years in the area of the economics of education. These approaches involve equilibrium models of education that are too rich and complex to yield policy-relevant theoretical insights and thus require computer simulations to yield either theoretical or empirical conclusions. This paper's aim is to provide a status report on this research agenda as well as to suggest that more can be learned from the approaches that are being developed. The aim is not to provide a comprehensive review of all simulation-based investigations but rather to use some of the more promising and more empirically oriented approaches to illustrate the potential for this methodology to yield useful policy insights. I begin with a brief discussion of the general ways in which computer simulation models of education can be used to advance our understanding of the economics of education and then proceed to discuss particular models and selected results. A general discussion of lessons regarding school production functions is followed by an overview of two broad classes of computer simulation models: those with a homogeneous public school sector and those with heterogeneous public schools. The first imposes the artificial assumption that all public schools are identical in order to focus on a detailed investigation of private school competition. The second, on the other hand, allows for multiple public school districts of different quality and focuses on policies intended to in part address this empirical reality. Some concluding remarks follow.

THE GOALS OF GENERAL EQUILIBRIUM COMPUTER SIMULATIONS: FROM THEORETICAL EXPLORATIONS TO EMPIRICAL INVESTIGATIONS

Researchers using computational methods seek either to explore the theoretical properties of complex models or to use real world data to generate an empirically plausible computer model that can be used for an empirical investigation of various policy alternatives. Generally both goals are pursued in the same research agenda to one degree or another – with simulation based papers typically falling somewhere on a continuum between purely theoretical and fully empirical exercises. Ideally, a research program might begin on the theoretical end of this continuum as researchers attempt to understand the theoretical properties of complex models. Given that results in such models typically depend critically on the values that are assumed for underlying preference and production parameters, such theoretical exercises would soon tend to focus on simulations that test the model's properties within the range of parameter values that are likely to be empirically relevant. Ultimately, this could then lead to the development of particular methods of introducing an increasing amount of data into the analysis – with the aim of generating a computer model that has increasing empirical content.

Regardless of where on this continuum between purely theoretical and empirical analysis a particular research program falls, the first step of the program always involves the specification of the underlying mathematical structure of those aspects of the economic environment that are most relevant to the research question at hand. In particular, the economic "primitives" of the model – such as preferences of parents, production

functions faced by schools, and the political and economic environment that determines school inputs – must be specified. This has led some to refer to the approach followed in this line of research as a *structural* approach. To the extent that the aim of the research is to simply explore the properties of a structural model, the computer can then facilitate this by simulating how equilibrium outcomes depend on the values that are assumed for different structural parameters.

In addition to merely exploring the properties of a particular model as the underlying structural parameters are changed, researchers may further seek to identify the empirically "correct" values of the most relevant structural parameters. Key parameters (such as preference and production parameters) and distributions (such as income) are set either to be consistent with empirical realities or to insure that an equilibrium generated on the computer is consistent with the data that we observe under the policies that are in place in the real world.[2] With structural parameters estimated from the data, the computer model then offers a simplified version of reality in which the researcher can freely change policies (which are part of the structure of the model) to see how responses to such policies unfold. Computer simulations of such empirical structural models thus allow us to learn both about how policies would alter *individual* household behavior and – more importantly -- how these changes aggregate to form a new equilibrium that illustrates a full unfolding of all the consequences of a particular policy change within the model. The empirical relevance of the predictions of course depends on both the care that was taken to specify an empirically relevant underlying structure to the model and on the degree to which the selection of the structural parameters enabled the computer model to replicate real world data under institutions similar to those observed in the world.[3]

SCHOOL PRODUCTION FUNCTIONS AND SCHOOL QUALITY: SPENDING IS NECESSARY BUT NOT SUFFICIENT

While a well-known literature has utilized conventional empirical techniques to ascertain a link between measurable school inputs and outputs (such as test scores or graduation rates), estimates from this literature may be of limited usefulness for predicting how parents will alter their choices when facing different school policies within the new economic environments produced by such policies. Instead of the rather narrow outcome measures like graduation rates and test scores, parents probably care about a much richer

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[2] Two different methods for matching the structural parameters to the data are used by researchers. Often, it is relatively easy to *calibrate* the model in a way that gives the researcher reasonable confidence that the computer model is operating within the empirically relevant parameter space without providing statistical evidence of the range around the estimated values that are used in simulations (e.g. Nechyba, 2000; Epple and Romano, 1998; Fernandez and Rogerson, 1998). Alternatively, the entire model can be structurally estimated using relatively sophisticated econometric techniques that yield more precise estimates of the underlying parameters and provide standard errors around these estimates (e.g. Epple and Sieg, 1999; Epple, Sieg and Romer, 2001; Ferreyra, 2002; Bayer, 2000).
[3] An even stronger criterion is for the calibrated or estimated structural model to replicate out-of-sample data from other institutional settings; for instance, a model calibrated to the New Jersey system of school finance could be tested by running it under the Michigan system of school finance and checking to see whether the Michigan data are replicated. Few, if any, of the current simulation models have been subjected to this stronger empirical test.

set of school characteristics and will respond as such characteristics change. Knowing how school inputs are related to test scores, for instance, is ultimately important for policy analysis when the policy aim is to raise test scores, but it is not sufficient for predicting parental responses to policy changes unless we assume that parents care only about test scores. A structural model of education-related household behavior must therefore come to terms with *parental perceptions* of school production functions, where school outputs are defined by the interests of parents and may include factors as varied as test scores, the success of athletic and arts programs and the mix of student characteristics that parents may care about regardless of whether this mix has a direct influence on measurable academic achievement.

Simulation models have varied in the degree to which they have dealt directly with this issue. In one strain of the literature (e.g. Fernandez and Rogerson, 1998, 1999, forthcoming; Nechyba, 1996), it is common to simply assume that school output is a function of per pupil spending – an assumption that seems contradicted by much of the traditional empirical literature on school production functions but successfully predicts widely differing levels of school spending.[4] In a second strain (e.g. Epple and Romano, 1998; Caucutt, 2001, 2002), it is assumed that (at least on the margin) only the composition of the peer group within schools ("peer effects") matters to parents. While this approach is consistent with at least a sub-set of empirical findings on school production, it is unable to generate the per pupil spending heterogeneity that is observed in the world or to explain why parents consistently prefer more spending to less.[5] Yet a third strain in the literature (Epple and Romano, 2002, 2003; Nechyba, 1999, 2000, 2003; forthcoming(a); Ferreyra, 2002)[6] combines these approaches by assuming that both financial resources as well as non-financial inputs matter to parents -- and then allows the data to determine how much each matters.

This third strain in the computer simulation literature provides at least some evidence (consistent with more traditional reduced-form evidence) that parents care about a variety of school inputs when choosing schools for their children – at least when such choices are placed within the assumed structure of the simulation models that are employed. In the Nechyba/Ferreyra model, for instance, parents simultaneously choose between different public school districts and between public and private schools, with a competitive private school market responding to household demand. All schools use both financial and non-financial inputs to produce the output that parents evaluate when making their choices, with non-financial inputs modeled as peer effects that can be broadly interpreted as inputs

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[4] The extent to which financial resources are at the margin important in producing measurable school outputs is a matter of some controversy, but even those that find a significant positive impact of financial resources acknowledge that other inputs such as parental involvement, peer effects and teacher quality (that is uncorrelated with teacher pay) matter a great deal as well.

[5] A possible exception to this could be offered by a model that treats spending as a signal of peer groups in a world where parents prefer peers from higher income families (Hoyt and Lee, forthcoming).

[6] Bayer (2000) develops a somewhat different estimation strategy with reduced form components of an equilibrium location model. While it allows him to separate the extent to which parents place value on various school characteristics, his results to date have not emphasized this aspect of model.

that are correlated with household income and child ability.[7] Table 1 presents the level of private school attendance predicted under different assumptions regarding the weight placed by parents on financial inputs (spending) as opposed to non-financial inputs (like peer quality) for the model employed in Nechyba (2003a). If the model places too little weight on spending, private schools in the model have such an advantage (because they can be selective about such features of the school as peer inputs) that no public school can co-exist with the private school market. On the other hand, if too much weight is put on spending, private school markets cease to function even when heavily subsidized through private school vouchers. Within the structure of this model, an empirically relevant computable version of the model must therefore place weight on both types of school inputs.[8] Ferreyra (2002) modifies this framework by introducing horizontal differentiation between schools in terms of a religious dimension to the curriculum, and she finds a similar result that indicates spending, peers (broadly defined) and curriculum differences are important.

TABLE 1: Percent Attending Private Schools*

Weight on Spending	Private School Voucher		
	$0	$2,500	$5,000
0.00	100%	100%	100%
0.25	92%	100%	100%
0.50	25%	42%	64%
0.75	0%	0%	20%
1.00	0%	0%	0%
*Based on calibrated computer simulation model detailed in Nechyba (2003a). In all cases, a minimum required per-pupil spending level is assumed, but this assumption does not bind until the weight on spending becomes low. While these results are obtained under the assumption that the private school competitive advantage arises from an ability on the part of private schools to select peers, similar results arise when private schools arise due to other types of competitive advantages (Nechyba, 2003b).			

Computational models that include only spending in school production processes therefore typically abstract from the existence of private school markets because *spending alone cannot easily create sufficient strength for a private sector alternative to arise within the model*. On the other hand, models that include only peer quality in the school production process generally require the inclusion of a fixed set-up cost for schools and/or a more detailed pricing structure for private school tuition than is included

[7] This includes traditional peer effects based solely on the average ability (or the a combination of the average ability and the variance in abilities) within a school, but it also permits other non-pecuniary inputs that are correlated with parental income. Empirically important inputs of this kind may include parental involvement in and monitoring of schools (which is correlated with parental income (McMillan, 2002), the ability of schools with higher income households to attract better teachers (Loeb and Page, 2000) or direct parental contributions to schools (Brunner and Sonstelie, forthcoming)).
[8] The calibrated value for the weight placed by parents on spending turns out to be 0.525 in Nechyba (2003a), with a weight of 0.475 on household peer quality in a Cobb-Douglas specification of the school production function.

in the Nechyba/Ferreyra models where each private school is assumed to charge the same tuition to all students who are selected for admission.[9] Most notably, Epple and Romano (1998) provide an elegant model of school markets in which private schools differentially price tuition based on the peer characteristics of students. Combined with a fixed set-up cost of schools (but with no marginal impact on quality of additional spending), this yields predictions of mixed public/private school systems.[10] Thus, it is generally the case that *school spending is a necessary but not a sufficient ingredient to the production process required in order for simulations to replicate empirically relevant private school attendance rates*. (The possible avenues available for constructing empirically relevant simulation models with private schools are explored in greater detail in the next section.)

The fact that the economic structure that underlies empirically motivated computational models of education *requires* the inclusion of both financial and non-financial inputs also implies that *school quality emerges as a sufficiently subtle construct so as to preclude relatively naïve policy prescriptions*. For instance, school finance policy simulations in multi-jurisdiction models suggest that there are severe limits to the degree to which traditional school finance reforms can reduce the inter-jurisdictional public school inequities that have been the subject of much court activity over the past three decades. As is discussed in more detail in the section dealing with multi-jurisdictional models, one computational model predicts that the gap in public school quality between middle income and low income districts will narrow by less than a third when financing of public schools changes from pure local to equalized state financing, and by less than ten percent when a hybrid system like New Jersey's is replaced by an equalized state system (Nechyba, forthcoming(b)). Thus, general equilibrium simulations (with school production functions that are calibrated to accurately predict the levels of private school attendance) predict that *spending equalization* will leave the public school system with continuing large inequalities in school *quality*.[11] Computational results in multi-jurisdiction settings are discussed in more detail in a later section of this paper after I review briefly the role private school markets play in computational models.

HOMOGENEOUS PUBLIC SCHOOLS, PRIVATE SCHOOL MARKETS AND VOUCHERS

Just as computational models of education have relatively little guidance from the traditional literature on the way in which parental perceptions of school quality should be modeled, even less traditional empirical evidence is available to guide proper models of private school markets. It is clear that -- if a model is to accurately predict private school attendance rates between 10% and 20% (as observed in most states) in the presence of "free" public schools, private schools must enjoy some advantage over public schools to

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[9] The model does allow for private school tuition to differ across private schools, just not within a single private school. Each private school in essence consists of a tuition rate and a minimum peer quality level.
[10] More specifically, Epple and Romano (1998) assume a fixed cost plus a variable cost per pupil, with spending above the minimum required for a given number of students adding nothing to school quality. More recent versions of their model have relaxed the latter assumption (Epple and Romano, 2002).
[11] The point that equalization of spending does not imply equalization of quality is similarly made by Epple and Romano (2003).

persuade parents to pay private school tuition. It is also clear from the discussion above that the ability to tailor spending more closely to parental tastes is simply not a sufficiently strong advantage for private schools to operate within an economic model. Other possible advantages of private schools over public schools are therefore discussed below, followed by a discussion of policy implications of computational models of private school markets.

Competitive Private School Advantages over Public Schools

Three possible private school advantages have emerged in the literature:

> (1) the ability of private schools to admit (and in some cases price) students selectively based on the qualities of students and/or parents;
> (2) an assumed greater efficiency of private schools in using resources to produce school quality; and
> (3) the ability of private schools to horizontally differentiate themselves by tailoring pedagogical approaches and/or curricula to the needs of particular families.

Of these, the first has been most widely assumed in computational models (Epple and Romano, 1998; Nechyba, 1999, 2000, 2003a), but the possibility of greater private school efficiency or gains from school competition (Manski, 1992; Nechyba, 2003b, forthcoming(a); Epple and Romano, 2002) as well as horizontal differentiation (Nechyba, 2003b, forthcoming(a); Ferreyra, 2002) are beginning to be more thoroughly explored. It is important to note, however, that the structural approach constrains the degree to which any of these three general categories of private school advantages can be incorporated in empirically plausible computational models. Put simply, private schools can only enjoy a certain amount of overall competitive advantage over public schools in order for computational models to generate realistic private school attendance rates – and this is true whether there is a single dimension of advantage or multiple dimensions. Thus, as additional advantages for private school markets are introduced into computational models, other advantages must play a smaller role in order for the models to continue predicting empirically observed private school activity.

For instance, Ferreyra (2002) finds a way to structurally estimate versions of the Nechyba/Ferreyra model that include religious schools – and a way to identify separately parameters on the importance of peers and religious preferences. With the inclusion of religion in the model, the estimated coefficient on peers drops because the presence of religious preferences gives an additional advantage to private schools and must thus be offset by a decline in private school advantages in some other dimension. Similarly, in a model where private schools are productively more efficient in addition to being able to select peers (as in Nechyba, 2003b), calibration exercises lead to a range of combinations of parameters that can generate empirically relevant private school attendance rates, but this range is such that whenever more weight is placed on peers, private schools must have less of a productive efficiency advantage. In the future, just as Ferreyra has found

ways to structurally estimate parameters for the importance of religious preferences and preferences over peers, structural estimation approaches may be able to narrow the range of empirically plausible weights on each of the three possible private school advantages. To date, however, the empirical evidence on which of the three private school advantages ought to be given the most weight remains inconclusive.

While alternative approaches are therefore clearly emerging (as in Ferreyra (2002) and Nechyba (2003b)), by far the most well-understood model of private school markets remains one that uses the ability of private schools to select peers as the primary competitive advantage of private schools. Epple and Romano (1998) and Caucutt (2001) develop models in which competitive private schools emerge endogenously as they select separate tuition prices for students of different types.[12] Nechyba (1999), on the other hand, assumes that private schools are restricted to offer a single tuition price to all students but are able to choose whom to admit. In either case, the ability to choose the characteristics of the student population directly is enjoyed by private schools but not by public schools who are legally obligated to admit all students (or at least all students who are residing within the school's geographic jurisdiction).

Policy Implications for Private School Vouchers and Ability Tracking

The primary policy application of these models has been to an investigation of private school vouchers. Epple and Romano (1998, 2002) and Caucutt (2002) undertake this in a setting in which public schools are homogeneous, while Nechyba (1999, 2000, 2003a,b) and Ferreyra (2002) introduce public school heterogeneity through residence-based admissions to public schools.[13] In each of these strands of the literature, the fact that private schools can select student characteristics leads to the prediction of increased "cream skimming" under private school vouchers – i.e. those who take up private school vouchers tend to be high peer quality students within the public school system. Unless an offsetting economic force (such as increased public school efficiency (Manski, 1992; Nechyba, 2003b) or gains from curriculum targeting (Nechyba, 2003b)) is included in the underlying structural model, this cream skimming is then likely to lead to declines in public school quality. An exception may occur under certain circumstances if the decline in public school peer quality is offset by an increase in per pupil expenditures given that tax dollars are spread over fewer students after the voucher and given that vouchers generally cost less per pupil than what is spent per pupil in public schools (Nechyba, 1999). In the presence of more explicit offsetting forces, on the other hand, there exist

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[12] The two approaches differ in several respects, including how they resolve a technical existence problem. In addition, Caucutt's (2001) model does not include public schools.

[13] A related literature on the political economy of different types of voucher proposals has also recently emerged and been assisted by simulation exercises. Two recent examples – both within the single community context – are Bearse, Glomm and Ravikumar (2000) and Chen and West (2000). While these offer interesting theoretical insights, they remain relatively exploratory exercises -- especially in light of the evidence from multi-community models that political economy considerations are likely to center more on factors that are not modeled, factors such as the impact of vouchers on property values (see next section for computational results and both Brunner, Sonstelie and Thayer (2001) and Brunner and Sonstelie (2002) for empirical evidence from ballot initiatives in California).

combinations of structural parameters (that are consistent with the data) under which private school vouchers may lead to increases in overall public school quality (Nechyba, 2003b).[14]

In the first strain of this literature – where public schools are treated as if they were a single school,[15] Epple and Romano (1998) use their model (of competitive private schools that differentially price peer quality through tuition policies) to investigate the impact of private school vouchers. Private schools in this model can be ranked in terms of school quality and are each composed of multiple peer quality types. High-income parents with lower ability children are willing to pay high tuition in order to subsidize high ability children from low-income households to attend (and thereby improve) their private school. *The introduction of vouchers increases competition for high ability students and in equilibrium lowers the tuition they must pay by substantially more (for some by twice as much) than the amount of the voucher.* This is an example of a result not easily obtained without an equilibrium model that not only considers how individual behavior is altered by a policy change but also how the economic environment itself changes the opportunities faced by different groups. And the detailed welfare analysis provided by Epple and Romano (1998) is one that relies heavily on the computable version of their equilibrium model.

This welfare analysis suggests that those who remain in public schools experience close to a five percent loss in achievement, while those who switch experience gains of between 13 and 20 percent under the voucher policy that is simulated.[16] Among those who switch to private schools, some are better off and others are worse off because – while they experience better achievement, this is not sufficient to offset the tuition they now pay to avoid the deteriorated public schools. Among those in private schools before and after the vouchers, all are unambiguously better off. Put differently, the model predicts that households with relatively high ability (especially those with relatively low income) benefit from the introduction of vouchers, but those with lower ability and relatively lower incomes lose because of a decline in public school quality brought about by the cream skimming of the private school market. While the introduction of offsetting forces (such as improvements in public school efficiency from increased competition)

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[14] While one common offsetting force is the inclusion of a "competitive effect" on public schools, it is not immediate that this competitive effect is necessarily positive. McMillan (2001) uses computational exercises to demonstrate that, if parental pressure is included in private school competition models, there may exist equilibria under which rent-seeking public schools will become *less* efficient (try less hard) under increased competition if it becomes easier for them to simply allow demanding parents to split off into private schools.

[15] One interpretation of this class of models is that they represent a large school district with many public schools under a truly open enrollment system in which public school quality differences cannot survive. Epple and Romano (2003) investigate this open enrollment assumption in a paper in which they explore the welfare consequences of relaxing neighborhood-based admission and moving to open enrollment. Their approach is discussed further in a later section of this paper.

[16] This is in part due to the fact that the model has the characteristic that overall efficiency improves with increased stratification (and thus with high voucher levels) – an assumption for which the empirical literature offers no strong consensus one way or another. Other computable simulation work in the homogeneous public school tradition finds voucher levels for which efficiency declines (Caucutt, 2002), but this work gives similar intuitions regarding the likely winners and losers from vouchers.

could clearly alter these results, the simulations nevertheless point to who is likely to benefit more and who is likely to benefit less regardless of the size of such effects. And the simulations suggest a focus on more creative policy proposals to alleviate the potential welfare losses for some of the most disadvantaged households.

In a continuation of this earlier work, Epple and Romano (2002) then extend their model to include school spending effects on achievement as well as the higher cost effectiveness of private schools.[17] As summarized in the first set of columns of Table 2, results similar to their earlier work are obtained for universally available vouchers – with relatively lower ability students from middle to lower income households losing. Given the efficiency gains from switching to a more cost effective private system, however, Epple and Romano then attempt to find ways of designing vouchers such that the system exploits the cost advantages of private schools without the negative impact of cream-skimming on lower ability students. They first explore the possibility of targeting vouchers differentially to lower ability students but find in their simulations that this results in the formation of low quality private schools that pay low ability, low income households to attend their school in exchange for receiving the voucher. These households are made better off in the sense that income is redistributed to them, but achievement of their children falls (see the second set of columns of Table 2). Additional restrictions therefore have to be placed on vouchers targeted by ability, and *care has to be taken to structure the targeting itself correctly*. Epple and Romano demonstrate that, when vouchers are equal to the effective marginal cost of an ability type (for a school with average ability equal to the population average), and if private schools that accept vouchers are prohibited from accepting any tuition above the voucher amount or offering any scholarships, private schools of homogeneous quality higher than current public schools will emerge to serve the current public school population at a lower cost. A brief summary of some of the results for such an appropriately designed voucher is given in the third set of columns of Table 2.

Table 2: Percentage Gain in Achievement from Different Vouchers

	Flat Rate Voucher[1]			Ability-Targeted Voucher[2]			Tuition-Constrained, Ability Targeted Voucher[3]		
	Low Income	Middle Income	High Income	Low Income	Middle Income	High Income	Low Income	Middle Income	High Income
Low Ability	-19.59	-16.61	-3.90	-18.17	-15.92	-5.33	+3.79	+3.79	+3.79
Middle Ability	-3.58	-1.48	+4.54	-3.11	-1.26	+4.27	+3.79	+3.79	+2.27
High Ability	+12.61	+6.45	-0.54	+12.92	+6.73	-0.74	+2.14	-2.95	+0.05

Source: Tables 1 and 3 in Epple and Romano (2002).
[1] Vouchers equal to per pupil spending in public schools are equally available to all students; no public schools remain after voucher is introduced.
[2] Vouchers targeted differentially to low ability students, with mean voucher levels equal to per pupil spending in public schools; no public schools remain after voucher is introduced.
[3] Vouchers targeted differentially to low ability students funded by tax rate equal to pre-voucher tax; private schools who accept vouchers restricted to charge no additional tuition and offer no scholarships; no public schools remain after voucher is introduced.

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[17] The calibration of public school inefficiency is based on Hoxby (2000).

The main lesson from Epple and Romano's more recent work is therefore that *the desire on the part of private schools to cream skim from the public schools is not sufficient to keep voucher proposals from benefiting low ability students if vouchers are appropriately designed*. While their model does not at this point fully capture all of the details a fully empirical computer model might require,[18] their simulations (accompanied by analytic results) provide a persuasive case for further research to be directed at the question of voucher design. The issue of vouchers, this research (and research discussed in the next section) suggests, turns out to be less polarizing when subjected to analytic and empirical rigor. With any given policy goal in mind, this literature – rather than suggesting that vouchers are either "good" or "bad" -- argues that some forms of vouchers may be desirable while other forms are not.[19]

In an important related paper, Epple, Newlon and Romano (2002) (henceforth ENR) explore the role of tracking within public schools when the public school system faces competition from private schools (in the absence of vouchers). In essence, the introduction of ability tracking within the public schools reduces the competitive advantage of private schools by allowing public schools to offer higher school quality to higher ability students that might otherwise be attracted to private schools. Through computer simulations, ENR demonstrate that tracking in public schools has some of the same welfare effects as vouchers, with low ability students becoming worse off at the expense of high ability students. Partial results are reported in Table 3, with the last column showing a dramatic variance in school quality within the public sector when tracking is introduced.

Table 3: The Effect of Tracking in Public Schools

	No Tracking		Complete Tracking	
	% Attending	Quality	% Attending	Quality
Low Public Track	90.5	12.15	60.6%	8.56
High Public Track			30.8%	20.62
Private School Sector[1]	9.5%	29.23	8.6%	25.46
Source: Epple, Newlon and Romano (2002), Table 1. [1]The private sector consists of multiple schools (9 under no tracking, 8 under tracking). The quality figures reported here are a school population weighted average of these schools as reported in Table 1 of ENR.				

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[18] For instance, while the model incorporates greater resource efficiency on the part of private schools, it does not at this point allow for competition to generate efficiency gains in public schools – a claim often made by voucher proponents and empirically tested in the paper (Hoxby, 2000) used for calibrating public school inefficiencies in Epple and Romano (2002). Similarly, the model at this point treats all public schools as identical, an issue we return to in the next section, and it does not allow for the possibility of gains from horizontal differentiation.

[19] A related point is made by Caucutt (2002) who shows that careful attention to the appropriate size of vouchers is warranted as well.

While ENR's work does not allow public schools to set tracking endogenously and does not investigate the impact of private school vouchers under public school tracking, the simulation results do suggest an important step for future investigations of vouchers. If tracking is indeed a way for public schools to gain some of the competitive advantage of private schools, then *one would expect tracking to increase with private school competition*. A model that endogenizes tracking decisions in public schools can thus be used to quantify the likely impact of such tracking as private school vouchers are introduced, although this remains to be done in future research.[20]

An important caveat to all of these results on private school markets lies in the fact that all the simulation exercises I have focused on thus far occur within a setting in which there is, in essence, a single public school. Perhaps the most distinguishing characteristic of U.S. public school systems, however, is the large degree of heterogeneity that exists within this system. In order for such public school heterogeneity to be sustainable as an equilibrium outcome, there must exist barriers to entry into good schools to keep parents whose children attend poor schools from switching between "free" public schools. An extensive empirical literature on housing markets suggests that these barriers arise from the residence-based nature of public school admission and the consequent link of public schools to housing markets, although other models of heterogeneous public school sectors have also been developed.[21] I therefore now turn to a review of computational models of heterogeneous public schools.

HETEROGENEOUS ("UNEQUAL") PUBLIC SCHOOLS: SCHOOL FINANCE MEETS HOUSING AND PRIVATE SCHOOL MARKETS

While much has been learned from models of private school markets with homogeneous public school sectors, much of the policy interest in school finance issues arises from the large observed heterogeneity in public school quality. Table 4 provides a simple categorization of some of the main models in which heterogeneous public schools arise.[22] It is models such as these that can replicate empirically important variances in public school quality as a benchmark exercise and can then proceed to an analysis of the likelihood that particular school finance policy reforms might address concerns regarding these variances. Such policies include dramatic changes from purely decentralized school finance to fully centralized financing, less dramatic state aid programs that involve combinations of block and matching grants, or newer proposals of using state education

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[20] McHugh (2003) finds empirical support for the prediction that increased school competition leads to responses of this kind within public schools.

[21] As pointed out by Fischel (2001), the local connection to housing markets has potentially important incentive effects as homeowners become particularly concerned about the impact of local policies on the major source of their savings (i.e. their house value), a theme which is echoed in some ways in the simulation literature reviewed next. Fischel also points out that, under certain assumptions, this creates efficient Tiebout mechanisms that are lost if local financing is abandoned even if it gives rise to inequities in public school quality.

[22] As in the previous section we focus here on models that are in some way calibrated to data or structurally estimated and leave aside papers where simulations are used solely as an expositional tool for theoretic results (as, for example, Fernandez and Rogerson, 1997).

funds to finance some form of school voucher. Each of these proposals has been analyzed within at least one of the models in Table 4.

As the table suggests, private school markets are still relatively rare in heterogeneous public school models, with only the Nechyba/Ferreyra model simulating a framework that can support both heterogeneous public schools and an active private school market.[23] With the exception of Epple and Romano (2003), those models that contain heterogeneous public schools without private school markets model school quality as a function of only per pupil spending – a feature I argued in the previous section is not sufficient for the endogenous formation of private schools under assumptions that are otherwise empirically plausible. Models (in Table 4) with no housing markets typically impose perfect sorting exogenously – i.e. each type of household is assumed to reside in a jurisdiction composed only of the same type, while models with homogeneous housing typically give rise endogenously to a different form of perfect sorting – one in which each community is composed of a continuous interval of the income distribution.[24] Models with heterogeneous housing markets, on the other hand can generate a more realistic endogenous mixing of household types within jurisdictions.[25]

Table 4: Computable Simulation Models of Heterogeneous Public Schools

				Private School Markets	
				No	Yes
Housing Markets	No	Dynamics	No	Fernandez & Rogerson (1999, forthcoming)	
			Yes		
	Yes*	Dynamics	No	Epple & Romano (2003) Nechyba (1996)	Nechyba (1999, 2000, 2003a,b, forthcoming(a),(b)) Ferreyra (2002)
			Yes	Fernandez & Rogerson (1998)	
*Housing markets in these models take various forms. A housing market can simply be a fixed set of homogeneous (Epple and Romano, 2003) or heterogeneous (Nechyba/Ferreyra models) houses equal to the number of households. Alternatively, some models assume exogenous, community specific supply functions of a continuous homogeneous housing good (Fernandez and Rogerson, 1999).					

[23] It should be noted that the theoretical underpinnings of this model had their origin in the work by Dunz (1985) as extended by Nechyba (1997, 1999).

[24] While this statement is correct for the models in Table 4, Epple and Platt (1998) demonstrate that mixing of types can arise in a model with a homogeneous housing good when households differ in their preferences. This approach is structurally estimated in Epple and Sieg (1999) as well as Epple, Sieg and Romer (2001), but these papers are more focused on the development of methods to estimate local public finance models in general than those related specifically to education.

[25] The models without housing assume that income taxation supports public schools; among models with housing markets, some assume income taxation (Fernandez and Rogerson, 1998; Epple and Romano, 2003) while others assume property taxation or some mix of state income and property taxation (Nechyba/Ferreyra models). Within the Nechyba/Ferreyra model, property taxation has been shown to be a dominant tax strategy for local governments (Nechyba, 1997b).

I begin our discussion of these models and the simulation results to date by first building on the previous section by exploring how the addition of housing markets and multiple school districts or attendance zones alters the economic environment explored in homogenous public school models. First, I discuss how the simultaneous existence of public schools, housing and private school markets combine to generate some of the most important features of the economic environment within structural models of education.[26] I then revisit the issue of private school vouchers – but this time in the presence of heterogeneous public schools, and proceed to discussing some insights regarding other school finance reforms. Finally, I discuss some recent results that shed light on the role of race and income in housing and public school markets – a role that is only beginning to be translated into the structure of computational approaches.

The Role of Public Schools, Housing and Private School Markets

Of the heterogeneous public school models in Table 4, the Nechyba/Ferreyra framework has been most successful at folding the public school sector into a broader model of housing and private school markets. The framework assumes a fixed housing stock in different school districts, with housing quality distributions overlapping across districts (as they do in the data) and thus inducing a mixing of different income groups within each district. Schools combine financial and non-financial inputs like peers or family characteristics, and profit maximizing private schools set a minimum peer quality standard as well as a uniform tuition rate.[27] (In some versions of the model discussed below, private schools also enjoy other competitive advantages.) Public schools, on the other hand, are required to admit all students who reside within the schools' attendance zone, and their budget is set in either local elections on property taxes or state elections on income taxes. (For the detailed description of the theoretical underpinnings of this model, see Nechyba (1999, 2000).) The calibrated computer version of the model (as exposited in Nechyba (2002, 2003a,b, forthcoming(a),(b)) is relatively successful in replicating important stylized features of data from the New Jersey school system – including within- and across-district distributions of income and property values, school spending levels, private school attendance rates and local tax efforts. (A version of the model that includes religious heterogeneity (Ferreyra, 2002) can similarly replicate important stylized features for other metropolitan areas.) Table 5 provides some comparisons of model predictions from Nechyba (forthcoming(b)) to actual data from a 3-district version of the computer model calibrated to New Jersey data and institutions.

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[26] The link between housing markets and public schools is one that has been established empirically in many ways – and its importance in general equilibrium policy simulations should therefore not come as a great surprise. For instance, capitalization studies dating back to Oates (1969) have consistently linked housing prices to public school quality, and discrete choice models have recently unearthed similar evidence using a very different methodology (Bayer, 2000; Nechyba and Strauss, 1998). The link between these markets and private schools has not been explored in as much detail.

[27] Some of the richness of the Epple and Romano/Caucutt approach of allowing private schools to differentially price tuitions within the same school is therefore lost in this model.

Table 5: Model Predictions and Data Values for New Jersey Calibration of Nechyba/Ferreyra Model*

	District 1		District 2		District 3	
	Model	Actual	Model	Actual	Model	Actual
Property Values[1]	$117,412	$157,248	$205,629	$192,867	$292,484	$271,315
Average Income	$31,120	$30,639	$46,216	$45,248	$65,863	$67,312
Public School Per Pupil Spending	$6,652	$6,702	$7,910	$7,841	$8,621	$8,448
Fraction Raised Locally	0.52	0.52	0.77	0.77	0.87	0.87
% Attending Private Schools	20%	21%	23%	23%	13%	20%

*This table is derived from Table 2 in Nechyba (forthcoming(b)).
[1] Property values are converted from annual flows (calculated in the computational model) using a 5.5% discount rate.

Nechyba (2003a) then offers a revealing table (a potion of which is replicated here as Table 6) which provides intuition regarding some of the most salient economic forces within an empirically calibrated structural model in which residents vote, choose residences and select between public and private schools. The first row of Table 6 provides a characterization of average incomes and property values in a representative poor (District 1), middle-income (District 2) and high-income (District 3) district in the absence of any distortions from the existence of a public school system – i.e. where all parents choose private schools because no public school sector exists. The calibrated house quality values thus clearly reflect inter-jurisdictional differences in housing, and the level of income segregation that is predicted is due solely to these differences. At the same time it is important to point out that these housing stocks are simply taken as given (and calibrated to *current* data), and the model is not equipped to say whether housing stocks would have developed differently had public schools never played a role in the past. A more dynamic model of housing and private school markets (absent from Table 4) would be required for the model to make predictions regarding the likely evolution of housing stocks – for now it can simply give researchers an idea of how much *current* segregation is due to *current* inter-jurisdictional housing stocks.

When private schools are not permitted to operate (rows 2 and 3), on the other hand, the model predicts substantially more inter-jurisdictional income segregation as well as greater inter-jurisdictional variance in housing values – and this is true regardless of whether the model simulates local property tax financing to support public schools or equalized state-income tax financing. The link between housing markets and public schools therefore introduces incentives for households to make different residential location decisions as the economic environment changes to reflect the tie of housing to schooling. *In the absence of private schools, the existence of a public school system that ties school admission to residential location causes greater income segregation than what is predicted by inter-district housing quality differences in the absence of public school distortions.*

Table 6: The Role of School Finance Centralization, Housing and Private Schools in Supporting Heterogeneous Public School Quality

Private Schools Allowed	Public School Financing	Average District Income			Average District Property Value			District Public School Quality[1]		
		Dist. 1	Dist. 2	Dist. 3	Dist. 1	Dist. 2	Dist. 3	Dist. 1	Dist. 2	Dist. 3
Yes	None	$25,700	$50,175	$67,325	$158,327	$227,189	$266,474	***	***	***
No	Local Prop. Tax	$17,628	$39,647	$85,925	$101,683	$204,075	$392,402	0.3239	0.6024	0.9521
	State Inc. Tax	$19,875	$42,250	$81,075	$102,086	$220,725	$387,549	0.3940	0.6244	0.9022
Yes[2]	Local Prop. Tax	$29,725	$50,262	$63,212	$123,224	$211,729	$294,825	0.3674	0.6192	0.8183
	State Inc. Tax	$29,891	$51,309	$67,325	$118,486	$226,345	$316,308	0.4616	0.6316	0.6841

Note: This table is derived from Table 3 in Nechyba (forthcoming(a)) supplemented with results that are not reported in Nechyba (fothcoming(a)). Various versions of this table also appear in Nechyba (forthcoming(b), 2002, 2003b).
[1] School quality is defined using the school production function with data-calibrated values for parental perceptions of the importance of per pupil spending and average peer quality within the school
[2] Private school attendance rates are predicted to be 30%, 20% and 10% in districts 1 through 3 respectively under local property taxation and 22.5%, 17.5% and 15% under state income taxation.

The last two rows of Table 6, however, provide a starkly different picture when private school markets are allowed to operate within the computer model. Again regardless of how the public schools are financed and regardless of whether the public sector equalizes school resources, the entry of private school markets causes huge reductions in residential income segregation and in inter-jurisdictional property value variances. The fundamental reason behind this result is *that private schools sever the well-established link between residential location and school quality for those that choose them* – thus allowing households to optimize separately in the housing market. Private school attending households then have an incentive to live in poor public school districts where housing values are depressed – at least to the extent to which appropriate housing in such areas is available.[28] In fact, it is the distortions in the housing market (which depress values in poor districts and inflate them in rich districts) that lead the computer model to predict *less residential income segregation in a mixed private/public school system than in a purely private system where there are no distortions from the existence of a public sector.*

The existence of a private sector – together with the general equilibrium housing market, also seems to benefit the public sector from the perspective of inter-jurisdictional variances in public school quality. While public schools in district 3 (the rich district) suffer from the introduction of a private school market, public schools in district 1 (the poor district) benefit. The reason for this lies in the fact that households who attend private schools (in rows 4 and 5 of Table 6) are disproportionately drawn from public schools in richer districts (in rows 2 and 3 of Table 6). They furthermore are households that stand to gain the most from the private sector – i.e. households with high peer

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[28] Given the large intra-jurisdictional heterogeneity in housing quality (Epple and Sieg, 1999), and given that this heterogeneity is calibrated into the computer simulation model, middle income families can generally find more housing at a cheaper price within poorer jurisdictions.

characteristics. Thus, the introduction of a private school market causes a drain of high peer quality households from public schools in relatively richer districts, while at the same time a similarly sized public education budget is spread across fewer students.[29] The latter is especially true in poorer districts that see a disproportionate increase in private school attending households due to depressed housing values in those districts. These simulation results regarding segregation are consistent across alternative specifications of public school responses to private schools and hold regardless of which of the three private school advantages (cream-skimming, efficient resource utilization or curriculum targeting) are assumed (Nechyba, forthcoming(a)).

Additional Lessons for School Voucher Policy

This intuition about the interconnectedness between private school markets, housing markets and public school districts then directly translates into important lessons (beyond those covered in the previous section on private school markets) for policy makers considering private school vouchers. With housing values depressed in poor school districts and inflated in rich districts, households that are on the margin between choosing public and private schools are likely to be under-consuming housing in wealthier districts in order to gain access to good public schools. With the introduction of private school vouchers, they can de-couple their choice of school from their choice of residence and take advantage of depressed housing values in lower income districts. This is precisely the result that emerges from a number of private school voucher simulations (Nechyba, 1999, 2000, 2002, 2003b, forthcoming(a),(b); Ferreyra, 2002), and it emerges in a context where other types of neighborhood externalities (such as crime, environmental quality, etc.) that might reduce migration are taken into account.[30] While the model predicts instantaneous mobility effects from vouchers, it should be kept in mind throughout that, in a more dynamic context, these mobility effects would likely arise over time as households move for a variety of reasons (family expansions, job relocation, etc.). It is when households move (which they on average do every five years in the U.S.) that they would choose where to live differently under the new economic environment created by voucher policies.

More precisely, computer simulations demonstrate a tendency for modest levels of unrestricted private school vouchers to cause the emergence of new private schools primarily in lower income districts.[31] In the top portion of Table 7, for instance, private school attendance rates rise fastest in district 1 (the poor district) as unrestricted vouchers

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[29] Since the model does incorporate a political process that results in public school spending, the model actually predicts a small decline in the overall public school budget – but an increase in per pupil spending.
[30] These factors are implicitly included because house *prices* (which include such externalities) are used to calibrate house quality levels in different neighborhoods and districts. As noted in Nechyba (2000), the computer model actually understates the level of migration that is likely from vouchers because it understates the degree to which housing stocks and neighborhood externalities would change to reinforce the predicted mobility and general equilibrium effects.
[31] As voucher levels approach public school spending levels, private schools emerge in all districts until the system becomes essentially a private school system similar to the top row in Table 6.

are introduced.[32] These new schools serve both high peer quality households from low income public schools and – to a larger extent -- middle to high income households from public schools elsewhere. For the same economic reasons that underlie results in Table 6, residential income segregation therefore declines (as shown by the declining ratio of average district 3 to district 1 income in Table 7). *Depending on what assumptions are made about the precise nature of the private school advantage* (pure cream skimming, curriculum targeting, resource efficiency), and depending on the response one assumes a public sector will make to increased competition (ranging from no response to greater resource efficiency), *public schools may decline or improve in quality. Even when they decline, however, the decline is concentrated more heavily in middle to high-income districts from which private school attendees are drawn* (Nechyba, 2003b).

In the top portion of Table 7, for instance, average public school quality declines with the introduction of unrestricted private school vouchers when no competitive response by public schools is allowed, *but the ratio of public school quality in the wealthy district over public school quality in the poor district declines.*[33] Under different assumptions about private schools and public school responses to competition, average public school quality can rise with unrestricted private school vouchers (as illustrated in the last column of Table 7 where private schools are assumed to be more resource efficient and public schools are assumed to respond to competitive pressures by becoming more efficient), but the ratios illustrated in Table 7 tend to move in the same directions.

Independent of any of the particular assumptions regarding the nature of private school advantages and the nature of public school responses is the persistent simulation result that property values in poor districts will rise dramatically under private school vouchers while property values in wealthy districts will decline (Nechyba, forthcoming(a)). In the top portion of Table 7, this is seen as a precipitous drop in the ratio of average property values in the wealthy district to average property values in the poor district as unrestricted vouchers are introduced. In fact, a welfare analysis suggests that *voter preferences over private school voucher policy are likely to be dominated by concerns over property values rather than a concern over school outcomes*. This implies that the strongest proponents for private school vouchers are likely to be found among homeowners in poor districts, and the strongest opponents among homeowners in wealthy districts. Recent empirical work on the two voucher ballot initiatives in California (during the last decade) tends to confirm this.[34]

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[32] Unrestricted vouchers are state income-tax financed vouchers with no eligibility restrictions. It is furthermore assumed for all vouchers discussed in this section that parents can use vouchers for all or part of their private school tuition obligations.

[33] This process ends at a voucher level of $4,000 when political support for public schools in district 1 falls below 50% -- causing per pupil spending to revert to a minimum of $5,000 per pupil assumed necessary for a school to operate.

[34] See Brunner, Sonstelie and Thayer (2001) and Brunner and Sonstelie (2002).

Table 7: Household- versus District-Targeting of School Vouchers

	Voucher Amount	Ratio: Dist.3/Dist.1			Percent in Private Schools			Average Public School Quality	
		Income	Property	Public School Quality	District 1	District 2	District 3	No Public School Response[1]	Competitive Public Response[2]
All Eligible for Voucher	$0	2.1164	2.4911	1.805	20%	22.5%	12.5%	0.6153	0.6023
	$1,000	1.9211	2.2836	1.767	32.5%	22.5%	15%	0.6035	0.6183
	$2,500	1.6904	1.6466	1.716	40%	27.5%	22.5%	0.5645	0.6320
	$4,000	1.8393	1.4091	2.339	67.5%	40%	30%	0.4773	0.6732
Voucher Targeted to District 1	$0	2.1164	2.4911	1.805	20%	22.5%	12.5%	0.6153	0.6023
	$1,000	1.8383	2.2830	1.698	35%	22.5%	12.5%	0.5971	0.6123
	$2,500	1.4657	1.4908	1.616	47.5%	30%	15%	0.5534	0.6375
	$4,000	1.2125	1.2091	2.460	82.5%	42.5%	15%	0.5019	0.6845
Voucher Targeted to Families with Income below $25,000	$0	2.1164	2.4911	1.805	20%	22.5%	12.5%	0.6153	0.6023
	$1,000	2.1164	2.4911	1.805	20%	22.5%	12.5%	0.6153	0.6023
	$2,500	2.1164	2.4911	1.805	20%	22.5%	12.5%	0.6153	0.6023
	$4,000	2.0237	2.4112	2.046	40%	22.5%	12.5%	0.6089	0.6092

[1] These quality figures assume pure cream skimming by private schools with no behavioral response by public schools. All numbers to the left of this column are generated from simulations using this assumption regarding public and private school markets.
[2] These quality figures assume that private schools are more efficient than public schools and public schools improve under competitive pressures. The calibrated value for the efficiency advantage of private schools lies in the middle of the range that the structure of the model permits given that it must replicated accurately the private school attendance rates in the absence of vouchers. Results in the remainder of the table would differ under this specification.

None of the versions of the Nechyba/Ferreyra heterogeneous public school model is at this point sufficiently formed to give a conclusive case either for or against private school vouchers. This is due in large part because of the many unknowns that current computer models have to incorporate – unknowns that with time will become clearer as empirical work advances. These include assumptions regarding the source of private school advantage, the degree to which public schools will respond to increased competition, etc. This does not, however, imply that current computer models do not have much to say about voucher policy design. As we saw in the previous section, Epple and Romano (2002) have used their homogeneous public school model to investigate the implications for cream skimming under different types of targeted vouchers. In the same way, the Nechyba/Ferreyra model can be used to investigate targeting issues in a heterogeneous public school context.

In particular, two types of targeting are often discussed in policy circles: targeting to low-income households and targeting to certain low-income ("under-performing") school districts. Regardless of what precise assumptions are made about factors that we do not

know much about, the heterogeneous public school model suggests that these two types of targeting will have very different outcomes (Nechyba, 2000, 2002, 2003b, forthcoming(a),(b)). In particular, private school vouchers targeted only at very low income households are predicted to have virtually none of the migration and general equilibrium price effects of unrestricted vouchers as described above, while vouchers targeted to anyone living in particular low income districts would indeed give rise to such general equilibrium effects. Put differently, *increased private school competition induced by vouchers targeted to very low income households has an effect only in poor districts where such households reside, while private school competition induced by district-targeted vouchers is felt throughout the public school system as marginal higher income households in public schools elsewhere can qualify for vouchers by moving to targeted districts.* This makes district-targeted vouchers look much more like unrestricted vouchers than it does household-targeted vouchers, as evidenced in the two lower portions of Table 7 where results from computer simulations of these two forms of targeting are reported.

Table 8: Voucher Targeting to Secular Private Schools

	% Attending Private Schools		% of Private School Attendees in Religious Schools	
Voucher Amount	Unrestricted Voucher	Only Secular Schools Eligible	Unrestricted Voucher	Only Secular Schools Eligible
$0	17%	17%	100%	100%
$1,000	27%	27%	100%	51%
$3,000	73%	60%	62%	3%
$5,000	87%	87%	58%	0%
$7,000	93%	100%	53%	0%
Note: Taken from Tables 6a and 7a in Ferreyra (2002).				

A second targeting issue concerns not the targeting of eligible recipients of vouchers but rather the targeting of eligible private schools that can accept the vouchers. Ferreyra (2002) extends the theoretical model underlying the results in Tables 6 and 7 to include religious school preferences as well as both religious and secular schools, and she structurally estimates the model (as opposed to calibrating it). Table 8 then provides computer simulation results using the structurally estimated model extended to include religion (where religious schools represent Catholic schools). These results offer rather stark predictions regarding the degree to which Catholic schools could survive a voucher system from which they were excluded and thus highlights the importance of the recent Supreme Court ruling regarding the constitutionality of public dollars going to Catholic schools through state-funded private school voucher programs.[35]

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[35] Fernandez and Rogerson (2003) undertake a more dynamic analysis of voucher design in an environment where no public schools exist. While this analysis offers significant insights into the degree to which credit constraints can be alleviated through appropriate voucher design, the model at this point remains of limited immediate empirical interest given the lack of public school institutions in the model.

Public School Choice

While much of the simulation literature on school choice focuses on private school vouchers, the competing idea of *public* school choice has received considerable attention in policy circles. Results in Table 6 certainly suggest that the link between residential location and public school admission is fundamental to an explanation of how public school quality heterogeneity can persist, but it is not immediate from this analysis how such heterogeneity could survive if the link between residential location and public school admittance were severed through a system of true public school choice.[36] While a switch to greater public school choice would almost certainly give rise general equilibrium price effects similar to those predicted for private school choice, the issue remains to be explored in the framework focused on thus far.[37]

The beginnings of an approach to studying public school choice within a computational setting are, however, emerging in recent work by Epple and Romano (2003) who illustrate the potential role of transportation costs in generating uneven public school quality even in a system of full public school choice where parents can select from many public schools without changing residences. Just as in the results under state financing in Table 6, the model gives yet another illustration of how equalization of school spending (which is assumed in the Epple and Romano (2003) framework) is not sufficient for equalization of school quality when sorting along other dimensions (such as peer quality) is important so long as some rationing mechanism exists – whether from property value difference across jurisdictions (as in Table 6) or within jurisdictions (due to transportation costs).

Alternate Systems of Public School Finance

The most obvious reason to build models that can give rise to the empirically important heterogeneity in public school systems is to address the policy issue that has driven the bulk of school finance reforms in the past three decades: a continuing concern over the existence of inequities and/or inadequacies of certain portions of the U.S. public school system. Some of the models cited in Table 4 attempt to model the economic root causes of these inequities, while others employ a simpler model in order to highlight particular salient issues. Overall, however, some areas of broad consensus within this simulation literature are emerging despite the fact that models are often quite different in their set-up. In addition, some important areas for future research are becoming apparent. The most obvious of these is seen straightforwardly in Table 4 – few simulation approaches have at this point taken a dynamic perspective that is likely to be important for empirical

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[36] Other issues emerge if public school choice relates to horizontal differentiation within the public sector – through, for instance, charter schools that specialize in particular areas. These issues bare some resemblance to issues raised in the private school literature but have not yet been formally treated in computer simulation models.

[37] Reback (2002) provides empirical evidence for the importance of such price effects.

analysis. In the absence of such a perspective, important issues such as the role of credit constraints and the long run evolution of income distributions remain unexplored.[38]

In fact, only models with the simplified "spending only" school production function have thus far successfully incorporated dynamics within models that are rich enough to have substantial empirical content. Yet it is from such a simplified context that simulations have provided an important reminder of the potential importance of school finance issues. Fernandez and Rogerson (1998) use a two-community, overlapping generations model calibrated to U.S. data to illustrate the possibility of substantial welfare gains from changes in school finance systems. In particular, they investigate a switch from local to equalized state financing and find a steady state increase in income, spending on schools and social welfare. The model should be viewed as illustrative of the potential of school finance issues to have real impacts on the size and distribution of the economic pie, although the particulars of the model are probably too simple to be viewed as giving reliable empirical estimates.[39] In fact, in a more static version of the model without a housing market but with a much larger set of communities, Fernandez and Rogerson (1999) suggest that the observed *decline* in per pupil spending in California (relative to other states) after centralization of school financing is consistent with the simulation model, a result echoed in other papers that specify a richer production process with an active private school market (Nechyba, 2002, 2003a, forthcoming(b)) to which I turn shortly.[40]

The more general question of how different financing systems (including mixed state/local systems) might alter both the distribution of education resources and the larger economic environment (including housing and private school markets as well as access to education quality) has been most directly tackled in a series of papers using the Nechyba/Ferreyra model (Nechyba, 2002, 2003a, b, forthcoming(b)). The approach differs from that taken by Fernandez and Rogerson (1999, forthcoming) in that it replicates school districts with quite heterogeneous households rather than assuming exogenously that a separate jurisdiction will arise for each type of household; it does so by introducing a relatively rich housing market that also replicates housing price heterogeneity within and across jurisdictions; and it models school production as only partially depending on financial inputs – thus allowing for the emergence of a private school sector. In these ways, the approach comes closer to one that attempts to find an empirically richer underlying structure, while the Fernandez and Rogerson approach takes a more "applied theory" perspective that puts particular issues into clearer focus.

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[38] A number of dynamic models in the "macro" tradition have employed some simulations, but these models remain beyond the scope of this article in that they are quite simplified in dimensions that are likely to be important for an analysis of school finance issues in the U.S. and are therefore most appropriately viewed as theoretical explorations.
[39] The model is such that the income distributions of the two communities do not overlap – thus leading to very large differences in school spending under local financing. There are no private schools, only spending matters in school production, etc.
[40] Echoing the importance of both the inclusion of a dynamic component to education models and the potential long-run importance of school finance issues in such models is a more recent paper by Fernandez and Rogerson (2003) in which the issue of vouchers is evaluated in a dynamic model under the assumption that there exist no public schools.

Still, as suggested throughout our discussion below, important areas of agreement between these very different approaches are emerging.

Table 9: General Equilibrium Simulations of Alternative Public School Finance Systems

		Local Property Tax Financing[1]	Universal Block Grant ($3,000)[2]	Universal Matching Grant (equiv.)[3]	Targeted Block Grant ($7000)[4]	Targeted Matching Grant (equiv.)[5]	Equalized State Inc. Tax Financing[6]	Universal School Voucher ($2,500)[7]	District Targeted Voucher ($2,500)[8]
Public School Per Pupil Spending	District 1	$5,000	$5,000	$5,373	$7,000	$7,021	$7,195	$5,000	$5,000
	District 2	$7,326	$7,267	$10,062	$8,496	$8,461	$7,195	$7,645	$6,346
	District 3	$10,215	$10,545	$14,042	$11,211	$9,324	$7,195	$9,555	$8,333
	All Districts	$7,731	$7,834	$9,944	$9,026	$8,277	$7,195	$8,012	$7,115
Public School Quality[9]	District 1	0.3674	0.3781	0.3992	0.4457	0.4721	0.4616	0.3393[*]	0.3247[*]
	District 2	0.6192	0.6042	0.7575	0.6883	0.6423	0.6316	0.4930[*]	0.4435[*]
	District 3	0.8183	0.9056	1.0951	0.9369	0.7855	0.6841	0.7299[*]	0.6503[*]
	All Districts	0.6204	0.6511	0.7601	0.7047	0.6380	0.5960	0.5739[*]	0.5271[*]
Average School Quality (including private schools)[9]	District 1	0.5421	0.5384	0.4821	0.5704	0.5578	0.5755	0.6318[*]	0.6137[*]
	District 2	0.6853	0.6756	0.7880	0.7350	0.6997	0.6904	0.6187[*]	0.5973[*]
	District 3	0.8314	0.9098	1.0934	0.9416	0.7855	0.7267	0.7396[*]	0.6794[*]
	All Districts	0.6863	0.7079	0.7878	0.7490	0.6810	0.6642	0.6634[*]	0.6368[*]

Note: Figures in this Table are derived from portions of Tables 5-8 in Nechyba (forthcoming(b)).

[1] All public school funds are assumed to be raised locally through local property taxation with no inter-jurisdictional transfers.

[2] The state is assumed to fund $3,000 per pupil (using a state income tax), with local districts supplementing this amount using local property taxes.

[3] The state is assumed to match locally raised public school dollars, with the match rate set so as to average $3,000 per pupil in state funds.

[4] The state is assumed to fund $7,000 per pupil in district 1 (using a state income tax), with no state aid to other districts.

[5] The state matches local spending in district 1 with the aim of producing approximately the same level of spending as under the targeted block grant.

[6] All public school funds come from the state (through a state income tax) and are spread equally (on a per pupil basis) to all public schools.

[7] The state offers the option of a $2,500 private school voucher to anyone who chooses a private school.

[8] The state offers the option of a $2,500 private school voucher to anyone who lives in district 1 and chooses a private school.

[8] School quality is defined using the school production function with data-calibrated values for parental perceptions of the importance of per pupil spending and average peer quality within the school.

[*] These quality figures assume no response from the public school system to increase private school competition and are thus a lower bound estimate. Alternative empirically plausible assumptions that incorporate public school responses yield significantly higher school quality numbers (Nechyba, 2003b).

Table 9 compares some different stylized school finance policies within the context of the same computational framework. It compares not only results under pure local and equalized state financing but also considers "in-between" programs that involve local financing combined with block and matching grant programs funded through state income taxation. And it compares these programs to state-financed private school

voucher programs discussed more extensively above. The table furthermore reports results in three categories – public school spending, public school quality, and overall school quality received by students (including those attending private schools).[41]

First, as in results from the very different model by Fernandez and Rogerson (forthcoming)[42], no simple recommendation regarding the twin-goals of raising overall quality while addressing distributional issues emerges from these results. While the relatively simple solution of state financing can effectively eliminate spending differences in public schools, the model suggests it will leave the public school sector far from equal in terms of quality. Furthermore, in a result consistent with Fernandez and Rogerson's (1999) simulation and Silva and Sonstelie's (1995) empirical results, the model predicts that overall public spending on schools will be lower under state financing[43] than under other public school financing methods– in part because of a subtle political economy explanation first provided by Silva and Sonstelie (1995).[44] And while *public* school quality differences do narrow considerably when a system moves from purely local financing to full state-equalized financing, the *average* school quality consumed within each district (including by those attending private schools) narrows by considerably less – and primarily because of a decline in average school quality in the wealthy district rather than an increase in school quality in the poor district. *When viewed through a strictly public school lens, state financing is thus shown to narrow school quality differences in large part because of an increase in quality in poor districts. But when viewed through the overall school quality lens, the narrowing in inter-district school quality differences is smaller and comes primarily because of a decline in quality in wealthy districts.*

Not reported in Table 9 is the impact of state equalization on private school attendance. While conventional wisdom suggests that the decrease in Tiebout choice that accompanies such equalization would lead to an increase in private school attendance,

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[41] The version of the model used to generate these results assumes that the private school advantage is solely from cream skimming, and public schools do not respond to increased competition.

[42] Their approach is simpler in many dimensions but also is more serious in coming to terms with political economy aspects of public school finance. More precisely, while voting occurs on property taxation in all versions of the simulations in Table 9 (with the exception of the state equalized system), the levels of state subsidy programs are exogenously imposed. Fernandez and Rogerson focus on the endogenous determination of program levels and the political economy choice between different types of programs.

[43] This result also appears in the empirical analysis of Hoxby (2001), and an compelling treatment by Fischel (1989) suggests an important interaction between court mandates and tax policy in California.

[44] In a model such as Fernandez and Rogerson (1999) where each community is composed of a single type of household, the average spending in the state can be predicted by the *mean* income community whereas the *median* voter (which is the median income household in the absence of private schools) is decisive in state financed systems. Given that income distributions are such that the median is typically substantially below the mean, one expects majority voting to result in lower average spending under state financing than under local financing. While this argument becomes less clear in more complicated models, it still drives the results we tend to simulate in such models. In terms of mixed state/local systems, Fernandez and Rogerson (1999) show that some of the decline in California may have resulted not from a switch from local to state financing but rather a switch from a hybrid state/local system to a centralized system. In their model, a switch to pure local financing would also have entailed a decline from the mixed system, a result that is also consistent with simulation results from other models (e.g. Nechyba, 2003a) as reported below.

simulation results using this model actually suggest a *decline* in private school attendance under centralization due to general equilibrium price effects detailed in Nechyba (2003a). While some (Sonstelie, Brunner and Ardon, 2000) have interpreted the modest *increase* in private school attendance following state equalization in California as evidence that parents did not generally sense less responsiveness to their concerns as control of schools shifted to the state, this finding casts doubt on this interpretation. More precisely, if structural models predict a *decline* in private school attendance following state equalization in the absence of modeling less responsiveness to local concerns under state equalization, *such an empirically documented increase in private school attendance in California might indeed be stronger evidence for less responsiveness than had previously been acknowledged.*[45]

More generally, the reason for the persistent public school quality differences across all the policies in Table 9 lies, of course, in (1) the school production function that places only partial weight on per pupil spending and (2) the segregating role played by the housing market.[46] In addition, the third set of rows in Table 9 are meant to illustrate that, in the presence of an active private school market, it may often be incomplete to analyze the impact of public school finance reforms on public school children. Given that some parents are likely to make different public/private choices as school finance policies change the economic environment, it becomes difficult to consider the full implications of school finance reforms without considering the impact on private school markets. Thus, the model suggests *a complete analysis of public school finance issues must include not only a recognition of the link between residential housing and schooling markets, but also the link between public and private schools.*

Consider, for instance, the columns in Table 9 that appear between the extremes of local and equalized state financing. Universal block grants are predicted to have relatively little impact on overall spending (given that local districts can simply substitute state funds for local funds). However, public school quality jumps considerably in district 3 because a number of parents who used private schools in district 1 under local financing switch to public schools in district 3 under universal block grants. The reason is subtle: while local property taxes are part of the opportunity cost of purchasing a home in one location over another, state income taxes used to fund block grants are the same regardless of residential location. Thus, tax obligations (to fund public schools) have become less connected to residential location choices. This provides sufficient incentives for some private school attending households in district 1 to switch to public schools in district 3 – bringing with them their high peer quality children and raising public school quality. A similar effect – compounded by rising school quality in district 3 from increased spending – occurs under universal matching grants. Again, while public school quality rises slightly in district 1, overall school quality in district 1 declines as high peer quality

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[45] The increase in private school attendance following equalization in California is documented in Downes and Schoeman (1998) and Downes and Greenstein (1996).

[46] Models such as those by Fernandez and Rogerson (1998, 1999, forthcoming) – which assume that only spending matters in school production functions – of course predict full quality equalization under state financing. Similarly, a model with no housing market would lack the underlying structure that could permit unequal school quality under state financing.

students switch from private schools in district 1 to public schools elsewhere. Overall, *the results suggest that universal state aid to local school districts does have the potential to raise school quality if properly designed (i.e. with matching components), but this may come at the cost of widening inter-district school quality differences.*

With block and matching grants targeted to poor districts, similar general equilibrium effects of different magnitudes arise. When directly comparing the general to the partial equilibrium predictions (as done in Nechyba, forthcoming(b)), these diverge more in the case of targeting precisely because they are targeted to particular districts and therefore give rise to larger relative price changes. And again, as in the case of universal state aid, the narrowing of public school quality differences is considerably larger than the narrowing of overall inter-district school quality differences given the migration effects as well as the change in public/private choices by parents. Nevertheless, *while the simulations provide a clear indication that there are real limits to the degree of equalization that can be achieved, they also suggest that policy makers can find considerably more creative policies than full state equalization to achieve the twin goals of narrowing inter-jurisdictional quality differences while raising overall school quality.* This is a message that is strongly echoed in Fernandez and Rogerson (forthcoming) where mixed state/local financing methods tend to improve in important ways on more extreme state financing reforms (despite the fact that school quality in their model is determined solely by spending differences.)[47]

For completeness, Table 9 also provides predictions for two types of state-funded voucher programs using the same model as in the remainder of the table (and assuming no public school sector response to increased private school competition). Here the results show once again that school vouchers – to the extent that they reduce public school quality due to a lack of public school adjustment to competition – reduce such quality disproportionately more in wealthier districts that lose a larger number of high peer quality families to private schools, families that tend to reside in poorer districts once they switch to private schools. Inter-district public school quality differences therefore narrow, as do even more dramatically overall inter-district quality differences. These effects, as discussed more thoroughly above, arise almost solely due to general equilibrium changes in the economic environment, changes that can be quantified only in structural models of this kind.

Race, Religion and Tastes for Education

Perhaps the two most glaring omissions from much of the simulation literature discussed above are race and religion. Ferreyra (2002) has already made the first serious effort to

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[47] One issue not raised here regards state finance policies that link school district aid to some measure of local wealth like property values (known as district power equalizing aid). Inman and Rubinfeld (1979), in a precursor to more recent computational models, estimated that such policies would be partially self-defeating in the sense that they would end up raising property values in poor districts and lowering them in rich districts – which in turn would lower aid to poor districts and raise it to rich districts. In an early version of the model used to derive results in Table 9, Nechyba (1996) suggests that real differences in housing stocks across jurisdictions are sufficiently large so as to cause this general equilibrium effect to be of relatively small magnitude.

include religion in the Nechyba/Ferreyra framework and furthermore structurally estimates the model providing strong empirical support for the role of religion in private school markets. Race, on the other hand, remains neglected in these approaches – despite early indications from a quite different structural model that it matters in subtle but important ways.

More precisely, Bayer (2000) estimates a random coefficient, discrete choice model of elementary school choices (linked to residential location and private school options) by parents in California with particular attention to the role played by race, income, parental education and employment location. In an approach that is closer to the empirical end of the spectrum between theoretical and empirical work than any of the papers discussed above, he estimates underlying structural parameters that then permit a disentangling of the roles played by these different household characteristics. With the estimated model, Bayer conducts computer simulations to investigate the magnitude of different economic forces. His conclusions are striking: While he finds significant evidence for differences in preferences in the sense that more educated parents are willing (all else being equal) to spend more for higher quality schools, he also finds *no evidence that preferences for school quality differ by race*. Rather, the dramatically lower consumption of school quality among certain minorities seems to arise from *larger constraints imposed on minority households by the bundling of schooling and residential location choices.*[48] The general equilibrium forces that connect housing and school markets (discussed in more detail above) therefore seem equally important as race becomes the focus of the analysis. It is only a matter of time before this important insight is incorporated more fully into the computational approaches I have discussed throughout this paper.

CONCLUSION

I have attempted to provide in this paper a selective description of some of the models and results arising from a growing research agenda that utilized increased computing power to construct empirically relevant computational models of education markets. The literature is still young and growing, and many of the models are still too focused on narrow aspects of particular problems to be considered truly empirical. At the same time, the approach has yielded a number of insights and has clarified important theoretical and quantitative issues, and it seems likely that future models will continue along this path.

In conclusion, it is appropriate to note that this methodology – even as it generates more empirically realistic models, does rely a lot on an underlying economic structure that itself is difficult to test fully. Its strength lies in precisely this structure – a structure that permits policy simulations that fully trace out the general equilibrium implications of policy proposals in ways that cannot be accomplished otherwise. But this same structure is also built with considerable uncertainty regarding the appropriate assumptions that ought to be incorporated. Through the combination of more traditional empirical work

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[48] More precisely, minorities are located near low quality schools not because they place less value on school quality but rather because other factors – such as housing preferences, employment opportunities, income, a desire to reside near neighbors of the same race, etc – lead to this residential location pattern.

that gives more guidance to researchers who focus on structural models and a greater emphasis by those same researchers to use all the available empirical evidence to build the structure of their computer models, it is likely that the computational approach can be an important complement to traditional theoretical and empirical work in advancing the analysis of the economics of education in general and of school finance issues in particular.

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