Rev Quant Finan Acc (2016) 47:943–971
DOI 10.1007/s11156-015-0526-0

ORIGINAL RESEARCH

Applications of simultaneous equations in finance research: methods and empirical results

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Published online: 2 July 2015

Abstract The main purposes of this paper are: (1) to review finance literature using simultaneous equations method, (2) to discuss the difference among two-stage least squares (2SLS), three-stage least squares (3SLS) and generalized method of moments (GMM) methods under different assumptions, and (3) to investigate the interrelationship among investment, financing, and dividend decisions as an example to demonstrate the discussion. We review studies that apply the simultaneous equations estimation on capital structure, corporate investment, payout decisions, ownership structure, corporate governance, stock return, firm performance and/or other corporate issues. In addition to these three methods, we also present Pagan and Hall's (Econom Rev 2:159–218, 1983) test of heteroskedasticity and weak instruments test for selecting the applicable method and testing the validity of instruments. Finally, we investigate the interrelationship among investment, financing and dividend decisions using 2SLS, 3SLS, and GMM methods based on the US listed firm annual data between 1965 and 2012. Our results show that these three corporate decisions are co-determined and the interaction among them should be taken into account in a simultaneous equations framework.

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Keywords 2SLS · 3SLS · GMM · Investment decision · Financing decision · Dividend decision

JEL Classification C18 · C30 · C36 · G10 · G30

1 Introduction

Simultaneous equations models have been widely adopted in finance literature. It is suggested that the relation, particularly the interaction, among corporate decisions, firm characteristics, and firm performance should be contemporaneously determined. For example, MacKay and Moeller (2007) investigate the relation between corporate hedging and firm value. Gong et al. (2008) decipher the cause-consequence relationship between repurchase and earnings management activities in system equations. Harford et al. (2014) consider the interdependence of a firm's cash holdings and the maturity of its debt. Therefore, to understand the application of simultaneous equations models, we survey the methodologies and review papers that apply these methods. We also illustrate how to implement the estimation of simultaneous equations with a test on corporate investment, leverage, and payout.

The utilization of ordinary least squares (OLS) estimation on simultaneous equations yields biased and inconsistent estimates since the assumption of uncorrelation between the regressors and the disturbance terms is violated in empirical data. The instrumental variable (IV) methods are commonly used to deal with this endogeneity problem, and both two-stage least squares (2SLS) and three-stage least squares (3SLS) estimations belong to IV class estimators.[1] The generalized method of moments (GMM) estimator proposed by Hansen (1982) further generalizes Sargan's (1958, 1959) linear and nonlinear IV estimators based on optimal weighting matrix for the moment conditions. In contrast to traditional IV class estimators, the GMM estimator uses a weighting matrix taking account of temporal dependence, heteroskedasticity or autocorrelation. In this paper, we discuss the differences among 2SLS, 3SLS and GMM methods under different assumptions. In addition, we introduce the F-statistic from first-stage regression to test whether instruments are weak and the Pagan and Hall (1983)'s test for the presence of heteroskedasticity is also investigated here.

The applications of simultaneous equations models in finance research are abundant. Some papers study the interrelationship among a firm's capital structure, investment, and payout policy (e.g., Grabowski and Mueller 1972; Higgins 1972; Fama 1974; McCabe 1979; Peterson and Benesh 1983; Switzer 1984; Fama and French 2002; Gugler 2003; MacKay and Phillips 2005; Aggarwal and Kyaw 2010; Harford et al. 2014), given the fact that these decisions are simultaneously determined. For example, an increase in debt financing may enhance the funds available to outlays for investment; meanwhile the increase in investment may change the supply-side debt capacity. Firms may adjust their major policies by taking into account the interdependencies among them. In addition, the interrelationship between board composition (or ownership) and firm performance is often investigated in simultaneous equations (e.g., Loderer and Martin 1997; Demsetz and Villalonga 2001; Bhagat and Black 2002; Prevost et al. 2002; Woidtke 2002; Boone et al. 2007; Fich and Shivdasani 2007; Ferreira and Matos 2008; Ye 2012). On one hand, insider (manager or director) holdings affect the insider's incentive to work and accordingly

[1] Wang (2015) reviews instrumental variables approach to correct for endogeneity in finance.

positively influence firm performance upon the agency theory; however, firm performance, which is usually proxied by Tobin's Q, also affects whether or not the insider is willing to sell their shares, leading to changes in the ownership structure. In addition to the above-mentioned studies, many other issues of research also apply the simultaneous equations model in their papers because firm decisions, characteristics, and performance may be jointly determined.[2]

Although many finance studies acknowledge the existence of endogeneity problems caused by omitted variables, measurement errors, and/or simultaneity, few of them provide the reason for the selected estimation methods (e.g., 2SLS, 3SLS, and/or GMM). In fact, different estimation methods for the simultaneous equations are not perfect substitutions under different assumptions. Thus, we need a detailed examination of which method is best for the model selection by some relevant statistical tests. In addition, the IVs are usually chosen arbitrarily in finance studies. Thus, we compare the differences among 2SLS, 3SLS and GMM methods, present the applicable method under different conditions, and also present the related test for the validity of instruments.

In an attempt to illustrate the application of simultaneous equations models, we also examine the interrelationship among a firm's investment, financing and dividend decisions using 2SLS, 3SLS, and GMM estimations. We collect US listed dividend-paying firms from 1965 to 2012.[3] From the results of Pagan and Hall's (1983) test of heteroskedasticity, we have the similar results for 2SLS and GMM methods because there is no heteroskedasticity in our study. The results of weak instruments test show the validity of our instruments.

Our study has the following empirical results. First, the finding that dividend and investment decisions are jointly determined is consistent with Lambrecht and Myers (2012). Firms may use dividend payout to signal the growth opportunity and then increase their investment. Firms with higher investment input may experience higher earnings and thus could increase the dividend payout. Second, we find that firms with higher investment have higher debt financing and vice versa. This result implies that debt is preferred to equity for managers to signal the optimistic investment opportunity to investors. The increases in debt financing help to increase the funds available to outlays for investment. Finally, we find that firms have more capability to pay dividend when they have lower leverage level.

Our research offers two contributions to the literature. First, this paper reviews applications of simultaneous equations models in finance research and their econometric estimation methods. The endogeneity problem in empirical studies is extensively noted and the appropriate estimation methods should be adopted. Second, we employ 2SLS, 3SLS,

[2] For example, capital structure and firm performance (Harvey et al. 2004; Ruland and Zhou 2005; Berger and Bonaccorsi di Patti 2006; Billett et al. 2007), financial policies and ownership (Jensen et al. 1992; Velury et al. 2003; Setia-Atmaja et al. 2009), agency problem and firm performance (Agrawal and Knoeber 1996; Coles et al. 2006), corporate governance and liquidity (Chen et al. 2007), repurchase and firm performance (Gong et al. 2008; Babenko 2009), mergers and acquisitions (Betton and Eckbo 2000; Officer 2003; Billett and Xue 2007; Edmans et al. 2012; Fidrmuc et al. 2012; De La Bruslerie 2013; Deng et al. 2013), stock option (Core and Guay 2001; Grundy et al. 2012), governance/risk in banking industry (Shrieves and Dahl 1992; Jacques and Nigro 1997; Aggarwal and Jacques 2001; Chen et al. 2006), risk management (Graham and Rogers 2002; MacKay and Moeller 2007; Aunon-Nerin and Ehling 2008; Lee et al. 2010) and capital asset pricing models (Simkowitz and Logue 1973; Lee 1976) are the issues of research applying simultaneous equations model in the papers.

[3] Smirlock and Marshall (1983) and Fama and French (2002) also only consider the firms paying dividend.

and GMM estimations in examining the interrelationship among a firm's investment, dividend payout and debt financing policies to discuss the application of estimation method and show the validity of instruments. We find these major decisions of firms correlate to each other and should be considered simultaneously.

The paper proceeds as follows. Section 2 presents the literature reviews about the application of simultaneous equations models in finance research. Section 3 discusses the econometric methodologies applied in estimating simultaneous equations models. Section 4 illustrates the application of simultaneous equations to investigate the interaction among investment, financing and dividend decisions. Conclusions are presented in Sect. 5.

2 Literature review

2.1 Applications of simultaneous equations models in capital structure, investment, and payout policy literatures

The simultaneous equations models are applied in the capital structure decisions. Harvey et al. (2004) address the potentially endogenous relation among debt, ownership structure, and firm value by estimating a 3SLS regression model. They find that debt can mitigate the agency and information problem for emerging market firms. Billett et al. (2007) suggest that the corporate financial policies, which include the choices of leverage, debt maturity, and covenants, are jointly determined, and thereby apply GMM in the estimation of simultaneous equations. They find that covenants can mitigate the agency costs of debt for high growth firms. Berger and Bonaccorsi di Patti (2006) ague that an agency costs hypothesis predicts that leverage affects firm performance, yet firm performance also affects the choice of capital structure. To address this problem of reverse causality between firm performance and capital structure, they use 2SLS to estimate the simultaneous equations model. They also estimate by 3SLS and do not change the main findings that higher leverage is associated with higher profit efficiency. In the similar reason, Ruland and Zhou (2005) consider the potential endogeneity between firms' excess value and leverage and find that compared to specialized firms, the values of diversified firms increase with leverage by using 2SLS. Aggarwal and Kyaw (2010) recognize the interdependence between capital structure and dividend payout policy by using 2SLS and find that multinational companies have significantly lower debt ratios and pay higher dividends than domestic companies. MacKay and Phillips (2005) use GMM and find that financial structure, technology, and risk are jointly determined within industries.

In addition, simultaneous equations models are applied in studies considering the interrelationship among a firm's major policies. Higgins (1972), Fama (1974), and Morgan and Saint-Pierre (1978) investigate the relationship between investment decision and dividend decision. Grabowski and Mueller (1972) examine the interrelationship among investment, dividend, and research and development (R&D). Fama and French (2002) consider the interaction between dividend and financing decisions. Dhrymes and Kurz (1967), McDonald et al. (1975), McCabe (1979), Peterson and Benesh (1983), and Switzer (1984) argue that investment decision is related to financing decision and dividend decision. Harford et al. (2014) consider the interdependence of a firm's cash holdings and the maturity of its debt by using a simultaneous equation framework and performing a 2SLS estimation.

2.2 Applications of simultaneous equations models in board composition/ownership structure literature

The interrelationship between board composition (or ownership) and firm performance is often investigated in simultaneous equations. Agrawal and Knoeber (1996) use seven mechanisms to control agency problems between managers and shareholders.[4] By using 2SLS procedure, Agrawal and Knoeber (1996) find the interdependence among these mechanisms and suggest the regression on any single mechanism for firm performance is misleading. Loderer and Martin (1997) examine the executive ownership and firm performance, and find that better performance leads to larger stockholdings of a manager, but not vice versa. Demsetz and Villalonga (2001) suggest that the ownership structure should be modeled as an endogenous variable and should be considered separately for the fractions of shares owned by outside shareholders and management. They run 2SLS regression to mitigate the endogeneity and find no statistically significant relation between ownership structure and firm performance. Similarly, by using 2SLS, Woidtke's (2002) results suggest that different types of institutional investors (public or private pension funds) have heterogeneous impacts on firm value. Velury et al. (2003) consider the endogeneity that firms may desire high quality audits to make themselves attractive to institutional investors and institutional investors are likely to demand high quality auditors via increased voting power. Their 2SLS results reveal that firms with more institutional ownership tend to employ industry specialist auditors. To investigate the reputational impact of financial fraud on outside directors, Fich and Shivdasani (2007) estimate a simultaneous-equations framework to account for the endogeneity between tainted director and fraud lawsuits. Boone et al. (2007) endogenize board size and independence by using 2SLS and find that board size and independence increase as firms grow and diversify over time. Ye (2012) considers the issue whether active institutional investors can alleviate the anomalous comovement of stock returns and adopts 2SLS to deal with the potential endogeneity problems stem from that active institutional ownership is likely to be affected by firm fundamentals that could also affect the magnitude of the comovement effect.

In addition to 2SLS, a 3SLS approach is also adopted in this issue. By using 3SLS in studying the joint determination of managerial incentives and policy choices, Coles et al. (2006) find that higher sensitivity of CEO wealth to stock volatility implements riskier policy choices and also find that riskier policy choices lead to compensation structures with higher sensitivity of CEO wealth to stock volatility and lower CEO pay-performance sensitivity. Ferreira and Matos (2008) apply 3SLS to investigate the relation between institutional ownership and firm performance. They find that ownership by foreign and independent institutions have a positive impact on firm valuations. Prevost et al. (2002) set up a simultaneous equations model to control potential endogeneity between board composition and firm performance by using a 3SLS system approach methodology. They find evidence that board composition and firm performance are jointly determined and influence each other in a positive manner for the sample of New Zealand firms. Bhagat and Black (2002) also use a 3SLS approach to investigate the similar issue for large American firms. However, they find that low-profitability firms increase the independence of their boards of directors, and firms with more independent boards do not perform better than other firms.

[4] These control mechanisms include insider shareholdings, institutional shareholdings, blockholders' shareholdings, uses of outsiders on the board of directors, debt financing, the labor market, and the market for corporate control.

The simultaneous equations models are also used to examine the interaction between financial policies and firm ownership. Jensen et al. (1992) examine the determinants of insider ownership, debt, and dividend policies within a system of equations and apply 3SLS estimation. They find that high insider ownership firms choose lower levels of both debt and dividends. By using Austrian data, Gugler (2003) investigates the interrelation among dividends, R&D, and capital investment, and compare the dividend payout policy of different ownership and control structure of firms. He finds the evidence that the investment, R&D, and dividends are jointly determined and thereby estimate the simultaneous equations system by 3SLS. By comparing with family-controlled firms, Gugler (2003) finds that state-controlled firms smooth dividends, have large payout ratios, and are most reluctant to cut dividends. Setia-Atmaja et al. (2009) examine the interrelationship among dividends, debt, and boards of directors of family controlled firms in the Australian capital market. By using 3SLS for a system of four equations they show that family controlled firms employ higher dividend payout ratios, higher debt levels, and lower levels of board independence than non-family firms.

2.3 Applications of simultaneous equations models in mergers and acquisitions literature

Mergers and acquisitions (M&A) literature also intensively uses simultaneous equations to control for endogeneity issue. Betton and Eckbo (2000) use 3SLS estimation to control for the potentially joint nature of the toehold-premium decision in takeover bids. They find that greater bidder toeholds are associated with lower bid premiums. Officer (2003) study the effects of termination fees on M&A and find that merger deals with target termination fees involve significantly higher premiums than deals without such clauses. Billett and Xue (2007) analyze the effects of pre-repurchase takeover probability on the repurchase decision by adopting a two-stage IVs approach to alleviate the measurement error induced by the ex post takeover probability. They find a positive relation between open market share repurchases and takeover probability.

Edmans et al. (2012) identify a strong effect of market prices on the likelihood of being a takeover target. Edmans et al. (2012) use mutual fund redemptions as an instrument for price changes to control the endogeneity of the anticipation effect, i.e. the influences from takeover likelihood to the market price discount. Deng et al. (2013) consider the potential endogeneity between value for acquiring firms' shareholders and corporate social responsibility (CSR). Namely, acquirers with good performance could invest more in CSR and acquirers with high CSR show good performance. By apply simultaneous equation system and 2SLS regression analyses, they find that acquirers' social responsibility has a positive impact on firm performance, merger performance and the probability of its completion.

There are other M&A literatures considering the takeover premium and applying simultaneous equations. Fidrmuc et al. (2012) focus on the possible interdependencies between the target firms' selling mechanism choice, buyer type and their impact on takeover premium. Their results show that both selling process and different buyer type have insignificant effects on takeover premium while the selling mechanism choice affects the buyer type. De La Bruslerie (2013) consider the endogenous relationship between the takeover premiums and the means of payment. By using a sample of European M&As, De La Bruslerie (2013) finds that higher premiums yield higher percentage of cash payments.

2.4 Applications of simultaneous equations models in other finance literature

In addition to the above-mentioned papers, simultaneous equations models are also applied in other issues of finance studies. Simkowitz and Logue (1973) propose a simultaneous equation capital asset pricing model (CAPM) to offer a robust test for the interdependent assumption of the Sharp model. But the effect of multicollinearity in their 2SLS estimation was challenged by Lee (1976). Instead of 2SLS, Lee (1976) shows that the modified 2SLS is more appropriate in estimation of Simkowitz and Logue's (1973) model.

The issue of risk management also considers the simultaneous equations models. Aggarwal and Jacques (2001) estimate a 3SLS model to examine the simultaneous impact of prompt corrective action (PCA) on both bank capital and credit risk. They show that PCA has a significant impact both in terms of raising capital ratios and reducing credit risk for banks. Shrieves and Dahl (1992) apply 2SLS and find a positive association between changes in risk and capital in commercial banks. Jacques and Nigro (1997) use a 3SLS model and find that the risk-based capital standards were effective in increasing capital ratios and reducing portfolio risk for commercial banks. Chen et al. (2006) employ a two-equation model using 2SLS to examine the relationship between executives' incentive compensation and firm risk for the banking industry. MacKay and Moeller (2007) estimate their four-equation simultaneous system by GMM and find evidence that risk management can add value on their sample of oil refiners. Graham and Rogers (2002) use 2SLS to study the tax incentives for corporations to hedge. Aunon-Nerin and Ehling (2008) apply GMM on the study of the relation between corporate debt capacity and risk management with insurance. Lee et al. (2010) construct a simultaneous equations system and use 3SLS to examine the hedging index by considering cross-country interaction and linkage.

Gong et al. (2008) investigate the earnings management problem of share repurchase. They consider the possible interaction between post-repurchase abnormal accruals and the percentage of share outstanding repurchased using 3SLS. Babenko (2009) employs 2SLS in estimating the relationship between share repurchases and pay-performance sensitivity of employee compensation. Core and Guay (2001) use 2SLS to estimate the grants and exercises of option incentives for non-executive employees. Grundy et al. (2012) analyze options volume and spreads during September 2008 short-sale ban by using 2SLS. Chen et al. (2007) adopt both 3SLS and GMM to control the possible simultaneity in the determination of a bid-ask spread and a firm's disclosure policy. They find that firms with poor information transparency and disclosure practices tend to have higher cost of equity liquidity. Antle et al. (2006) suggest that the audit fees, non-audit fees and abnormal accruals are jointed determined and apply 2SLS estimation on UK data. In addition to the knowledge spillover from non-audit to auditing services, which has been found on past studies, Antle et al. (2006) find another knowledge spillover from auditing to non-audit services.

We classify the above-mentioned articles by topic issues and methodologies, including 2SLS, 3SLS, and GMM, as shown in Table 1. The categories contain capital structure, investment, payout policy, board composition/ownership structure, mergers and acquisitions, and so on. In addition to conventional 2SLS, some papers such as Officer (2003), Billett and Xue (2007), Fich and Shivdasani (2007), De La Bruslerie (2013) use two-stage regression by other estimations such as probit, logit, and Tobit methods.

The above literature review of finance shows many studies acknowledge the existence of endogeneity problem caused by omitted variables, measurement errors, and/or simultaneity, however, seldom studies provide the reason for the selected estimation method (e.g., 2SLS, 3SLS, and/or GMM). In fact, different methods of estimating the simultaneous

Table 1 Finance research that uses simultaneous equations models

Paper	Methodology		
	2SLS	3SLS	GMM
Capital structure, investment, and payout policy			
Grabowski and Mueller (RES[a] 1972)	X		
Higgins (JFQA 1972)	X		
Fama (AER 1974)	X		
McCabe (JFQA 1979)	X		
Petersen and Benesh (JFQA 1983)	X	X	
Switzer (RES 1984)	X	X	
Fama and French (RFS 2002)	X		
Gugler (JBF 2003)		X	
MacKay and Phillips (RFS 2005)			X
Aggarwal and Kyaw (IRFA 2010)	X	X	
Harford et al. (JF 2014)	X		
Capital structure and firm performance			
Harvey et al. (JFE 2004)		X	
Ruland and Zhou (RQFA 2005)	X		
Berger and Bonaccorsi di Patti (JBF 2006)	X		
Billett et al. (JF 2007)			X
Board composition/ownership structure			
Jensen et al. (JFQA 1992)		X	
Agrawal and Knoeber (JFQA 1996)	X		
Loderer and Martin (JFE 1997)	X		
Demsetz and Villalonga (JCF 2001)	X		
Bhagat and Black (JCL 2002)		X	
Prevost et al. (JEF 2002)		X	
Woidtke (JFE 2002)	X		
Velury et al. (RQFA 2003)	X		
Coles et al. (JFE 2006)		X	
Boone et al. (JFE 2007)	X		
Fich and Shivdasani (JFE 2007)	X[b]		
Ferreira and Matos (JFE 2008)		X	
Setia-Atmaja et al. (JBFA 2009)		X	
Ye (JFQA 2012)	X		
Mergers and acquisitions			
Betton and Eckbo (RFS 2000)		X	
Officer (JFE 2003)	X[c]		
Billett and Xue (JF 2007)	X[d]		
De La Bruslerie (JBF 2013)	X[e]		
Deng et al. (JFE 2013)	X		
Capital asset pricing models			
Simkowitz and Logue (JFQA 1973)	X		
Lee (JFQA 1976)	X		

Table 1 continued

Paper	Methodology		
	2SLS	3SLS	GMM
Governance/risk in banking industry			
Shrieves and Dahl (JBF 1992)	X		
Jacques and Nigro (JEB 1997)		X	
Aggarwal and Jacques (JBF 2001)		X	
Chen et al. (JBF 2006)	X		
Risk management			
Graham and Rogers (JF 2002)	X[f]		
MacKay and Moeller (JF 2007)			X
Aunon-Nerin and Ehling (JFE 2008)			X
Lee et al. (RPBFMP 2010)		X	
Repurchase and firm performance			
Gong et al. (JF 2008)		X	
Babenko (JF 2009)	X		
Stock option			
Core and Guay (JFE 2001)	X		
Grundy et al. (JFE 2012)	X		
Corporate governance			
Chen et al. (CGIR 2007)		X	X
Accounting			
Antle et al. (RQFA 2006)	X		

[a] The name of the journals and their abbreviations are as follows: The American Economic Review (AER); Corporate Governance: An International Review (CGIR); International Review of Financial Analysis (IRFA); Journal of Banking and Finance (JBF); Journal of Business Finance and Accounting (JBFA); Journal of Corporate Finance (JCF); Journal of Corporation Law (JCL); Journal of Economics and Business (JEB); Journal of Empirical Finance (JEF); The Journal of Finance (JF); Journal of Financial Economics (JFE); Journal of Financial and Quantitative Analysis (JFQA); The Review of Economic Studies (RES); Review of Financial Studies (RFS); Review of Pacific Basin Financial Markets and Policies (RPBFMP); Review of Quantitative Finance and Accounting (RQFA)

[b] Fich and Shivdasani (2007) apply two-stage logit regression

[c] Officer (2003) employs the estimation technique for observed/dichotomous systems

[d] Billett and Xue (2007) apply two-stage instrumental variables regression

[e] De La Bruslerie (2013) apply two-stage probit regression

[f] Graham and Rogers (2002) use a Tobit regression in their first-stage estimation because the dependent variable is censored at zero

equations have different assumptions and thereby cause they are not perfect substitutions. For example, the parameters estimated by 3SLS, which is a full information estimation method, are asymptotically more efficient than the limited information method (e.g., 2SLS), although 3SLS is vulnerable to model specification errors. Thus, a comprehensive analysis of which method is best for the model selection would require some contemplation and relevant statistical tests. Moreover, the IVs used in finance studies are usually chosen arbitrarily. Thus, in Sect. 3, we will discuss the difference among 2SLS, 3SLS and GMM methods, present the applicable method under different conditions, and also present the related test for the validity of instruments.

3 Methodology and related tests

Suppose that a set of observations on a variable y is drawn independently from probability distribution depends on an unknown vector of parameters $\boldsymbol{\beta}$ of interest. One general approach for estimating parameters $\boldsymbol{\beta}$ is based on maximum likelihood (ML) estimation. The intuition behind ML estimation is to specify a probability distribution for it, and then find an estimate $\widehat{\boldsymbol{\beta}}$ in which the data would be most likely to have been observed. The drawback with ML methods is that we have to specify a full probability distribution for the data. Here, we introduce an alternative approach for parameter estimation known as GMM. The GMM estimation is formalized by Hansen (1982), and is one of the most widely used methods of estimation in economics and finance. Hansen won his Nobel Prize in 2013 in economics for deriving the GMM estimation. In contrast to ML estimation, the GMM estimation only requires the specification of certain moment conditions rather than the form of likelihood function.

The idea behind GMM estimation is to choose a parameter estimate so as to make the sample moment conditions as close as possible to the population moment of zero according to the measure of Euclidean distance. The GMM estimation proposes a weighting matrix reflecting the importance given to matching each of the moments. Alternative weighting matrix is associated with alternative estimator. Many standard estimators, including OLS, method of moments (MM), ML, IV, 2SLS, and 3SLS can be seen as special cases of GMM estimators. For example, when the number of moment conditions and unknown parameters are the same, solving the quadratic criterion yields the GMM estimator, which is the same as MM estimator that sets the sample moment condition exactly equal to zero. The weighting matrix does not matter in this case. In particular, in models for which there are more moment conditions than model parameters, GMM estimation provides a straightforward way to test the specification of the proposed model. This is an important feature that is unique to GMM estimation.

Recently, the endogeneity concern has received much attention in empirical corporate finance research. There are at least three generally recognized sources of endogeneity: omitted explanatory variables, simultaneity bias, and errors in variables. Whenever there is endogeneity, the application of OLS estimation yields biased and inconsistent estimates. In literature, the IV methods are commonly used to deal with this endogeneity problem. The basic motivation for the IV method is to deal with equations that exhibited both simultaneity and measurement errors in exogenous variables. The idea behind IV estimation is to select suitable instruments that are orthogonal to the disturbance while sufficiently correlated with the regressors. The IV estimator makes the linear combinations of sample orthogonality conditions close to zeros. Sargan (1958, 1959) establishes a fully developed theory of IV estimation. The GMM estimator proposed by Hansen (1982) is also based on orthogonality conditions and provides an alternative solution. Hansen's (1982) GMM estimator generalizes Sargan's (1958, 1959) linear and nonlinear IV estimators based on optimal weighting matrix for the moment conditions. In contrast to traditional IV class estimators such as 2SLS and 3SLS estimators, the GMM estimator uses a weighting matrix taking into account temporal dependence, heteroskedasticity or autocorrelation.

3.1 Application of GMM estimation in the simultaneous equations model

Consider the following linear simultaneous equations model:

$$
\begin{aligned}
y_{1t} &= \delta_{12}y_{2t} + \delta_{13}y_{3t} + \cdots + \delta_{1J}y_{Jt} + \mathbf{x}_{1t}\gamma_1 + \varepsilon_{1t} \\
y_{2t} &= \delta_{21}y_{1t} + \delta_{23}y_{3t} + \cdots + \delta_{2J}y_{Jt} + \mathbf{x}_{2t}\gamma_2 + \varepsilon_{2t} \\
&\vdots \\
y_{Jt} &= \delta_{J1}y_{1t} + \delta_{J2}y_{2t} + \cdots + \delta_{J(J-1)}y_{(J-1)t} + \mathbf{x}_{Jt}\gamma_J + \varepsilon_{Jt}
\end{aligned} \tag{1}
$$

Here $t = 1, 2, \ldots, T$. Define that $\mathbf{y}_t = [\, y_{1t} \quad y_{2t} \quad \cdots \quad y_{Jt} \,]'$ is an $J \times 1$ vector for endogenous variables, $\mathbf{x}_t = [\, \mathbf{x}_{1t} \quad \mathbf{x}_{2t} \quad \cdots \quad \mathbf{x}_{Jt} \,]$ is a vector for all exogenous variables in this system includes constant term. $\boldsymbol{\varepsilon}_t = [\, \varepsilon_{1t} \quad \varepsilon_{2t} \quad \cdots \quad \varepsilon_{Jt} \,]'$ is an $J \times 1$ vector for the disturbances. Here, $\boldsymbol{\delta}$ and $\boldsymbol{\gamma}$ are the parameters matrices of interest defined as

$$
\boldsymbol{\delta} = \begin{bmatrix} \delta_{12} & \delta_{13} & \cdots & \delta_{1J} \\ \delta_{21} & \delta_{23} & \cdots & \delta_{2J} \\ \vdots & \vdots & \vdots & \vdots \\ \delta_{J1} & \delta_{J2} & \cdots & \delta_{J(J-1)} \end{bmatrix} = \begin{bmatrix} \boldsymbol{\delta}_1 \\ \boldsymbol{\delta}_2 \\ \vdots \\ \boldsymbol{\delta}_J \end{bmatrix} \quad \text{and} \quad \gamma = \begin{bmatrix} \gamma_1 \\ \gamma_2 \\ \vdots \\ \gamma_J \end{bmatrix} \tag{2}
$$

There are two approaches to estimate the structural parameters $\boldsymbol{\delta}$ and $\boldsymbol{\gamma}$ of the system, one is the single equation estimation and the other is the system estimation. First, we introduce the single equation estimation shown below. We can rewrite the jth equation in our simultaneous equations model in terms of the full set of T observations:

$$
\mathbf{y}_j = \mathbf{Y}_j\boldsymbol{\delta}_j + \mathbf{X}_j\boldsymbol{\gamma}_j + \boldsymbol{\varepsilon}_j = \mathbf{Z}_j\boldsymbol{\beta}_j + \boldsymbol{\varepsilon}_j, \quad j = 1, 2, \ldots, J \tag{3}
$$

where $\mathbf{y}_j$ denotes the $T \times 1$ vector of observations for the endogenous variables on left-hand side of jth equation. $\mathbf{Y}_j$ denotes the $T \times (J-1)$ data matrix for the endogenous variables on right-hand side of this equation. $\mathbf{X}_j$ is a data matrix for all exogenous variables in this equation. Since these jointly determined variables $\mathbf{y}_j$ and $\mathbf{Y}_j$ are determined within the system, they are correlated with the disturbance terms. This correlation usually creates estimation difficulties because the OLS estimator would be biased and inconsistent (e.g., Johnston and DiNardo 1997; Greene 2011).

As discussed above, the application of OLS estimation to Eq. (3) yields biased and inconsistent estimates because of the correlation of $\mathbf{Z}_j$ and $\boldsymbol{\varepsilon}_j$. The 2SLS approach is the most common method used to deal with this endogeneity problem resulting from the correlation of $\mathbf{Z}_j$ and $\boldsymbol{\varepsilon}_j$. The 2SLS estimation uses all the exogenous variables in this system as instruments to obtain the predictions of $\mathbf{Y}_j$. In the first stage, we regress $\mathbf{Y}_j$ on all exogenous variables in the system to receive the predictions of the endogenous variables on right-hand side of this equation, $\widehat{\mathbf{Y}}_j$. In the second stage, we regress $\mathbf{y}_j$ on $\widehat{\mathbf{Y}}_j$ and $\mathbf{X}_j$ to obtain the estimator of $\boldsymbol{\beta}_j$ in Eq. (3). Thus, the 2SLS estimator for $\boldsymbol{\beta}_j$ in Eq. (3) is,

$$
\widehat{\boldsymbol{\beta}}_{j,2SLS} = \left[\left(\mathbf{Z}_j'\mathbf{X}\right)(\mathbf{X}'\mathbf{X})^{-1}\mathbf{X}'\mathbf{Z}_j \right]^{-1} \left(\mathbf{Z}_j'\mathbf{X}\right)(\mathbf{X}'\mathbf{X})^{-1} \tag{4}
$$

where $\mathbf{X} = [\, \mathbf{X}_1 \quad \mathbf{X}_2 \quad \cdots \quad \mathbf{X}_J \,]$ is a matrix for all exogenous variables in this system.

The GMM estimation provides an alternative approach to deal with this simultaneity bias problem. As for the GMM estimator with instruments $\mathbf{X}$, the moment conditions in the Eq. (3) is,

$$
\mathrm{E}_t\left(\mathbf{x}_t'\varepsilon_{jt}\right) = \mathrm{E}_t\left[\mathbf{x}_t'\left(y_{jt} - \mathbf{Z}_{jt}\boldsymbol{\beta}_j\right)\right] = 0 \tag{5}
$$

We can apply the 2SLS estimator in Eq. (4) with instruments $\mathbf{X}$ to estimate $\boldsymbol{\beta}_j$ and obtain the sample residuals $\hat{\boldsymbol{\varepsilon}}_j = \mathbf{y}_j - Z_j \widehat{\boldsymbol{\beta}}_{j,2SLS}$. Then, compute the weighting matrix $\mathbf{W}_j$ for GMM estimator based on those residuals as follows:

$$\mathbf{W}_j = \left[\frac{1}{\mathrm{T}^2} \left(\sum_{t=1}^{\mathrm{T}} \mathbf{x}_t' \hat{\varepsilon}_{jt} \hat{\varepsilon}_{jt} \mathbf{x}_t \right) \right] \tag{6}$$

The GMM estimator based on the moment conditions (5) minimizes the following quadratic function:

$$\left[\sum_{t=1}^{\mathrm{T}} \mathbf{x}_t' \left(\mathrm{y}_{jt} - \mathbf{Z}_{jt} \boldsymbol{\beta}_j \right) \right] \mathbf{W}_j^{-1} \left[\sum_{t=1}^{\mathrm{T}} \mathbf{x}_t' \left(\mathrm{y}_{jt} - \mathbf{Z}_{jt} \boldsymbol{\beta}_j \right) \right] \tag{7}$$

The GMM estimator that minimizes this quadratic function (7) is obtained as

$$\hat{\boldsymbol{\beta}}_{GMM} = \left[\left(\mathbf{Z}_j' \mathbf{X} \right) \widehat{\mathbf{W}}_j^{-1} (\mathbf{X}' \mathbf{Z}_j) \right]^{-1} \left[\left(\mathbf{Z}_j' \mathbf{X} \right) \widehat{\mathbf{W}}_j^{-1} (\mathbf{X}' \mathbf{y}_j) \right] \tag{8}$$

In the homoscedastic and serially independent case, a good estimate of the weighting matrix $\widehat{\mathbf{W}}_j$ would be

$$\widehat{\mathbf{W}} = \left[\frac{\hat{\sigma}^2}{\mathrm{T}} (\mathbf{X}' \mathbf{X}) \right] \tag{9}$$

Given the estimate of $\hat{\sigma}^2$ is obtained, then rearrange terms in Eq. (8), which yields

$$\hat{\boldsymbol{\beta}}_{GMM} = \left[\left(\mathbf{Z}_j' \mathbf{X} \right) (\mathbf{X}' \mathbf{X})^{-1} (\mathbf{X}' \mathbf{Z}_j) \right]^{-1} \left(\mathbf{Z}_j' \mathbf{X} \right) (\mathbf{X}' \mathbf{X})^{-1} (\mathbf{X}' \mathbf{y}_j) \tag{10}$$

Thus the 2SLS estimator is a special case of GMM estimator.

As Chen and Lee (2010) pointed out, the 2SLS estimation is a limited information method. The 3SLS estimation is a full information method. The 3SLS estimation takes into account the information from a full system of equations. Thus, it is more efficient than the 2SLS estimation. The 3SLS method estimates all structural parameters of this system jointly. This allows the possibility of contemporaneous correlation between the disturbances in different structural equations. We introduce the 3SLS estimation below. We rewrite our full system of equations in Eq. (3) as

$$\mathbf{Y} = \mathbf{Z} \boldsymbol{\beta} + \boldsymbol{\varepsilon} \tag{11}$$

where $\mathbf{Y}$ is a vector defined as $[\mathbf{y}_1 \quad \mathbf{y}_2 \quad \cdots \quad \mathbf{y}_J]'$. $\mathbf{Z} = \mathrm{diag}[\mathbf{Z}_1 \quad \mathbf{Z}_2 \quad \cdots \quad \mathbf{Z}_J]$ is a block diagonal data matrix for all variables on right-hand side of this system with the form $\mathbf{Z}_j = [\mathbf{Y}_j \quad \mathbf{X}_j]$ as defined in Eq. (3). $\boldsymbol{\beta}$ is a vector of interest parameters defined as $[\boldsymbol{\beta}_1 \quad \boldsymbol{\beta}_2 \quad \cdots \quad \boldsymbol{\beta}_J]'$. $\boldsymbol{\varepsilon}$ is a vector of disturbances defined as $[\boldsymbol{\varepsilon}_1 \quad \boldsymbol{\varepsilon}_2 \quad \cdots \quad \boldsymbol{\varepsilon}_J]'$ with $\mathrm{E}(\boldsymbol{\varepsilon}) = \mathbf{0}$ and $\mathrm{E}(\boldsymbol{\varepsilon}\boldsymbol{\varepsilon}') = \Sigma \otimes \mathbf{I}_T$ where $\otimes$ signifies the Kroneker product. Here, $\boldsymbol{\Sigma}$ is defined as

$$\sum = \begin{bmatrix} \sigma_{11} & \sigma_{12} & \cdots & \sigma_{1J} \\ \sigma_{21} & \sigma_{22} & \cdots & \sigma_{2J} \\ \vdots & \vdots & \ddots & \vdots \\ \sigma_{J1} & \sigma_{J2} & \cdots & \sigma_{JJ} \end{bmatrix} \tag{12}$$

The 3SLS approach is the most common method used to estimate the structural parameters of this system simultaneously. Basically, the 3SLS estimator is a generalized least square (GLS) estimator in the entire system taking account of the covariance matrix in Eq. (12). The 3SLS estimator is equivalent to using the all exogenous variables as instruments and estimating the entire system using GLS estimation (Intriligator et al. 1996). The 3SLS estimation uses all exogenous variables $\mathbf{X} = [\mathbf{X}_1 \quad \mathbf{X}_2 \quad \cdots \quad \mathbf{X}_J]$ as instruments in each equation of this system, pre-multiplying the model (11) by $\mathbf{X}_I' = \mathrm{diag}[\mathbf{X}' \quad \cdots \quad \mathbf{X}'] = \mathbf{X} \otimes \mathrm{I}_J$ yields the model

$$\mathbf{X}_I'\mathbf{Y} = \mathbf{X}_I'\mathbf{Z}\boldsymbol{\beta} + \mathbf{X}_I'\boldsymbol{\varepsilon} \tag{13}$$

The covariance matrix from (12) is

$$\mathrm{Cov}\left(\mathbf{X}_I'\boldsymbol{\varepsilon}\right) = \mathbf{X}_I'\mathrm{Cov}(\boldsymbol{\varepsilon})\mathbf{X}_I = \mathbf{X}_I'(\Sigma \otimes \mathrm{I}_T)\mathbf{X}_I \tag{14}$$

The GLS estimator of the Eq. (13) is the 3SLS estimator. Thus the 3SLS estimator is given as follows:

$$\hat{\boldsymbol{\beta}}_{3SLS} = \left\{\mathbf{Z}'\mathbf{X}_I\left[\mathbf{X}_I'(\Sigma \otimes \mathrm{I}_T)\mathbf{X}_I\right]^{-1}\mathbf{X}_I'\mathbf{Z}\right\}^{-1}\mathbf{Z}'\mathbf{X}_I\left[\mathbf{X}_I'(\Sigma \otimes \mathrm{I}_T)\mathbf{X}_I\right]^{-1}\mathbf{X}_I'\mathbf{Y} \tag{15}$$

In this case, $\boldsymbol{\Sigma}$ is a diagonal matrix, the 3SLS estimator is equivalent to the 2SLS estimator. As discussed above, the GMM estimator with all exogenous variables $\mathbf{X} = [\mathbf{X}_1 \quad \mathbf{X}_2 \quad \cdots \quad \mathbf{X}_J]$ as instruments, the moment conditions of this system (11) is,

$$\begin{aligned} \mathrm{E}\left(\mathbf{X}_I'\boldsymbol{\varepsilon}\right) &= \mathrm{E}\left[\mathbf{X}_I'(\mathbf{Y} - \mathbf{Z}\boldsymbol{\beta})\right] \\ &= \left(\mathrm{E}\left[\mathbf{X}_I'(\mathbf{y}_1 - \mathbf{Z}_1\boldsymbol{\beta}_1)\right]\mathrm{E}\left[\mathbf{X}_I'(\mathbf{y}_2 - \mathbf{Z}_2\boldsymbol{\beta}_2)\right]\cdots\mathrm{E}\left[\mathbf{X}_I'(\mathbf{y}_J - \mathbf{Z}_J\boldsymbol{\beta}_J)\right]\right)' = \mathbf{0} \end{aligned} \tag{16}$$

We can apply the 2SLS estimator with instruments $\mathbf{X}$ to estimate $\boldsymbol{\beta}_j$ and obtain the sample residuals $\hat{\boldsymbol{\varepsilon}}_j = \mathbf{y}_j - \mathbf{Z}_j\hat{\boldsymbol{\beta}}_{j,2SLS}$. Then, compute the weighting matrix $\widehat{\mathbf{W}}_{jl}$ for GMM estimator based on those residuals as follows:

$$\widehat{\mathbf{W}}_{jl} = \left[\frac{1}{\mathrm{T}^2}\left(\sum_{t=1}^{\mathrm{T}}\mathbf{x}_t'\hat{\varepsilon}_{jt}\hat{\varepsilon}_{lt}\mathbf{x}_t\right)\right] \tag{17}$$

The system GMM estimator based on the moment conditions (16) minimizes the quadratic function:

$$\begin{bmatrix} \mathbf{X}'(\mathbf{y}_1 - \mathbf{Z}_1\boldsymbol{\beta}_1) \\ \mathbf{X}'(\mathbf{y}_2 - \mathbf{Z}_2\boldsymbol{\beta}_2) \\ \vdots \\ \mathbf{X}'(\mathbf{y}_J - \mathbf{Z}_J\boldsymbol{\beta}_J) \end{bmatrix}' \begin{bmatrix} \widehat{\mathbf{W}}_{11} & \widehat{\mathbf{W}}_{12} & \cdots & \widehat{\mathbf{W}}_{1J} \\ \widehat{\mathbf{W}}_{21} & \widehat{\mathbf{W}}_{22} & \cdots & \widehat{\mathbf{W}}_{2J} \\ \vdots & \vdots & \ddots & \vdots \\ \widehat{\mathbf{W}}_{J1} & \widehat{\mathbf{W}}_{J2} & \cdots & \widehat{\mathbf{W}}_{JJ} \end{bmatrix}^{-1} \begin{bmatrix} \mathbf{X}'(\mathbf{y}_1 - \mathbf{Z}_1\boldsymbol{\beta}_1) \\ \mathbf{X}'(\mathbf{y}_2 - \mathbf{Z}_2\boldsymbol{\beta}_2) \\ \vdots \\ \mathbf{X}'(\mathbf{y}_J - \mathbf{Z}_J\boldsymbol{\beta}_J) \end{bmatrix} \tag{18}$$

The GMM estimator that minimizes this quadratic function (18) is obtained as

$$\begin{bmatrix} \hat{\boldsymbol{\beta}}_{1,GMM} \\ \hat{\boldsymbol{\beta}}_{2,GMM} \\ \vdots \\ \hat{\boldsymbol{\beta}}_{J,GMM} \end{bmatrix} = \begin{bmatrix} \mathbf{Z}_1'\mathbf{X}\widehat{\mathbf{W}}_{11}^{-1}\mathbf{X}'\mathbf{Z}_1 & \cdots & \mathbf{Z}_1'\mathbf{X}\widehat{\mathbf{W}}_{1J}^{-1}\mathbf{X}'\mathbf{Z}_J \\ \mathbf{Z}_2'\mathbf{X}\widehat{\mathbf{W}}_{21}^{-1}\mathbf{X}'\mathbf{Z}_1 & \cdots & \mathbf{Z}_2'\mathbf{X}\widehat{\mathbf{W}}_{2J}^{-1}\mathbf{X}'\mathbf{Z}_J \\ \vdots & \ddots & \vdots \\ \mathbf{Z}_J'\mathbf{X}\widehat{\mathbf{W}}_{J1}^{-1}\mathbf{X}'\mathbf{Z}_1 & \cdots & \mathbf{Z}_J'\mathbf{X}\widehat{\mathbf{W}}_{JJ}^{-1}\mathbf{X}'\mathbf{Z}_J \end{bmatrix}^{-1} \begin{bmatrix} \sum_{l=1}^{J} \mathbf{Z}_1'\mathbf{X}\widehat{\mathbf{W}}_{1l}^{-1}\mathbf{X}'\mathbf{y}_l \\ \sum_{l=1}^{J} \mathbf{Z}_2'\mathbf{X}\widehat{\mathbf{W}}_{2l}^{-1}\mathbf{X}'\mathbf{y}_l \\ \vdots \\ \sum_{l=1}^{J} \mathbf{Z}_J'\mathbf{X}\widehat{\mathbf{W}}_{Jl}^{-1}\mathbf{X}'\mathbf{y}_l \end{bmatrix} \tag{19}$$

The 2SLS and 3SLS estimators are the special cases of system GMM estimator. If $\widehat{\mathbf{W}}_{jj} = \left[\frac{\hat{\sigma}_{jj}}{\mathrm{T}}\left(\sum_{t=1}^{\mathrm{T}} \mathbf{x}_t'\mathbf{x}_t\right)\right]$ and $\widehat{\mathbf{W}}_{jl} = 0$ for $j \neq l$, then the system GMM estimator is equivalent to the 2SLS estimator. In the case that $\widehat{\mathbf{W}}_{jl} = \left[\frac{\hat{\sigma}_{jl}}{\mathrm{T}}\left(\sum_{t=1}^{\mathrm{T}} \mathbf{x}_t'\mathbf{x}_t\right)\right]$, the system GMM estimator is equivalent to the 3SLS estimator.

3.2 Weak instruments and heteroskedasticity

As mentioned above, we introduce three alternative approaches, 2SLS, 3SLS and GMM estimations to estimate a simultaneous equations system. Regardless of whether 2SLS, 3SLS or GMM estimation is used to estimate in the second-stage, the first-stage regression instrumenting for endogenous regressors is estimated via OLS. The choice of instruments is critical to the consistent estimation of the IV methods. Previous works have demonstrated that if the instruments are weak, the IV estimator will not possess its ideal properties and will be misleading (e.g., Bound et al. 1995; Staiger and Stock1997; Stock and Yogo 2005).

A simple way to detect the presence of weak instruments is to look at the R^2 or F-statistic of first-stage regression testing the hypothesis that the coefficients on the instruments are jointly equal to zero (Wang 2015). Institutively, the first-stage F-statistic must be large, typically exceeding 10, for inference of 2SLS estimation to be reliable (Staiger and Stock 1997; Stock et al. 2002). In addition, Hahn and Hausman(2005) show that the relative bias of 2SLS estimation declines as the strength of the correlation between the instruments and the endogenous regressor increases, but grows with the number of instruments. Stock and Yogo (2005) tabulate critical values for the first-stage F-statistic to test whether instruments are weak. They report, for instance, that when there is one endogenous regressor, the first-stage F-statistic of the 2SLS regression should have a value higher than 9.08 with three instruments and 10.83 with five instruments.

As we have emphasized before, GMM estimation produces more efficient estimator than 2SLS or 3SLS estimation in the presence of heteroskedasticity. In the absence of heteroskedasticity, the GMM estimator is asymptotically equivalent to the 2SLS or 3SLS estimator. The problem, as Hayashi (2000) points out, is that the optimal weighting matrix at the core of GMM estimation is a function of fourth moments, and in need of very large sample sizes to obtain reasonable estimates of fourth moments. The consequence is that if the error term is homoskedastic, 2SLS or 3SLS estimator would be preferable to GMM estimator in a small sample. For this reason, a test for the presence of heteroskedasticity may be useful in deciding whether 2SLS, 3SLS or GMM estimator is adopted in the empirical study. However, Pagan and Hall (1983) and Pesaran and Taylor (1999) demonstrate that the traditional tests for heteroskedasticity such as Breusch–Pagan or Cook–Weisberg tests are not suitable in the context of IVs estimation. Pagan and Hall (1983) discuss a number of tests to examine the presence of heteroskedasticity and compute an auxiliary regression of squared IV estimation residuals on a constant as well as the levels, squares, and cross products of instruments. They also provide an alternative to use the first-stage prediction of endogenous regressors in a test for heteroskedasticity. It is worth noting that the first-stage prediction of endogenous variables rather than the IV estimation fitted values are used here to avoid the simultaneity problem (Pesaran and Taylor 1999). A test of null hypothesis of homoscedasticity can be carried out by testing the significance of all parameters (excluding the constant) in the auxiliary regression. A standard F-statistic and centered R^2 from an auxiliary regression can be used for this purpose.

To sum, the choice of instruments is critical to the consistent estimation of the IV methods. As the weakness of instruments in explaining the endogenous regressor can be measured by F-statistic from first-stage regression and compared to critical value in Stock and Yogo (2005). In addition, the traditional IV models such as 2SLS and 3SLS overcome the endogeneity problem by instrumenting for variables that are endogenous. The main difference of GMM estimation from 2SLS and 3SLS estimations is the use of the efficient weighting matrix that accounts for possible heteroskedasticity. To discriminate either traditional IV or GMM estimation, the Pagan and Hall (1983)'s test for heteroskedasticity is recommended for the empirical application. As the null hypothesis of homoscedasticity is rejected, the GMM estimation is preferred. If the error term is homoskedastic and the sample size is small, the traditional IV estimation will be preferable to GMM estimation for inference.

4 Applications in investment, financing and dividend policy

4.1 Model and data

The investment, dividend, and debt financing are major decisions of a firm. Past studies argue some relations among investment, dividend and debt financing.[5] To control for the possible endogenous problems among these three decisions, we apply 2SLS, 3SLS, and GMM methods to estimate the simultaneous-equations model that consider the interaction of the three policies.

There are three equations in our simultaneous-equations system; each equation contains the remaining two endogenous variables as explanatory variables along with other exogenous variables. The three endogenous variables are investment (Inv_{it}), dividend (Div_{it}), and book leverage ($Leverage_{it}$) of firm i in year t. *Inv* denotes net property, plant, and equipment. *Div* denotes dividends. Following Fama (1974), both *Inv* and *Div* are measured on a per share basis. We follow Fama and French (2002) to use book leverage, *Leverage*, as the proxy for leverage. *Leverage* is defined as the ratio of total liabilities to total assets.

We also use the following exogenous variables in the model. In addition to lag-terms of the tree policies, we follow Fama (1974) to respectively incorporate sales plus change in inventories (Q_{it}) and net income minus preferred dividends (P_{it}) into investment and dividend decisions. Moreover, we follow Fama and French (2002) to add natural logarithm of lagged total assets ($ln\ A_{i,t-1}$) and the lag of earnings before interest and taxes divided by total assets ($E_{i,t-1}/A_{i,t-1}$) as the determinants of leverage. Finally, Leary and Roberts (2014) argue that the characteristic of peer firms is important to influence firms' capital structure and thus we also follow them to consider lagged industry averages book leverage ($Industry_{i,t-1}$) into our leverage decision.

The structural equations are estimated as follows:

[5] Higgins (1972), Fama (1974), Morgan and Saint-Pierre (1978), Smirlock and Marshall (1983), Lee et al. (2011), and Chen et al. (2013) investigate the relationship between investment decision and dividend decision. Fama and French (2002) and Aivazian et al. (2006) consider the interaction between dividend and financing decisions. Dhrymes and Kurz (1967), McDonald et al. (1975), McCabe (1979), Peterson and Benesh (1983), Switzer (1984), and Pruitt and Gitman (1991) argue that the investment decision is related to financing decision and dividend decision. Chava and Roberts (2008) show how financing impacts corporate investment via debt covenants. Lambrecht and Myers (2012) develop a combined theory of payout, debt, and investment.

$$Inv_{it} = \alpha_{1i} + \alpha_{2i}Div_{it} + \alpha_{3i}Leverage_{it} + \alpha_{4i}Inv_{i,t-1} + \alpha_{5i}Q_{it} + \epsilon_{it}, \tag{20}$$

$$Div_{it} = \beta_{1i} + \beta_{2i}Inv_{it} + \beta_{3i}Leverage_{it} + \beta_{4i}Div_{i,t-1} + \beta_{5i}P_{it} + \eta_{it}, \tag{21}$$

$$\begin{aligned} Leverage_{it} = \gamma_{1i} + \gamma_{2i}Inv_{it} + \gamma_{3i}Div_{it} + \gamma_{4i}Leverage_{i,t-1} + \gamma_{5i}\ln A_{i,t-1} \\ + \gamma_{6i}\left(E_{i,t-1}/A_{i,t-1}\right) + \gamma_{7i}Industry_{i,t-1} + \xi_{it}. \end{aligned} \tag{22}$$

Our sample consists of all dividend-paying US firms listed on NYSE, AMEX, OTC, and NASDAQ stock markets from 1965 to 2012. All of our accounting variables are annual and collected from Compustat Annual Industrial Files. Following previous research (e.g., Fama and French 2002; Huang and Ritter 2009; Cook and Tang 2010), we exclude financial firms (SIC 6000–6999) and regulated utilities (SIC 4900–4999) from the sample. We also require firms to have positive total assets and a number of common shares outstanding.[6] To increase the testing power in the regression analysis, we also require firms to survive 30 years or longer.[7] Specifically, we collect firms which pay dividends at least 30 years as our sample during the sample period, and set dividend equal to zero for other years without dividend payment during the sample period.[8] These exclusions leave us with complete information for 563 firms.

Table 2 presents summary statistics on the investment, dividend, and debt financing for different time periods. All of these variables are winsorized at the 1st and 99th percentiles to avoid the influence of extreme observations. Compared with different time periods, the investment during the 1980s is the highest. This result may be from the simulating policies (e.g., the reduction of capital gain tax and the reduction of interest rate), which was promoted by US President Ronald Reagan during the 1980s. Dividend payout is more likely to be reduced after the 1990s. Such finding is consistent with Fama and French (2001), Grullon and Michaely (2002), and Brav et al. (2005), indicating that repurchase is more prevalent to adopt than dividend payout in the recent decades. The average book leverage is 0.499 for all time periods and the book leverage tends to be higher in later years than in earlier years. Usually, these firms which survive more have greater tangible assets as the collateral for loan and thereby they are more likely to obtain the debt financing. Thus, the increases in leverage over time may reflect the situation of longer survival. In addition, the standard deviations of leverage among different time periods are quite similar. This finding shows the leverage is stable and is consistent with many capital structure studies (e.g., DeAngelo and Roll 2015).

4.2 Results of weak instruments and heteroskedasticity

We perform the first-stage F-statistic to test whether instruments are weak and Pagan and Hall (1983)'s test is used to examine the presence of heteroskedasticity.

Table 3 shows the results of testing the relevance of instruments and heteroskedasticity. We regress each endogenous variable on all exogenous variables in the system to receive the prediction of endogenous variable and obtain as well as F-statistics for each firm. The values of R^2 for investment, dividend, and book leverage are 0.8944, 0.8443 and 0.8056

[6] These variables are used to deflate other variables and the results become difficult to interpret when they have non-positive values.

[7] In addition to the case with firm surviving 30 years or longer, we also estimate the simultaneous equations system for the firms with different survive years (10 and 20 years). All these results are quantitatively similar and available upon request.

[8] We do not restrict our sample firms to pay dividends continuously for 30 years because this criterion may decrease the representativeness of real situation.

Table 2 Summary statistics

	N	Inv					Div				
		Mean	Median	Q1	Q3	SD	Mean	Median	Q1	Q3	SD
1965–1969	1651	15.739	9.784	4.786	19.213	17.506	1.017	0.895	0.427	1.394	0.797
1970–1979	5193	17.346	10.572	5.315	21.310	19.406	0.895	0.731	0.359	1.200	0.775
1980–1989	5576	19.775	11.867	6.240	26.133	20.369	1.038	0.800	0.425	1.403	0.857
1990–1999	5475	15.982	9.859	5.151	19.667	17.485	0.824	0.628	0.363	1.068	0.701
2000–2012	5605	13.648	7.519	4.051	15.864	17.046	0.709	0.565	0.241	0.968	0.678
1965–2012	23,500	16.610	9.842	5.038	20.425	18.666	0.877	0.680	0.356	1.177	0.769

	N	*Leverage*				
		Mean	Median	Q1	Q3	SD
1965–1969	1651	0.415	0.416	0.305	0.521	0.149
1970–1979	5193	0.446	0.456	0.341	0.550	0.149
1980–1989	5576	0.479	0.489	0.375	0.580	0.152
1990–1999	5475	0.535	0.549	0.424	0.653	0.171
2000–2012	5605	0.559	0.564	0.439	0.672	0.185
1965–2012	23,500	0.499	0.505	0.383	0.611	0.171

This table presents the summary statistics where we show the mean, median, first quartile, third quartile, and the standard deviation of each variable from 1965 to 2012. Only firms that survive 30 years or longer are included in the sample. These exclusions leave us with complete information for 563 firms. *N* is the number of firm-year observations. The sample consists of 23,500 firm-year observations from annual Compustat files, excluding financial and regulated firms. *Inv* denotes net property, plant, and equipment, *Div* denotes dividends. Both *Inv* and *Div* are measured on a per share basis. *Leverage* refers to book leverage, defined as the ratio of total liabilities to total assets. All variables are winsorized at the 1st and 99th percentiles to avoid the influence of extreme observations

Table 3 Results of testing the relevance of instruments and heteroskedasticity

Instruments	*Inv*	*Div*	*Leverage*
Average (R^2)	0.8944	0.8443	0.8056
Average (F-statistic)	73.76	52.05	32.44
Ratio of F-statistic >10	0.94 (531/563)	0.85 (479/563)	0.76 (430/563)
Ratio of rejecting PB-test	0.1314 (74/563)	0.2895 (163/563)	0.0764 (43/563)

We regress each endogenous variable on all exogenous variables in the system to receive the prediction of endogenous variable and obtain R^2 as well as F-statistics for each firm. The null hypothesis of F test is that the instruments are jointly equal to zero. The three endogenous variables are Inv_{it}, Div_{it}, and $Leverage_{it}$, which are net plant and equipment, dividends, and book leverage ratio, respectively. The value is shown in averages across the 563 firms. Ratio of rejecting PB-test reports the ratio of rejecting Pagan–Hall test's null hypothesis of no heteroskedasticity based on a 5 % significant level for the investment, dividend and financing decisions, respectively

respectively that show the strength of instrument. Likewise, the ratios of F-statistics over 10 for three endogenous variables again indicate that instruments are sufficiently strong. In addition, the ratios of rejecting Pagan–Hall test's null hypothesis of no heteroskedasticity for the investment, dividend and financing decision equations are only 0.1314, 0.2895 and 0.0764, respectively. In our case, error is homoskedastic from the results of Pagan and Hall (1983)'s test and the sample size is small for each firm, so the traditional IV estimation is preferable to GMM estimation for the empirical application.

4.3 Empirical results

Table 4 shows 2SLS regression results for simultaneous-equations model. Averages of individual firms' coefficient estimates of the investment, dividend, and debt financing regressions are presented. The results of relations among these three financial decisions could be directly obtained in this method. First, the positive coefficient of $Leverage_{it}$ (which is marginally significant in investment decision), and Inv_{it} (in debt financing decision) imply that firms with higher investment have higher debt financing and vice versa. Ross (1977) and Myers and Majluf (1984) suggest that debt is preferred to equity for managers to signal the optimistic investment opportunity to investors because firms are expected to have higher future cash flows to repay the debt. Harris and Raviv (1990) argue that debt is a device to solve the asymmetric information for the investors because it helps to monitor managers and force the firm to liquidation. In addition, our finding that increases in debt financing enhance the funds available to outlays for investment is consistent with McDonald et al. (1975), McCabe (1979), Peterson and Benesh (1983), John and Nachman (1985), and Froot et al. (1993). Thus, our optimal debt ratio may be the result of a trade-off between the value of information (from more debt) and the cost of monitor.

Second, the significant coefficients of Div_{it} and Inv_{it} imply that dividend outlays influence investment decisions and vice versa. This finding implies that the firms may use dividend payout to signal the growth opportunity and then these firms increase their investment. The firm with higher investment input may experience the higher earnings and thus could increase the dividend payout. Such finding, that dividend payout responds to investment, confirms the model prediction of Lambrecht and Myers (2012). The relationship between dividend payout and investment is also consistent with the signaling cash flow hypothesis of dividend payout in Yoon and Starks (1995).

Table 4 Results of 2SLS

Independent variables	Dependent variables					
	Inv_{it}		Div_{it}		$Leverage_{it}$	
Constant	−0.433 (−0.62)		0.233 (7.06)		0.100 (7.82)	
$Inv_{i,t-1}$	0.417 (42.37)	[+]				
$Div_{i,t-1}$			0.490 (40.40)	[+]		
$Leverage_{i,t-1}$					0.581 (54.07)	[+]
Inv_{it}			0.015 (6.41)	[?]	0.003 (4.56)	[+]
Div_{it}	1.271 (2.99)	[?]			0.017 (1.44)	[?]
$Leverage_{it}$	1.854 (1.59)	[+]	−0.411 (−6.06)	[?]		
Q_{it}	0.179 (16.65)	[+]				
P_{it}			0.066 (16.05)	[+]		
$ln\ A_{i,t-1}$					0.012 (6.29)	[+]
$E_{i,t-1}/A_{i,t-1}$					−0.049 (−2.54)	[−]
$Industry_{i,t-1}$					0.010 (0.92)	[+]

Table 4 continued

Independent variables	Dependent variables		
	Inv_{it}	Div_{it}	$Leverage_{it}$
Adjusted R^2	0.82	0.73	0.71

This table presents the 2SLS regression results of a simultaneous equation system model for investment, dividend, and debt financing:

$Inv_{it} = \alpha_{1i} + \alpha_{2i}Div_{it} + \alpha_{3i}Leverage_{it} + \alpha_{4i}Inv_{i,t-1} + \alpha_{5i}Q_{it} + \epsilon_{it}$, $Div_{it} = \beta_{1i} + \beta_{2i}Inv_{it} + \beta_{3i}Leverage_{it} + \beta_{4i}Div_{i,t-1} + \beta_{5i}P_{it} + \eta_{it}$, $Leverage_{it} = \gamma_{1i} + \gamma_{2i}Inv_{it} + \gamma_{3i}Div_{it} + \gamma_{4i} Leverage_{i,t-1} + \gamma_{5i}ln\,A_{i,t-1} + \gamma_{6i}(E_{i,t-1}/A_{i,t-1}) + \gamma_{7i}Industry_{i,t-1} + \xi_{it}$.

The coefficients are shown in averages across the 563 firms. Regressions are based on non-missing observations and winsorization at the 1st and 99th percentiles. The three endogenous variables are Inv_{it}, Div_{it}, and $Leverage_{it}$, which are net plant and equipment, dividends, and book leverage ratio, respectively. The independent variables in the investment regression are lagged investment ($Inv_{i,t-1}$), and sales plus change in inventories (Q_{it}). The independent variables in the dividend regression are lagged dividends ($Div_{i,t-1}$), and net income minus preferred dividends (P_{it}). All the variables in both of investment and dividend equations are measured on a per share basis. The independent variables in the debt financing regression are lagged book ($Leverage_{i,t-1}$), natural logarithm of lagged total assets ($ln\ A_{i,t-1}$), the lag of earnings before interest and taxes divided by total assets ($E_{i,t-1}/A_{i,t-1}$), and lagged industry averages book leverage ($Industry_{i,t-1}$). Numbers in the parentheses are t-statistics. The sign in bracket is the expected sign of each variable of regressions

Table 5 Interrelationship among investment, dividend, and debt financing found in the literature

Independent variables	Dependent variables: Inv_{it}		Div_{it}		$Leverage_{it}$	
Inv_{it}			+	Lambrecht and Myers (JF 2012)	+	McDonald et al. (JFQA 1975) McCabe (JFQA 1979) Peterson and Benesh (JFQA 1983) Switzer (RES 1984)
			(−)	Higgins (JFQA 1972) McCabe (JFQA 1979) Peterson and Benesh (JFQA 1983) Switzer (RES 1984)	(−)	
Div_{it}	+	McDonald et al. (JFQA 1975) Yoon and Starks (RFS 1995)			(+)	McCabe (JFQA 1979) Peterson and Benesh (JFQA 1983)
	(−)	McCabe (JFQA M1979) Peterson and Benesh (JFQA 1983)			(−)	Switzer (RES 1984) Jensen et al. (JFQA 1992)
$Leverage_{it}$	+	McDonald et al. (JFQA 1975) McCabe (JFQA 1979) Peterson and Benesh (JFQA 1983) John and Nachman (JF 1985) Froot et al. (JF 1993)	(+)	McCabe (JFQA 1979) Peterson and Benesh (JFQA 1983) Switzer (RES 1984)		
	(−)		−	Jensen et al. (JFQA 1992) Fama and French (RFS 2002)		

The name of the journals and their abbreviations are as follows: The Journal of Finance (JF); Journal of Financial and Quantitative Analysis (JFQA); The Review of Economic Studies (RES); Review of Financial Studies (RFS). The signs without parentheses show the same signs as our empirical results

Third, the impact of debt financing on dividend is significantly negative, showing that firms pay more dividend when they have lower leverage level. The pecking order hypothesis of Myers and Majluf (1984) implies that firms with less leverage level have more internal funds and thus these firms tend to have capability to pay dividend. Thus, our finding seems to support the concept of Myers and Majluf (1984) and is also consistent with Jensen et al. (1992) and Fama and French (2002).

To briefly compare our findings with the existing studies, we also tabulate the interrelationship among investment, dividend, and debt financing found in the literature in Table 5. The positive and negative signs in Table 5 show the relationship among these three variables. The signs with shadow show the same signs as our empirical results. Table 5 also shows the controversial results of past findings about the interrelationship among these three decisions.

Table 6 Results of 3SLS

Independent variables	Dependent variables					
	Inv_{it}		Div_{it}		$Leverage_{it}$	
Constant	−0.601 (−0.73)		0.247 (6.42)		0.119 (9.34)	
$Inv_{i,t-1}$	0.420 (39.18)	[+]				
$Div_{i,t-1}$			0.474 (36.73)	[+]		
$Leverage_{i,t-1}$					0.561 (49.94)	[+]
Inv_{it}			0.016 (7.13)	[?]	0.003 (3.35)	[+]
Div_{it}	1.494 (3.10)	[?]			0.010 (0.93)	[?]
$Leverage_{it}$	2.500 (1.79)	[+]	−0.438 (−5.56)	[?]		
Q_{it}	0.170 (16.93)	[+]				
P_{it}			0.066 (17.40)	[+]		
$ln\ A_{i,t-1}$					0.011 (6.45)	[+]
$E_{i,t-1}/A_{i,t-1}$					−0.063 (−3.42)	[−]
$Industry_{i,t-1}$					0.003 (0.32)	[+]

Table 6 continued

Independent variables	Dependent variables		
	Inv_{it}	Div_{it}	$Leverage_{it}$
Adjusted R^2	0.86		

This table presents the 3SLS regression results of a simultaneous equation system model for investment, dividend, and debt financing:

$Inv_{it} = \alpha_{1i} + \alpha_{2i}Div_{it} + \alpha_{3i}Leverage_{it} + \alpha_{4i}Inv_{i,t-1} + \alpha_{5i}Q_{it} + \epsilon_{it}$, $Div_{it} = \beta_{1i} + \beta_{2i}Inv_{it} + \beta_{3i}Leverage_{it} + \beta_{4i}Div_{i,t-1} + \beta_{5i}P_{it} + \eta_{it}$, $Leverage_{it} = \gamma_{1i} + \gamma_{2i}Inv_{it} + \gamma_{3i}Div_{it} + \gamma_{4i} Leverage_{i,t-1} + \gamma_{5i}ln A_{i,t-1} + \gamma_{6i}(E_{i,t-1}/A_{i,t-1}) + \gamma_{7i}Industry_{i,t-1} + \xi_{it}$.

The coefficients are shown in averages across the 563 firms. Regressions are based on non-missing observations and winsorization at the 1st and 99th percentiles. The three endogenous variables are Inv_{it}, Div_{it}, and $Leverage_{it}$, which are net plant and equipment, dividends, and book leverage ratio, respectively. The other variables are the same as in Table 4. Numbers in the parentheses are t-statistics. The sign in bracket is the expected sign of each variable of regressions

Table 7 Results of GMM

Independent variables	Dependent variables					
	Inv_{it}		Div_{it}		$Leverage_{it}$	
Constant	−0.662 (−0.94)		0.235 (7.23)		0.108 (8.88)	
$Inv_{i,t-1}$	0.454 (43.51)	[+]				
$Div_{i,t-1}$			0.524 (42.00)	[+]		
$Leverage_{i,t-1}$					0.585 (54.07)	[+]
Inv_{it}			0.013 (6.42)	[?]	0.003 (4.31)	[+]
Div_{it}	1.412 (3.57)	[?]			0.011 (1.23)	[?]
$Leverage_{it}$	2.250 (1.92)	[+]	−0.417 (−5.89)	[?]		
Q_{it}	0.160 (15.54)	[+]				
P_{it}			0.065 (17.55)	[+]		
$ln\ A_{i,t-1}$					0.010 (6.10)	[+]
$E_{i,t-1}/A_{i,t-1}$					−0.057 (−3.03)	[−]
$Industry_{i,t-1}$					0.012 (1.09)	[+]

Table 7 continued

Independent variables	Dependent variables		
	Inv_{it}	Div_{it}	$Leverage_{it}$
Adjusted R^2	0.80	0.70	0.68

This table presents the GMM regression results of a simultaneous equation system model for investment, dividend, and debt financing:

$Inv_{it} = \alpha_{1i} + \alpha_{2i}Div_{it} + \alpha_{3i}Leverage_{it} + \alpha_{4i}Inv_{i,t-1} + \alpha_{5i}Q_{it} + \epsilon_{it}$, $Div_{it} = \beta_{1i} + \beta_{2i}Inv_{it} + \beta_{3i}Leverage_{it} + \beta_{4i}Div_{i,t-1} + \beta_{5i}P_{it} + \eta_{it}$, $Leverage_{it} = \gamma_{1i} + \gamma_{2i}Inv_{it} + \gamma_{3i}Div_{it} + \gamma_{4i}Leverage_{i,t-1} + \gamma_{5i}ln A_{i,t-1} + \gamma_{6i}(E_{i,t-1}/A_{i,t-1}) + \gamma_{7i}Industry_{i,t-1} + \xi_{it}$.

The coefficients are shown in averages across the 563 firms. Regressions are based on non-missing observations and winsorization at the 1st and 99th percentiles. The three endogenous variables are Inv_{it}, Div_{it}, and $Leverage_{it}$, which are net plant and equipment, dividends, and book leverage ratio, respectively. The other variables are the same as in Table 4. Numbers in the parentheses are t-statistics. The sign in bracket is the expected sign of each variable of regressions

The results of control variables are shown as follows. First, the impact of output, Q_{it}, on the investment is significantly positive, which is consistent with Fama (1974). Second, the coefficient of P_{it} in the dividend model is significantly positive, implying that firms with high net income tend to increase to pay dividends. Third, in the debt financing equation, the coefficient of $ln A_{i,t-1}$ is significantly positive, indicating that large firms leverage more than smaller firms. This finding results from large firms that tend to have a greater reputation and less information asymmetry than small firms and thus large firms can finance at a lower cost. The positive relation between size and leverage is consistent with Fama and French (2002), Flannery and Rangan (2006), and Frank and Goyal (2009). The coefficient of $(E_{i,t-1}/A_{i,t-1})$ of leverage model is significantly negative. This result implies that more profitable firms have higher internal funds from their earnings and thus have less incentive to obtain the outside funds by debt issuing. The negative relationship between profitability and leverage is consistent with the findings of Long and Malitz (1985), Rajan and Zingales (1995), Fama and French (2002), and Flannery and Rangan (2006).

Tables 6 and 7 shows results of 3SLS and GMM, respectively. Similarly, we present averages of an individual firm's coefficient estimates of the investment, dividend, and debt financing regressions. All the signs and significance of the estimated coefficients are consistent with the results of 2SLS. All the exogenous variables have a similar impact in the literature. Our empirical results also can be used to test the joint determination theory of investment, financing, and dividend decisions developed by Lambrecht and Myers (2012).

5 Conclusion

In this paper, we investigate the endogeneity problems related to simultaneous equations system, and introduce how 2SLS, 3SLS, and GMM estimation methods deal with endogeneity. We discuss these three methods and present Pagan and Hall's (1983) test of heteroskedasticity and weak instruments test for selecting the applicable method and testing the validity of instruments. In addition to reviewing applications of simultaneous equations on many finance issues, we also use US listed firms from 1965 to 2012 to examine the interrelationship among corporate investment, leverage, and dividend payout policies in a simultaneous-equation system by employing 2SLS, 3SLS, and GMM.

Our results from 2SLS, 3SLS, and GMM are similar. First, we show that dividend outlays influence investment decisions and vice versa. The fact that dividend payout does not cut back to finance capital investment confirms the model prediction of Lambrecht and Myers (2012). Moreover, the investment has a positive impact on debt financing and vice versa. An increase in debt financing enhances the funds available to outlays for investment, and the increase in investment raises willingness of fund supply by the increase in mortgage of capital investment or investment's future profitability, and thus further improves firm's debt capacity. The impact of debt financing on dividend is significantly negative, showing that the firms may have greater capability to pay dividend when they have lower leverage level. Accordingly, our findings suggest that these three corporate decisions are jointly determined and the interaction among them should be taken into account in a simultaneous equations framework.

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