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The endogeneity problem in electoral studies: a critical re-examination of Duverger's mechanical effect☆

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Abstract

Studies of electoral law consequences typically treat electoral laws as exogenous factors affecting political party systems, even while acknowledging that political parties often tailor electoral institutions to suit their own distributional needs. This study represents a departure from that approach, directly examining one aspect of the endogeneity of electoral systems: the endogeneity of Duverger's 'mechanical' effect. Theory clearly posits that the Duvergerian 'psychological' effect of electoral rules occurs in anticipation of their reductive mechanical effect, yet in empirical models this endogenous character is typically ignored. In this paper I formalize the two types of Duvergerian effects of electoral laws in a structural model and implement this model using two-stage-least-squares regression to re-estimate the mechanical effect model of Amorim Neto and Cox [Electoral institutions, cleavage structures, and the number of parties. Am. J. Polit. Sci. 41 (1997) 149-174] and Cox [Making Votes Count: Strategic Communication in the World's Electoral Systems. Cambridge University Press (1997)]. I also generalize the model and compare it to two other approaches taken by Ordeshook and Shvetsova [Ethnic heterogeneity, district magnitude, and the number of parties. Am. J. Polit. Sci. 38 (1994) 100-123] and Taagepera and Shugart [Predicting the number of parties: a quantitative model of Duverger's mechanical effect. Am. Polit. Sci. Rev. 87 (1993) 455-464]. The results indicate that because electoral structure affects the number of parties in the legislature both directly through the mechanical effect as well as indirectly through the psychological effect, simple OLS estimates that do not take into account this endogenous

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model will overestimate the mechanical effect by 45–100%.

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1. Two effects of electoral laws

Duverger's famous proposition that "the simple-majority single-ballot system favors the two-party system" (Duverger, 1951, p. 217) has generated a huge field of subsequent empirical research linking electoral structure to the number of political parties present in a nation's political system (Amorim Neto and Cox, 1997; Ordeshook and Shvetsova, 1994; Lijphart, 1994; Taagepera and Shugart 1989, 1993; Blais and Carty, 1991; Rae, 1967). Theory identifies a dual mechanism by which electoral institutions shape political party systems: "two forces working together: a mechanical and a psychological factor" (Duverger, 1951, p. 224). The mechanical effect of electoral systems describes how the electoral rules constrain the seats that can be awarded from distributions of votes, while the psychological effect deals with the shaping of party and voter strategies in anticipation of the electoral function's mechanical constraints. Analysis of the mechanical effect considers the number of parties *winning seats* as a dependent variable, using electoral structure—typically represented by district magnitude—as the key explanatory variable. Research into the psychological effect, on the other hand, focuses on the role of electoral rules in shaping the number of parties *contesting seats*, as well as the way that votes for these parties are cast, often controlling for such factors as ethnic cleavages (Ordeshook and Shvetsova, 1994), issue dimensions (Taagepera and Grofman, 1985), and the character and timing of presidential elections (Amorim Neto and Cox, 1997).

Empirical research since Duverger, however, has not always drawn a rigid distinction between the two types of effects (for an explanation see Blais and Carty, 1991), nor has it fully explored the theoretical implications of these two mechanisms for empirical modeling. Why should it be important to distinguish between the two effects and to estimate each with accuracy? First, without a clear distinction, as this paper demonstrates, estimation of the mechanical effect in particular tends to be biased. Since the psychological effect consists of anticipations of the mechanical effect, then an incorrect understanding of the mechanical effect may also warp the psychological effect. Second, real-world political actors, especially those considering alternative electoral systems, require an accurate understanding of the mechanical consequences of various electoral rules. Especially in cases of initial electoral system choice where configurations of political parties may be shaped prior to institutions, decision-makers will be interested in how electoral rules will reduce the number of parties through purely mechanical means. Since political science knowledge increasingly influences decision-makers selecting among alternative electoral institutions, a clear and accurate understanding of the mechanical properties of these institutions is of critical importance.

In this study I focus renewed attention on the estimation of the mechanical effect.

In what follows I express the mechanical and psychological effects in a single structural model, then apply this model to replicate and re-estimate the mechanical effect reported in Amorim Neto and Cox (1997) and Cox (1997).[1] The results indicate that because electoral structure psychologically influences the composition of votes which condition the mechanical effect, non-structural estimates of electoral structure's mechanical effect will be overestimated. Variations of this result applied to two other approaches to estimating the mechanical effect taken from Ordeshook and Shvetsova (1994) and Taagepera and Shugart (1993) reveal a similar upward bias.

2. Data

My purpose here is to offer a clarification and correction of previous models of the mechanical effect, not to extend them using essentially new data. For this reason I have chosen to adhere closely to the data and design of previous empirical research into the mechanical effect. While this approach carries over all of the flaws in the data, variable names, measures, and estimation methods of the original studies, it has the advantage of isolating the essential model for direct comparison. Substantive work to follow will hopefully incorporate the lessons derived from this re-examination, although a full implementation of these lessons is left to future work. For example, mechanical effects as defined here really operate at the district level, and therefore are likely to be obscured when observing only aggregate results.[2] Since the objective of this re-analysis is to focus on an issue in modeling the mechanical effect, however, the data and methods used here closely follow those of Cox (1997) and Amorim Neto and Cox (1997) for purposes of directly comparing and extending previous estimates of the mechanical effect.

The dataset from Amorim Neto and Cox (1997) provides 54 cross-national observations of elections from the 1980s. The dependent variable ENPS refers to the effective number of legislative parties ($1/\Sigma s_i^2$, where s_i is party i's seat share). The independent variables include ENPV, the effective number of parties in the electorate (analogous to ENPS but using v_i as party i's vote share); UPPER, indicating the proportion of all assembly seats allocated in the upper tier(s) of the electoral system; and LML, the natural logarithm of the median legislator's district magnitude. Using the logarithm of district magnitude M is standard practice, designed to indicate the marginally decreasing consequences of M on the number of parties; for the purposes of replicating Amorim Neto and Cox (1997) I follow their use of the natural logarithm. Finally, ENETH represents the effective number of electoral groups (analogous

[1] Controlling for the number of parties in the electorate was also the approach of Blais and Carty (1991), to which the following discussion also applies.

[2] Another issue which might be raised concerns heteroskedasticity. While heteroskedasticity may be present in the data, I did not report heteroskedasticity corrections of the standard errors for purposes of adhering to the previous models. Testing revealed, however that adding these corrections does not change the significance of any of the estimated coefficients.

to the party counts but using g_i to denote the proportion of the population of ethnic group i), based on data collected by Ordeshook and Shvetsova (1994).

3. The model

The mechanical effect of electoral rules may be thought of as a physical limit on the number of parties which can gain representation. For instance, in any electoral district at most M parties may win seats (where M represents district magnitude), no matter how many parties contest the M seats.[3] The number of parties winning seats when $M>1$, however, will depend on the number of parties receiving votes as well as their relative shares of the votes. Theoretically this is the complete information set necessary to observe the mechanical effect: the electoral rules and the votes which the rules convert into seats. "Once electoral rules are fixed, their effect is mechanical in the sense that no human manipulation or strategy is involved" (Taagepera and Shugart, 1989). "It is mechanical in the sense of accounting not for political issues, personalities, or culture but only for the limits imposed on such features by institutional structures" (Taagepera and Shugart, 1993, p. 456). Eq. (1) states this relationship formally, specifying β_1 and β_2 as the structural parameters indicating the mechanical effect (and using the variable notation from Amorim Neto and Cox, 1997).

$$\text{ENPS} = \beta_0 + \beta_1 \text{LML} + \beta_2 \text{UPPER} + \beta_3 \text{ENPV} + U_1 \quad (1)$$

$$\text{ENPV} = \gamma_0 + \gamma_1 \text{LML} + \gamma_2 \text{UPPER} + \gamma_3 \text{ENETH} + U_2 \quad (2)$$

Eq. (2) specifies the psychological effect, modeling the effective number of parties receiving votes as a function of electoral rules as well as exogenous social factors such as ethnic cleavages. It also highlights the endogenous nature of ENPV in Eq. (2), since the psychological effect is driven by the perceived workings of the mechanical effect in Eq. (1). ENPV is also mechanically related to ENPS, since ENPS will be equal to or less than ENPV (unless an electoral rule awards seats to parties receiving zero votes or the difference is an artifact of aggregation from districts).

Together the equations fully specify the structural relationship between the mechanical and psychological effects of electoral rules and the additional influence of sociological factors on influencing the number of parties that both contest and win office. The first equation separates the filtering of votes into seats by electoral rules, *for a given set of votes*. The second equation describes how this set of votes is

[3] This is what Taagepera and Shugart (1993, p. 458) forebodingly call the "Forbidden Zone," placing an upper limit of 1.0 on a linear coefficient relating ML to ENPS. While this upper limit of 1.0 will not apply to the coefficient of LML since LML is logged, in real data the estimate will tends almost always less than 1.0—leading to estimates in practice of 0–1.0 even for the logged measures of district magnitude. It is also possible to construct exceptions when district-level data is aggregated, although none exist in the data used in this study.

determined, including its shaping by the "the anticipations, both by elites and voters, of the workings of the mechanical factor" (Blais and Carty, 1991, p. 92). Electoral rules therefore exert a double effect: first in influencing the number of parties that compete and the concentration of votes they receive, and second by controlling the conversion of these parties' votes into seats. In non-mathematical terms, votes which are converted by the mechanical effect into seats have been 'pre-filtered' by the psychological effect, by voters and parties having some knowledge of how the rules affect the chances of winning seats. It also implies that any *observation* we make of the mechanical effect of electoral rules will also represent the influence of the psychological effect, unless we have a method of taking into account the structural relationship. While this endogenous relationship is sometimes implicit to previous models of Duverger's effects, none have attempted to control for it when making empirical estimates. The model here is therefore distinguished from previous characterizations by the explicitness of its structural treatment of the mechanical and psychological effects and its direct control for the consequences of this endogenous relationship.

Pictorially we can represent Eqs. (1) and (2) in a path model (Fig. 1), highlighting the means by which electoral institutions affect seats both directly (the mechanical effect) and indirectly (the psychological effect) by shaping the votes to be converted into seats. Because these functions are modeled as stochastic, the error terms U_1 and U_2 also affect both models.[4] In terms of Eqs. (1) and (2), the structural parameters

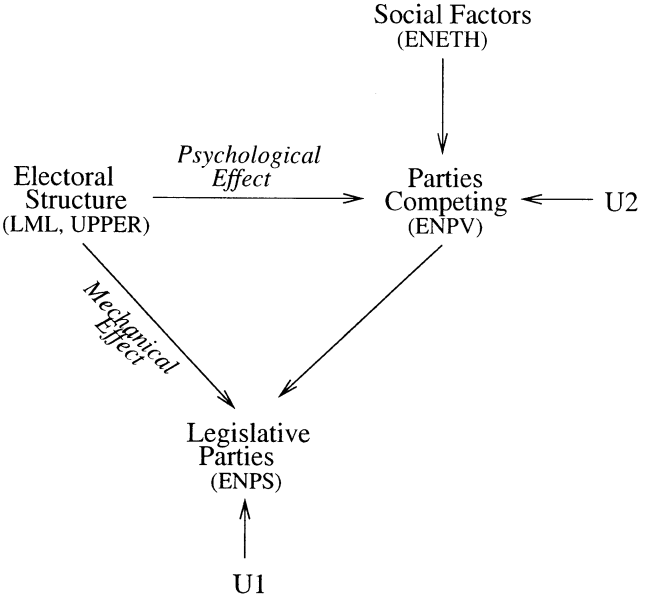

Fig. 1. A path model of Duverger's two effects.

[4] If we strictly interpret the views of Taagepera and Shugart (1993), then the mechanical effect is not really a stochastic function at all. In practice, however, it is modeled with a residual term, since summary

β_1 and β_2 represent the mechanical effect, while γ_1 and γ_2 represent the psychological effect.

The proper method of estimating these parameters depends on the structural assumptions we can make about the correlation of error terms U_1 and U_2. If these error terms are correlated, then in the language of structural equations, the model is non-recursive. The consequences are that OLS estimates of the structural parameters will be both biased and inconsistent. In the case of the two effects of electoral systems represented by Eqs. (1) and (2), there is excellent reason to believe that the errors terms are correlated. First, because the tendency to reduce the number of parties in both the mechanical and the psychological effects is driven by the same set of institutional causes, any observation-specific forces—such those uniquely occurring in one country or election—not captured in the systematic part of the model are likely to have a similar affect on both error terms. For example, an idiosyncratic election where the number of parties competing for election was unusually fragmented would also result in a potentially fragmented legislature, with the deviation from the psychological effect reflected directly as a deviation in the mechanical effect. In addition, measurement problems are likely to affect both the psychological and the mechanical models in a similar way. This is because electoral statistics such as formula and district magnitude are invariably classified into discrete categories or averaged at the national level, introducing potentially correlated disturbances between the psychological and mechanical effect models which both incorporate them. Both sets of forces should lead us to suspect a structural correlation and to attempt modeling the problem using a more appropriate estimator. Two-stages least-squares (2SLS) is one of the simplest methods of estimating structural parameters for hierarchical and non-recursive models of this sort, producing consistent estimates of structural parameters (Greene, 1993, pp. 602–4). In the two sections which follow I replicate and then re-estimate using 2SLS three previous empirical models of the mechanical effect.

4. Re-estimating Amorim Neto and Cox (1997)

Amorim Neto and Cox's (1997) estimates of the mechanical effect provide a suitable setting for testing the model and its implications for empirical observations of the mechanical effect. First, Amorim Neto and Cox's (1997) study, also reproduced in Cox (1997), is familiar to many electoral systems researchers and uses variables and methods common to most previous empirical studies of electoral system consequences. Second, the precise nature of the original study and the thorough description of its data and variables facilitates replication. Finally, the study also estimated the

characterizations of electoral structure (e.g. district magnitude) are almost never complete, since data is national- and not district-level, and since each observation of ENPV itself contains error. The empirical estimation of the mechanical effect can therefore be thought of as an average effect for the system. While theorizing the mechanical effect to be deterministic raises interesting implications, its treatment for estimation purposes as stochastic here is completely consistent with prior practice.

psychological effect, allowing for an extension of the original results using the structural model developed here.

Result (1) in Table 1 replicates Amorim Neto and Cox's (1997, Table 1) estimate of the mechanical effect, using ENPV, ENPV*LML, and ENPV*UPPER as independent variables. Their study also included estimates of the psychological effect, providing a means to obtain predicted values for ENPV to use in a 2SLS procedure to re-estimate Result (1).[5] This yielded consistent estimates for the effect of the electoral institutions in Result (2) of Table 1—indicating that the effect of the multiplicative LML variable is over-estimated by OLS by more than 45% relative to the 2SLS result (0.080 versus 0.055). Note that this replication did not involve any new variables or any respecification of the original Amorim Neto and Cox (1997)

Table 1
Modeling the mechanical effect. Dependent variable: ENPS[a]

Independent variables	Amorim Neto and Cox (1997, Table 1) OLS (1)	Structural approach 2SLS (2)	No interactive ENPV 2SLS (3)	Ordeshook and Shvetsova (1994) approach OLS (4)	Taagepera and Shugart (1993) approach OLS (5)
Constant	0.582	0.276	0.433	1.504	2.110
	(0.135)	(0.144)	(0.530)	(0.507)	(0.264)
ENPV	0.507	0.637	0.589	–	–
	(0.048)	(0.044)	(0.183)	–	–
ENPV*LML	**0.080**	**0.055**	–	–	–
	(0.012)	(0.011)	–	–	–
ENPV*UPPER	0.372	0.367	–	–	–
	(0.111)	(0.141)	–	–	–
LML	–	–	**0.253**	**0.518**	**0.510**
	–	–	(0.097)	(0.128)	(0.129)
UPPER	–	–	0.156	0.358	0.240
	–	–	(0.187)	(0.440)	(0.436)
ENETH	–	–	–	0.358	–
	–	–	–	(0.258)	–
SEE	0.40	0.46	0.54	1.25	1.27
Adj. R^2	0.92	0.90	0.86	0.24	0.25
N	54	54	54	54	54

[a] All data are from Amorim Neto and Cox (1997). Standard errors are in parentheses.

[5] The estimate of the psychological effect I used was $[\widehat{\text{ENPV}}]=1.61+0.52\text{LML}+3.95\text{UPPER}-5.95\text{PROXIMITY}+2.14\text{PROXIMITY}*\text{ENPRES}+.51\text{ENETH}$, all statistically significant at the $p<0.05$ level, which I replicated in order to obtain predicted values for ENPV. The variables PROXIMITY and ENPRES refer to the time between legislative and presidential elections and to the effective number of presidential candidates. Although the inclusion by Amorim Neto and Cox (1997) of presidential variables is unique, for replication purposes I retain their specification here. One reason not to include variables on the psychological effect on presidential candidate is that these may also be determined by some of the exogenous social factors included as control variables.

regressions, but instead simply combined information from the separate estimates of each effect into a structural model.

How should these results be interpreted? The answer has to do with the difference between the *total effect* of district magnitude on the number of elected parties versus the specific *mechanical effect* caused by electoral structure. The total effect of district magnitude, for instance, includes both β_1 and γ_1, but the mechanical effect refers only to the former. When the votes to be filtered through the electoral rules have already been 'pre-filtered' in anticipation of the actual mechanical process, then the non-structural model provides estimates that are too large, identifying a mechanical effect from what is actually a total effect.

This endogeneity of the psychological effect can be seen when we compare ENPV and ENPS for systems even with very different median district magnitudes (Table 2). For some of the elections from the Amorim Neto and Cox (1997) dataset using extremely disproportional first-past-the-post systems we would *observe*, because of the prefiltering of the psychological effect, results just as proportional as those from systems with PR rules and much higher district magnitudes. The United States, for example, using a single-member-district system with plurality rules, has 2.03 effective parties in the electorate and 1.95 parties winning seats, for a ratio of 1.04. Similar results for single-member-district systems are the Bahamas and St Kitts and Nevis with ratios of 1.08 and 1.00 respectively. Nearly identical ratios are also observed in systems with much larger district magnitudes, such as Malta (M=5), and in Portugal, Finland, and Bolivia, with magnitudes between 16 and 17.5. In each case, the psychological effect causes an equilibration between the number of parties that contest elections and the number that win them, and this effect is quite independent of the mechanical effect of the electoral rules. These examples are selected of course—the full range can be assessed from the regression results—but they serve as illustrations of the dangers of observing mechanical effects in situations where the psychological effect has already caused the parties competing and the parties winning to equilibrate. This should deter us from the conclusion that "the proper formulation is one which ENPS would equal ENPV, were the electoral system perfectly proportional, with strong electoral systems reducing ENPS below ENPV" (Amorim Neto

Table 2
Examples of psychological effect of 'pre-filtering'[a]

Country	ENPV	ENPS	Ratio	Median M
United States	2.03	1.95	1.04	1.0
St Kitts and Nevis	2.45	2.46	1.00	1.0
Bahamas	2.11	1.96	1.08	1.0
Malta	2.01	2.00	1.01	5.0
Portugal	3.73	3.41	1.09	16.0
Finland	5.45	5.14	1.06	17.0
Bolivia	4.58	4.32	1.06	17.5

[a] All data are from Amorim Neto and Cox (1997). None of these examples have additional elements such as upper-level compensation lists or additional-member systems.

and Cox, 1997, pp. 161–2) to the extent that the psychological effect does not fully equilibrate ENPV.

Result (3) from Table 1 estimates a model of the mechanical effect without multiplying all of the other variables by ENPV, but retaining ENPV as a standard control variable. This simple additive formulation is consistent with previous models of the mechanical effect and facilitates direct comparison for the purposes of illustrating the bias caused by estimating the mechanical effect separately. The coefficient of UPPER is not significant when not multiplied by ENPV, but for purposes of comparison I keep it and simply focus the remaining discussion on district magnitude (LML). The result of 0.253 as a coefficient on LML may be interpreted as the true mechanical effect estimate of structural parameter β_1 from Eq. (1). This does not mean that the *total* consequences of district magnitude on the effective number of parties is 0.253, but merely that this is a better measure of the strictly mechanical effect of district magnitude where ENPV is fixed and exogenous. The next section compares this figure to two other previous approaches to estimating the mechanical effect.

5. Comparison to other models

Comparison of the structural approach to modeling the mechanical effect may be extended to two other classes of previous models. The first type, included in Ordeshook and Shvetsova (1994), includes sociological control variables directly in the model of the mechanical effect. The second, outlined (although not estimated empirically) by Taagepera and Shugart (1993), disregards control variables altogether. This section demonstrates the superiority of the structural model to both of these approaches.[6]

Result (4) in Table 1 uses the specification of Ordeshook and Shvetsova (1994) with the data from Amorim Neto and Cox (1997).[7] In this specification the operation of the mechanical effect is assessed while holding sociological factors constant. Yet because sociological factors do not intrude on the mechanical process of vote-to-seat conversion, ENETH is really just a proxy for a measure of votes. It is incomplete, however, and still results in an upwards-biased estimate of β_1 as compared to Result (3)—in fact it more than doubles the estimate of the 'mechanical' effect. This occurs because ENETH is only a partial determinant of ENPV,

[6] This section does not strictly replicate either of these two studies, although the Amorim Neto and Cox (1997) dataset is essentially the same as that used by Ordeshook and Shvetsova (1994). I was not able to use Taagepera and Shugart's (1993) dataset because even with Matthew Shugart's willing help I was unable to reconstruct it exactly, and because their estimation procedure is not an empirical one which can be replicated in the same way. Hence I replicate their model specifications while using the Amorim Neto and Cox (1997) dataset, which keeps attention centered on the modeling issues which are the focus of this paper.

[7] In fact the data are essentially the same, since Amorim Neto and Cox (1997) used the measure of ENETH as provided by Shvetsova.

and because the psychological effect of LML is still being conflated into the mechanical estimate through the omission of ENPV. As a consequence the coefficient on LML in Result (4) is an estimate of a reduced form parameter combining several effects, rather than of the structural parameter β_1. Appendix A demonstrates this result mathematically.

The second alternative approach to estimating the mechanical effect is simply to estimate the effect of electoral institutions on the number of parties winning seats without any control variables. This approach was taken by Taagepera and Shugart (1993), and followed using the Amorim Neto and Cox (1997) dataset in the last column of Table 1. It causes a similar upward bias in the estimate of β_1, ascribing a much greater mechanical consequence to district magnitude “only for the limits imposed... by institutional structures” (Taagepera and Shugart, 1993, p. 456), because it fails to control for any other influences. The results in Table 1 show likewise that the estimate of the electoral institution-only model yields a coefficient double that estimated by the structural model. Here the problem of endogeneity can be demonstrated as one of simple omitted variable bias: the omitted variable ENPV is highly correlated with the included variable district magnitude through the very nature of the psychological effect. In this case the omitted variable ENPV is both positively correlated with ENPS and with the included variable LML, causing a positive upward bias in the estimate of LML’s mechanical effect, detailed mathematically in Appendix B. Because the approach using ENETH also suffered from this omitted variable bias, it is not surprising that the two estimates of 0.518 and 0.510 should be similar.

6. Concluding remarks

This study has focused on empirical models of the mechanical effect, attempting to bring empirical estimates closer to the purely mechanical factor identified in electoral systems theory. The results demonstrate quite clearly in the context of previous research that non-structural empirical estimates of Duverger’s mechanical effect will be biased, yielding results stronger than those caused by the strictly mechanical operation of electoral rules. This bias occurs because the operation of electoral systems on the number of parties winning seats operates twice, both on the conversion of votes to seats but also on the composition of votes itself. This result is robust to several alternative approaches to estimating the mechanical effect. A more correct approach is to model the structural relationship using two-stage least-squares (e.g.) to separate the purely mechanical workings of electoral rules.

An unbiased estimate of the strictly mechanical effect might be of particular interest in situations where the number and composition of political parties might be at least partially independent of the electoral rules. Such a situation is common in emerging democracies who are selecting from alternative rules based on their understanding of the mechanical effects of the alternatives. The separate estimation points to the fact that in equilibrium, where ENPV is ‘prefiltered’ by electoral constraints, the results might be proportional even though the electoral institutions were having an indisputable effect on the number of political parties in the parliament. In such contexts it is the number of political parties in parliament that is the most important immediate issue to electoral law designers, rather than the more theoretical issues pertaining to strategic voting and party exit and entry which political scientists prefer to examine under the rubric of the psychological effect. The structural model estimates presented here provide for such contexts a more accurate picture of the institutional effects as separated from the equilibrium effects which may only occur after a learning process has taken place. For political scientists interested in the Duvergerian effects of electoral law, the approach outlined here clarifies our understanding of the mechanical effect and focuses attention where it is probably more deserved: on the psychological effect of electoral laws on political parties and voters.

Appendix A. Demonstration of bias using ENETH as a control variable

Substituting Eq. (2) into Eq. (1), we get:

$$\begin{aligned}\text{ENPS} &= \beta_0+\beta_1\text{LML}+\beta_2\text{UPPER}+\beta_3\gamma_0+\beta_3\gamma_1\text{LML}+\beta_3\gamma_2\text{UPPER}+\beta_3\gamma_3\text{ENETH}+\beta_3U_2+U_1\\ &= (\beta_0+\beta_3\gamma_0)+(\beta_1+\beta_3\gamma_1)\text{LML}+(\beta_2+\beta_3\gamma_2)\text{UPPER}+\beta_3\gamma_3\text{ENETH}+\beta_3U_2+U_1 \quad (3)\\ &= \pi_0+\pi_1\text{LML}+\pi_2\text{UPPER}+\pi_3\text{ENETH}+V\end{aligned}$$

where the last step substitutes reduced form parameters π_0 through π_3 for the structural parameters. This formulation highlights the relationship

$$\pi_1=\beta_1+\beta_3\gamma_1$$

$$\pi_1>\beta_1$$

since the effect of both ENPV and LML on ENPS are always positive. Ordeshook and Shvetsova's (1994) procedure is equivalent to estimating π_1, while the 2SLS model provides a consistent estimate of β_1. The estimate of π_1 will always be greater by the product of the effect β_3 of ENPV in the mechanical effect model and the effect γ_1 of LML in the psychological effect model.

Appendix B. Demonstration of bias using no control variables

Consider two reduced versions of Eq. (1), omitting the constant and UPPER for simplicity (not affecting the results):

$$\text{ENPS}=\beta_1\text{LML}+\beta_3\text{ENPV}+U_1$$

$$\text{ENPS}=\delta_1\text{LML}+U_3$$

The OLS estimator d_1 for δ_1 will be:

$$
\begin{aligned}
E(d_1) &= \frac{\sum \mathrm{LML}_i E(\mathrm{ENPS}_i)}{\sum \mathrm{LML}_i^2} \\
&= \frac{\sum \mathrm{LML}_i(\beta_1 \mathrm{LML}_i + \beta_3 \mathrm{ENPV}_i)}{\Sigma \mathrm{LML}_i^2} \\
&= \frac{\beta_1 \sum \mathrm{LML}_i^2 + \beta_3 \sum \mathrm{LML}_i \mathrm{ENPV}_i}{\sum \mathrm{LML}_i^2} \\
&= \beta_1 + \beta_3 \frac{\sum \mathrm{LML}_i \mathrm{ENPV}_i}{\sum \mathrm{LML}_i^2}
\end{aligned} \tag{4}
$$

where the last term in Eq. (4) is equivalent to the slope coefficient from an OLS regression of ENPV on LML—a measure of the psychological effect, in other words. The estimates of the effect of LML in Eq. (4) will therefore be larger than the estimate of β_1 in Eq. (4) by the product of the magnitude of LML in the psychological effect and by the direct correlation of ENPV with ENPS.

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