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Crowding-out or crowding-in? Public and private investment in India ☆

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ABSTRACT

This paper contributes to the debate on the relationship between public and private investment in India along the following dimensions. First, acknowledging major structural changes that the Indian economy has undergone in the past three decades, we study whether public investment in recent years has become more or less complementary to private investment in comparison to the period before 1980. Second, we construct a novel data-set of quarterly aggregate public and private investment in India over the period 1996–2015 using investment-project data from the CapEx-CMIE database. Third, embedding a theory-driven long-run relationship on the model, we estimate a range of Structural Vector Error Correction Models (SVECMs) to re-examine the public and private investment relationship in India. Identification is achieved by decomposing shocks into those with transitory and permanent effects. Our results suggest that while public investment crowds out private investment in India over the period 1950–2012, the opposite is true when we restrict the sample to post 1980 or conduct a quarterly analysis since 1996. This change can likely be attributed to the policy reforms which started during the early 1980s and gained momentum after the 1991 crisis.

1. Introduction

The relationship between public and private investment has received renewed interest among academics and policy makers alike in the aftermath of the global financial crisis. On the one hand, higher public investment may "crowd out" private spending on capital goods, irrespective of the financing mechanism (including through levying taxes or issuing debt). On the other hand, higher government spending on infrastructure facilities (like roads, highways, and power) as well as health and education may have a complementary impact on private investment by raising its marginal productivity. The literature, which mostly relies on time-series and cross-country regression analyses, finds mixed predictions on the relationship between public and private investment. We re-examine this relationship in India by estimating Structural Vector Error Correction Models (SVECM) in three variables (public investment, private investment, and output) over different time periods.

Importantly, we investigate whether this relationship has changed over time after the policy reforms that started during 1980s (using annual observations) as well as post liberalization in early 1990s (using quarterly data over 1996–2015 from the CapEx-CMIE database), and compute the corresponding rupee response of private investment to an equivalent increase in public investment. Our main contribution to the literature is the adoption of a novel identification strategy and the use of a theory-driven long-run relationship, namely, the "great ratio" of aggregate investment and output. We estimate a SVECM and decompose the structural shocks into those with permanent and transitory effects on the level of the variables for identification. We find that while public investment crowds out private investment in India over the full sample (1950–2012), the opposite is true when we restrict the sample to post 1980 or focus on private corporate and household investment separately. The crowding in result continues to hold when we construct and use quarterly data over 1996–2015. These findings underscore how pro-business reforms of the early 1980s and the structural reforms of 1990s induced a complementary relationship between public and private investment in India.

We use long-run restrictions for identification as they are typically free of particular model assumptions and are motivated from what is generally agreed-upon in the empirical macroeconomic

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literature, see Chudik, Mohaddes, Pesaran, and Raissi (2016, 2017) for details. This is in contrast to solving the identification problem in VAR models by imposing short-term restrictions which require assumptions on the short-run dynamics of the variables that may be too restrictive (especially with annual data).[1] Specifically, we impose a long-run relationship between the three variables considered based on the "great ratio" of aggregate investment to output. Regarding identification, we assume that private-sector demand disturbances have transitory effects (given evidence for the presence of one cointegrating, or long run, relationship among the three variables considered), while the two structural innovations that have permanent effects are productivity shocks and (possibly) public investment innovations. As evidence, Binder and Pesaran (1999) argue that in the long run, the evolution of per-capita output is largely determined by technological process. Furthermore, endogenous growth models predict that per-capita output follows a stochastic trend where certain policy changes (i.e. productive public-investment decisions) may have long-run consequences for the level of output, see Jones (1995) and Kocherlakota and Yi (1996).[2]

Although there is a large body of literature analyzing the relationship between public and private investment, the empirical findings are mixed and research on developing and emerging market economies is rather limited. What is even more scarce is an attempt to identify whether the interaction between public and private investment has changed over time in those developing and emerging market economies which have witnessed significant structural reforms like deregulation of domestic/foreign goods markets (liberalization). Aschauer 1989a, 1989b argues that public investment in the United States, especially on infrastructure facilities, has a significant positive impact on private investment by increasing its productivity. While this conclusion of complementarity between public and private investment was further supported by Greene and Villanueva (1991) and Blejer and Khan (1984), there were also some strong criticism of Aschauer's results by Evans and Karras (1994) among others.

Erden and Holcombe (2005) compare the interaction of public and private investment in developing and developed economies, and conclude that while public investment is complementary to private investment in developing countries, the effect is opposite in developed countries. The difference in these results is attributed to structural differences between the two types of economies: while public investment may provide the necessary infrastructure facilities in developing countries and hence boost private investment, in developed economies the public sector is already large and may compete with the private sector. For the case of India, Mitra (2006) estimates a structural VAR model (using data over 1969–2005) in three variables (public investment, private investment, and output), and argues that public investment "crowds out" private investment. Serven (1996) analyzes how public and private investment interact with each other in India, and finds evidence of crowding-out in the short run but crowding-in over the long term due to investment in infrastructure sector.

Our main departure from these studies is the use of theory-driven long-run restrictions in our structural vector error correction models.[3] Garratt, Lee, Pesaran, and Shin (2012) argue that there are inherent difficulties with the interpretation that are given to the impulse responses that are obtained under the Structural VAR approach, and stress the importance of embedding structural long-run relationships in unrestricted VAR models as their steady-state solutions.[4] To the best of our knowledge, no previous study has employed this method to study the relationship between private and public investment in India.

The findings of our paper are in line with Mitra (2006) and Serven (1996) when, like these earlier studies, our data encompasses annual observations before 1980. However, we find that unlike in the period 1950–2012, public investment is complementary to private-sector investment after 1980. Our "crowding in" finding is corroborated by similar results obtained from SVECMs on quarterly data over the period 1996–2015, using public and private investment data constructed from the Indian CapEx-CMIE database (see Section 4).

The rest of the paper is organized as follows. Section 2 discusses the econometric methodology and outlines our identification approach. Section 3 describes the data while Section 4 presents the empirical findings. Section 5 concludes with some policy recommendations.

2. Structural VECM

We estimate a range of SVECMs with the baseline specifications including log per capita output, y_t, public investment, gi_t, and private investment, pi_t. As Appendix B discusses, all the variables are integrated of order one with evidence of one cointegrating relation among the three variables. The long run relationship between y_t, gi_t and pi_t can be motivated from the stationarity of the "great ratio" of aggregate investment and output. Appendix A expresses this relationship as $\beta_1 gi_t + \beta_2 pi_t - y_t$ where both β_1 and β_2 are less than 1. We embed this relationship in the following reduced form vector error correction model:

$$\Delta \mathbf{z}_t = \boldsymbol{\alpha}\boldsymbol{\beta}'\mathbf{z}_{t-1} + \sum_{i=1}^{m}\Gamma_i \Delta \mathbf{z}_{t-i} + \mathbf{u}_t \quad (1)$$

where $\mathbf{z}_t = (y_t, gi_t, pi_t)'$ is a (3×1) vector of endogenous variables, $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ are (3×1) vectors of loading coefficients and cointegrating vectors respectively, Γ_i is a (3×3) parameter matrix.[5] Finally, $\mathbf{u}_t$ represent the reduced form residuals $(u_t^y, u_t^{gi}, u_t^{pi})$.

To express the reduced form residuals in terms of structural shocks, $\mathbf{u}_t$ can be represented as $\mathbf{B}\boldsymbol{\varepsilon}_t$, where $\mathbf{B}$ is a (3×3) matrix, while $\boldsymbol{\varepsilon}_t$ represent the structural innovations $(\varepsilon_t^y, \varepsilon_t^{gi}, \varepsilon_t^{pi})$ of the system. Specifically, ε_y denotes a productivity shock, ε_t^{gi} a structural disturbance to public investment, and ε_t^{pi} can be motivated as a demand shock. Identification is usually achieved by imposing short run restrictions on the matrix $\mathbf{B}$—See for e.g., Blanchard and Perotti (2002) for details.[6] This requires a well-defined economic theory of the short-run dynamics and can be rather restrictive in data with annual frequency. Our identification strategy, instead, relies on long-run restrictions as they are typically free of particular model assumptions and are motivated from what is generally agreed-upon in empirical macroeconomic modelling.[7] We take the structural innovations in productivity and public investment to have long term effects on the variables and assume a demand disturbance, ε_{pi}, to have transitory effects. Our choice of public investment having a

[1] For example, most economists agree that monetary policy shocks are neutral in the long run, whereas productivity shocks can have permanent effects. This idea was first introduced in the context of a bivariate model in Blanchard and Quah (1989).

[2] Rodrik and Subramanian (2005) identify a productivity-boosting role for public infrastructure investment in India. Serven (1996) finds that government investment in infrastructure projects in India "crowds in" private investment over the long run.

[3] Serven (1996) does find cointegration, but estimates a single equation conditional model.

[4] Mitchell (2000) shows that ignoring cointegration when it indeed exists (by estimating a VAR in first differences) can result in misspecification error and bias at both long and short run horizons in the impulse responses.

[5] Given the ordering of the variables, $\boldsymbol{\beta}$ can be equivalently written as $(1, -\beta_1, -\beta_2)$.

[6] See Kilian (2013) for relevant literature on identification using short and long run restrictions.

[7] The idea of imposing restrictions on the long-run response of variables to shocks was first motivated by Blanchard and Quah (1989) in a bivariate model of output and rate of unemployment. They argue that unlike demand disturbances, supply shocks have a long run impact on output; see also King, Plosser, Stock, and Watson (1991) and Gali (1999).

long term impact on output is motivated from the endogenous growth literature which highlights that certain policy changes (like productive public-investment decisions) may have long run consequences on the level of output, see Cashin (1995), Jones (1995) and Kocherlakota and Yi (1996). Furthermore, Aschauer (1989a) reports public investment in 'core' infrastructure projects like in transport, communication, water systems, etc. to have significant impact on productivity (and hence output) in the long-run.

The long-term relationship between y_t, gi_t, and pi_t also implies one transitory and two permanent shocks. We follow Breitung, Brüggemann, and Lütkepohl (2004) in identifying the two permanent shocks.[8] Specifically, from Granger's Representation theorem, the process in Eq. (1) can be represented in the following Beveridge-Nelson moving average representation

$$\Delta \mathbf{z}_t = \underbrace{\Xi \sum_{i=1}^{t} \mathbf{u}_i}_{I(1)} + \underbrace{\sum_{j=0}^{\infty} \Xi_j^* \mathbf{u}_{t-j}}_{I(0)} + \mathbf{z}_0^* \quad (2)$$

where $\mathbf{z}_0^*$ contains the initial values, while Ξ_j^* are absolutely summable where the matrices Ξ_j^* converge to zero as $j \to \infty$. The $\Xi \sum_{i=1}^{t} \mathbf{u}_i$ is the common trends term which represents the long run effect of the shocks. In a K variable system with r cointegrating vectors, the matrix

$$\Xi = \boldsymbol{\beta}_{\perp} \left[\boldsymbol{\alpha}'_{\perp} \left(I_K - \sum_{i=1}^{m} \Gamma_i \right) \boldsymbol{\beta}_{\perp} \right]^{-1} \boldsymbol{\alpha}'_{\perp} \quad (3)$$

has reduced rank $K-r$. Given the presence of $K-r$ common trends, at most $r$of the underlying structural innovations can have transitory effects on the variables of the system. This is because the matrix Ξ can have at most r columns of zeros. Correspondingly, the remaining $K-r$ structural innovations have permanent effects. With a system of three variables and evidence of one cointegrating vector (see Tables 1 and 2 and Appendix B for unit root and cointegration rank tests) the matrix Ξ is of rank 2, with one transitory and two permanent shocks with at most one column of zeros. This distinction between transitory and permanent shocks enables more maneuverability to identify the SVECM through long-run restrictions, in addition to having short run restrictions in the contemporaneous matrix **B** if required.

The long run effects of the structural innovations are obtained by substituting $\mathbf{u}_t = \mathbf{B}\boldsymbol{\varepsilon}_t$ in the common trends term of Eq. (2) to give $\Xi\mathbf{B}\sum_{i=1}^{t}\boldsymbol{\varepsilon}_i$. Hence the matrix $\Xi\mathbf{B}$ captures the long run effects of the structural innovations. Since matrix **B** is nonsingular, the long run matrix $\Xi\mathbf{B}$ is also of rank two with at most one column of zeros. For local just-identification, we need a total of $K(K-1)/2 = 3$ restrictions. The presence of one cointegrating vector imposes two (and not three) independent restrictions from the column of zeros that correspond to the transitory demand shock in $\Xi\mathbf{B}$ (as $\Xi\mathbf{B}$ is of reduced rank). Since identification of r transitory shocks require $r(r-1)/2 = 0$ restriction, the transitory demand shock ε_t^{pi} is already identified in our model. Therefore, only $(K-r)(K-r-1)/2 = 1$ restriction is required to identify the two permanent shocks in our model. We distinguish the two permanent shocks by restricting the structural disturbance associated with government investment to have no long-run impact on private investment. Therefore we place the following restrictions on our short and long run matrices:

$$\mathbf{B} = \begin{bmatrix} * & * & * \\ * & * & * \\ * & * & * \end{bmatrix}, \quad \mathbf{B}\Xi = \begin{bmatrix} * & * & 0 \\ * & * & 0 \\ * & 0 & 0 \end{bmatrix} \quad (4)$$

Lütkepohl (2008) and Lucke (2010) show that the number of admissible zero restrictions placed on columns of **B** and $\Xi\mathbf{B}$ associated with transitory and permanent shocks cannot be greater than $r-1$ and $K-r-1$, respectively. Our identification scheme satisfies both these criteria as we place no zero restriction on matrix **B** and put only one zero restriction on the column of $\Xi\mathbf{B}$ that is associated with the permanent public investment shock.

3. Data

Our baseline specification uses annual Indian data on GDP, public and private Gross Fixed Capital Formation (GFCF) for the period 1950–2012, all variables expressed in real per capita terms.[9] The data is sourced from National Account Statistics as published by the Central Statistics Office (CSO), Government of India. For both public and private sectors, GFCF comprises of two main components: construction and machinery. The GFCF series exclude "Change in Stocks" and "Valuables".

Fig. 1 shows the time series plot of public and private GFCF as a percent of GDP. As the figure shows, the sharp increase in private investment together with a secular decline in public investment represent a clear break in the series from around early/mid 1980s.

While quarterly GDP data is available from the national accounts statistics from 1996, we construct quarterly frequency data on public and private investment using the CapEx database of the Centre for Monitoring of Indian Economy (CMIE).[10] The CapEx database covers around 45,000 investment projects between 1996(Q2) and 2015(Q1) that entail capital expenditure of ten million rupees or more. As there exists no single comprehensive source of information on investment-projects, the CapEx data is compiled from all available credible sources.

Given the lack of data on actual quarterly spending profiles, we estimate a measure of cash-flow based on project-level information on total costs and key project events such as dates of announcement, implementation, and project completion (among many other project statuses). To identify a project as public or private investment, we use information on its ownership.

For the projects that have been completed, the total project cost is divided equally between the date of announcement and completion. However, not all projects get completed. For ongoing, "stalled", "shelved" or "abandoned" projects, the expected duration of a project at the time of its announcement is equal to the average length of all completed investment projects of the given economic sector (private domestic, private foreign, public, or private–public partnership) and industry (manufacturing, mining, electricity, construction, or services).[11] We deflate the nominal cost of the projects by the GFCF deflators from the national accounts.[12] Finally, we aggregate the project expenditures (as calculated above) in each quarter for all ongoing private foreign and domestic projects across all industries to create our series of quarterly private

[8] For a discussion on SVECMs see e.g.. King et al., 1991; Gonzalo and Ng, 2001; and Pagan and Pesaran, 2008.

[9] While we include Market Price GDP in our regressions, our findings are robust to using Factor Cost GDP instead. The latter removes the effects of indirect taxes and subsidies on the value-added growth. All annual variables are expressed in 2004–05 prices.

[10] CMIE has been monitoring India's investment activity since 1976.

[11] The projects classified as shelved or abandoned are those where promoters announce no further intentions to start implementation. In practice, there is no clear distinction between a project being shelved or abandoned, therefore, we also do not distinguish between such events.

[12] All variables in quarterly frequency are measured in real per capita terms (in 2011–12 prices).

Table 1
Unit root tests.

Annual Data 1950–2012				
	y	gi	pi	gi^{infra}
ADF	1.15	−2.98	−0.31	−1.23
ADF-GLS	0.16	−1.61	−0.76	−1.30
PP	1.02	−2.55	−1.28	−0.86
	Δy	Δgi	Δpi	Δgi^{infra}
ADF	-6.88^{***}	-5.66^{***}	-4.40^{***}	-6.35^{***}
ADF-GLS	-6.54^{***}	-5.70^{***}	-2.39^{**}	-6.00^{***}
PP	-6.88^{***}	-5.71^{***}	-7.81^{***}	-6.35^{***}

Annual Data 1980–2012			
	y	gi	pi
ADF	−0.58	−0.53	−2.07
ADF-GLS	−0.68	−0.85	−1.49
PP	−0.37	−0.47	−3.02
	Δy	Δgi	Δpi
ADF	-4.32^{***}	-4.48^{***}	-3.66^{**}
ADF-GLS	-4.40^{***}	-4.45^{***}	-3.63^{**}
PP	-4.32^{***}	-4.48^{***}	-6.98^{***}

Quarterly Data 1996Q2-2015Q1						
	y	gi_1	pi_1	gi_2	pi_2	gi_2^{infra}
ADF	−1.99	−2.32	−2.70	−1.71	−2.46	−1.38
ADF-GLS	−1.27	−1.86	−2.10	−1.09	−1.89	−1.37
PP	−2.47	−1.42	−1.66	−1.45	−1.83	−1.96
	Δy	Δgi_1	Δpi_1	Δgi_2	Δpi_2	
ADF	-9.14^{***}	-2.81^{*}	−2.01	-6.20^{***}	−2.06	−0.80
ADF-GLS	-4.54^{***}	-2.82^{***}	-1.97^{*}	-6.11^{***}	−1.73	-3.77^{***}
PP	-9.14^{***}	-5.82^{***}	-4.72^{***}	-6.20^{***}	-5.72^{***}	-6.37^{***}

$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$. ADF denotes the Augmented Dickey-Fuller Test, ADF-GLS the generalized least squares version of the ADF test, and PP the Phillips-Perron test. Trend and intercept are included as deterministic terms in tests with level variables while only intercept is included in tests with differenced variables. For each variable, the number of lags are selected on Ng–Perron modified Akaike information criterion (MAIC) as reported in ADF-GLS.

Table 2
Lag orders and cointegrating rank of the VECMs

Annual Data		
	VECM Order*	Cointegrating relations
Model 1: $(y, gi, pi)'$	0	1
Model 2: $(y, gi^{i}, pi)'$	0	1
Model 3: $(y, gi, pi)'_{1980}$	0	0
Quarterly Data		
	VECM Order*	Cointegrating relations
Model 4: $(y, gi_1, pi_1)'$	7	1
Model 5: $(y, gi_2, pi_2)'$	7	2
Model 6: $(y, gi_2^{infra}, pi_2)'$	7	1

Notes: * denotes lag order in first differences selected by the Akaike Information Criterion, with the maximum lag orders set to 2 in models with annual data and 8 in models with quarterly data (see Appendix B for details). Selection of the number of cointegrating relations is based on the trace test statistics calculated at 99% critical values.

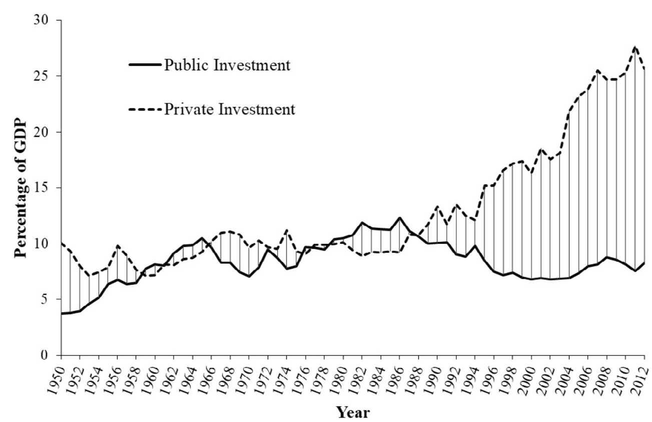

Fig. 1. Public and Private Investment in India. *Note*: The figure shows the evolution of public and private investment in India as a percent of GDP from 1950–2012. The unit of observation is country-year (63 observations). *Source*: Central Statistics Office, Government of India.

investment. The quarterly public investment series is created analogously, using projects under public ownership.

A key limitation of using the CapEx CMIE data is that a lot of investment is reported based on Memorandum of Understanding (MoUs) which may not be realized. This may overstate investment intentions and consequent outlays. To overcome this limitation, we construct two measures of investment spending that differ with respect to the treatment of shelved and abandoned projects. *Type 1* series includes estimated investment spending on projects up to the point they are declared as shelved or abandoned. *Type 2* series, however, completely excludes all costs associated with failed projects in the calculation of investment flows. The latter measure thus narrows investment activity only to projects that are more likely to make up productive capital stock. Given that we are not able to isolate current investments that may eventually become shelved or abandoned, robustness checks with a trimmed end-point were conducted.[13] Fig. 2 shows a time series plot of new investment projects in public and private sector (left axis) alongside the total value of the projects declared as stalled and shelved (right axis).

Finally, note that the overall public investment includes projects by central government, state governments, and public sector enterprises. In recent years, Indian states and public sector

[13] The correlation between the new series (on an annual basis) with public and private gross fixed capital formation from National Accounts Statistics is 0.95 over the period 1995–2012.

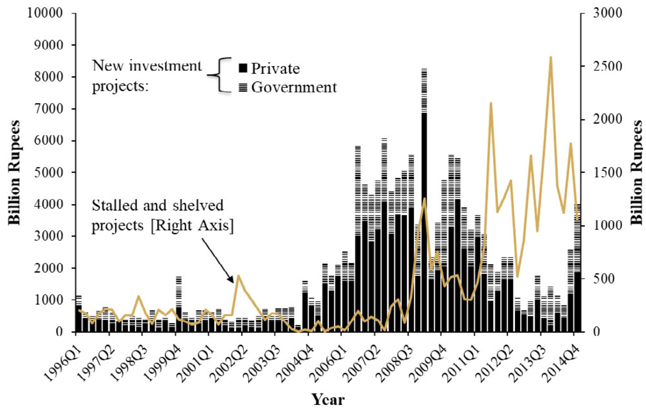

Fig. 2. CapEx (CMIE) Investment Projects. *Note*: The figure shows new investment projects in public and private sector (left axis) and stalled and shelved projects (right axis). All variables are reported in quarterly frequency. *Source:* CapEx database, Centre for Monitoring Indian Economy and authors' calculations.

enterprises have played an increasing role in capital formation by the public sector, reflecting the government's fiscal decentralization efforts. Thereby, aggregate investment by the public sector is not affected by internal shifts within different levels of the government. Nonetheless, understanding whether different components of public investment have heterogeneous impact on private investment is an important question for future research. Another important aspect is to study if depending on the state, similar public investment projects have different marginal effects on private investment indicating the importance of local institutions in enabling private investment. Finally, although investment projects classified as public–private partnership have a separate sector category, only a small fraction of the investment is attributed to such undertakings in the CMIE dataset (less than 3 percent of projects classified as public sector). These projects are not included in either the private or public investment series.

4. Empirical findings

This section discusses the results of models estimated with annual as well as quarterly frequency data. Our baseline specification (hereafter Model 1) contains annual data on y_t, gi_t, and pi_t over the period 1950–2012 (63 observations). We treat this specification as the baseline to enable comparison with earlier studies like Mitra (2006) and Serven (1996), which also used annual data on roughly comparable (though shorter) samples. We also check whether private investment responds differently to changes in public infrastructure investment like in electricity, railways, other transport, and communication, while keeping the sample period and identification strategy unchanged. Accounting for this heterogeneity is important as public infrastructure projects can raise the profitability of private production and thereby encourage private investment. To test this hypothesis, we estimate Model 2 with variables y_t, gi_t^{infr}, and pi_t, where gi_t^{infr} denotes investment in infrastructure sectors.[14]

Columns 1 and 2 of Table 3 report the estimated loading coefficients and cointegrating vectors, respectively. The $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ vectors of Models 1 and 2 are reported in rows 1 and 2, respectively.[15] Although a discussion of causality cannot be made on the basis of cointegrating vectors alone, it is reassuring to observe that the estimated coefficients on public and private investment have the theoretically-correct sign in both models. The estimated long run relationships in both models underline a positive relation between output, public and private investment. Next we identify Models 1 and 2 based on the long run restrictions as shown in Eq. (4).

Table 3
Loading coefficients and cointegrating vectors.

	$\boldsymbol{\alpha}'$			$\boldsymbol{\beta}'$		
Annual Data						
Model 1: $(y, gi, pi)'$	(0.001	0.76^{***}	0.71^{***})	(1	-0.12^{***}	-0.44^{***})
Model 2: $(y, gi^i, pi)'$	(0.16^{**}	0.70^{***}	0.90^{***})	(1	-0.20^{***}	-0.35^{***})
Model 3: $(y, gi, pi)'_{1980}$	(-0.11	-0.52^{**}	0.76^{**})	(1	-0.13^{*}	-0.65^{***})
Quarterly Data						
Model 4: $(y, gi_1, pi_1)'$	(-0.74^{***}	-0.10	1.73^{**})	(1	0.07^{**}	-0.12^{***})
Model 5: $(y, gi_2, pi_2)'$	(-0.25^{***}	0.15	0.97^{***})	(1	-0.03	-0.13^{***})
Model 6: $(y, gi_2^{\text{infra}}, pi_2)'$	(-0.24^{***}	0.37^{**}	0.99^{***})	(1	-0.12	-0.10^{***})

$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

The estimated short ($\mathbf{B}$) and long run ($\mathbf{B\Xi}$) matrices of Models 1 and 2 are reported in rows 1 and 2 of Table 4, respectively. Given the ordering of the variables, $(y, gi, pi)'$ and $(y, gi^i, pi)'$ respectively, we observe that a structural innovation in public investment crowds out private investment in the short run in both models. The effect on output due to ε_t^{gi} on the other hand is positive and statistically significant in both models on impact as well as in the long run.[16] Columns 1 and 2 of Fig. 3 show the impulse responses of variables to a one standard deviation shock in productivity and public investment for Models 1 and 2 respectively.

For Model 1, as can be seen from Panel (a) of Fig. 3, the impact of a productivity shock on public investment is not significantly different from zero over both the short-term and the long run, while the response of private investment to a productivity shock is significantly positive, both on impact and over the long run. Panel (b) shows the response of output and private investment to a structural innovation in public investment. As the graphs show, the response of output is positive throughout, while private investment is shown to be temporarily crowded out by public investment. This response is statistically significant for the first 3 years after the shock; thereafter the long run response converges to zero.

The impulse responses of Model 2, reported in column 2 of Fig. 3, are very similar to those of Model 1. Here gi_t^{infr} does not respond significantly to a productivity shock, while private investment's response is positive and significantly different from zero (after 1 year) which grows over time. The response of output is also very comparable to that reported in column 1. Most importantly, the crowding out result for private investment in response to a shock in public infrastructure investment stands as compared to Model 1.

Overall, the results of Models 1 and 2 suggest that over the whole sample, 1950–2012, public investment crowds out private investment in the short run. Furthermore, we do not find any significant differences if we focus our attention only on public investment in infrastructure. This may be because large investment efforts of the public sector over the last three decades were concentrated on infrastructure investment in areas such as agricultural irrigation, transport, telecommunications and power, so the results of Model 2 are very similar to those of Model 1 with aggregate public investment.

[14] The industry-wise investment data does not disaggregate data into public and private sector. Therefore we focus on the industries where most of the investment in the sample period came from the public sector.

[15] The coefficients corresponding to output in the cointegrating vectors are normalized to one.

[16] Note that the long run impact of private investment to ε_{gi} is already restricted to zero.

Table 4
Short and long run matrices.

	B	**ΞB**
Annual Data		
Model 1: $(y, gi, pi)'$	$\begin{pmatrix} 0.03^{***} & 0.01^{***} & 0.00 \\ -0.02 & 0.06^{***} & 0.04^{***} \\ 0.07^{***} & -0.05^{***} & 0.04^{***} \end{pmatrix}$	$\begin{pmatrix} 0.03^{***} & 0.01^{***} & 0 \\ -0.02 & 0.11^{***} & 0 \\ 0.07^{***} & 0 & 0 \end{pmatrix}$
Model 2: $(y, gi^{i}, pi)'$	$\begin{pmatrix} 0.03^{***} & 0.01^{*} & 0.01^{***} \\ -0.03^{**} & 0.05^{***} & 0.05^{***} \\ 0.03 & -0.06^{***} & 0.06^{***} \end{pmatrix}$	$\begin{pmatrix} 0.04^{**} & 0.02^{***} & 0 \\ 0.02 & 0.09^{***} & 0 \\ 0.09^{***} & 0 & 0 \end{pmatrix}$
Model 3: $(y, gi, pi)'_{1980}$	$\begin{pmatrix} 0.02^{***} & 0.01^{**} & -0.01^{**} \\ -0.01 & 0.05^{***} & -0.03^{***} \\ 0.07^{***} & 0.02^{**} & 0.04^{***} \end{pmatrix}$	$\begin{pmatrix} 0.02^{***} & 0.01^{***} & 0 \\ 0.01 & 0.07^{***} & 0 \\ 0.04^{***} & 0 & 0 \end{pmatrix}$
Quarterly Data		
Model 4: $(y, gi_1, pi_1)'$	$\begin{pmatrix} 0.01^{***} & -0.00 & -0.01 \\ 0.01 & 0.02 & -0.00 \\ 0.04^{***} & -0.01 & 0.02 \end{pmatrix}$	$\begin{pmatrix} 0.01 & -0.002^{**} & 0 \\ 0.07 & 0.02^{**} & 0 \\ 0.16 & 0 & 0 \end{pmatrix}$
Model 5: $(y, gi_2, pi_2)'$	$\begin{pmatrix} 0.01^{***} & 0.00 & -0.01^{***} \\ -0.01 & 0.02^{***} & 0.00 \\ 0.03^{***} & 0.00 & 0.02^{***} \end{pmatrix}$	$\begin{pmatrix} 0.02 & 0.001^{**} & 0 \\ 0.03 & 0.03^{**} & 0 \\ 0.11 & 0 & 0 \end{pmatrix}$
Model 6: $(y, gi_2^{\text{infra}}, pi_2)'$	$\begin{pmatrix} 0.01^{***} & 0.01^{***} & -0.01^{***} \\ -0.01^{***} & 0.02^{***} & 0.01^{***} \\ 0.03^{***} & 0.01 & 0.02^{***} \end{pmatrix}$	$\begin{pmatrix} 0.02 & 0.002^{***} & 0 \\ 0.03 & 0.02^{***} & 0 \\ 0.13 & 0 & 0 \end{pmatrix}$

$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

These findings are not surprising, as India relied on a state-led, inward-oriented growth strategy for more than three decades post independence. A key component of this strategy was rapid industrialization based on capital-intensive industries, guided by the central plans of government, see Serven (1996) for details. The comprehensive licensing of firms' entry, expansion and diversification plans; reservation of entire productive sectors for the state; high barriers to foreign trade and investment; and mandatory credit allocation imposed on the banking system were key components of this strategy.

To understand the magnitude of crowding out in our baseline specification, we compute interim multipliers after one, two, and three years for private sector investment in response to a one rupee increase in public investment.[17] A one rupee increase in public investment is shown to crowd out private investment by 0.60, 0.31, and 0.17 rupees after one, two, and three years, respectively. Overall, our baseline results of crowding out in the short run are close to those obtained in past studies by Mitra (2006) and Serven (1996); both of whom report similar short run dynamics.

Although the analysis in Models 1 and 2 is useful to compare with similar earlier studies, it does not acknowledge the substantial structural changes that the Indian economy has undergone during the past three decades. Starting from late 1970s and throughout the 1980s, the Indian economy witnessed reforms in industrial and trade policies. This included deregulation of the domestic market which implied loosening of restrictions on entry, expansion and output mix. Trade reforms were aimed at reducing quantitative controls on import goods, resulting in availability of high quality machinery and capital goods.

Furthermore, the 1991 liberalization process marked a complete restructuring of major policy areas, see Ahluwalia (2002) among others. License restrictions were abolished and all except a few industries were made open to the private sector. Import quotas were eliminated and there was a substantial reduction in tariff rates. Monetary policy focused on price stability and availability of credit to investors. There was a substantial easing of restrictions on the banking sector including a reduction of the cash reserve ratio (CRR) and the statutory liquidity ratio (SLR). Correspondingly, there is a voluminous debate on the timing of the structural break in India's growth story. While Rodrik and Subramanian (2005) and DeLong (2003) suggest a break in early 1980s, Bhagwati and Panagariya (2013) and Ghate and Wright (2012) argue the turnaround to be a late-eighties phenomenon. On the other hand, Ahluwalia (2002) (among others) attribute the break to 1990s due to the economic reforms following the 1991 balance of payments crisis.

While we are agnostic about the exact timing of India's growth turnaround, it is important to check whether the response of private investment to public investment changed in the latter half of our sample due to the series of structural reforms that started from the early 1980s. First, we let parameter stability indicate a possible structural break in the data. Using Chow break-point and Chow-forecast tests, we check for the existence of a break during the 1975–2000 period in our sample. Instead of choosing a single break date, we perform the test assuming the break-point to be anytime between 1975–2000 and repeat the test for each year in the sample. For both tests, the null of parameter constancy is rejected for a range of years between 1975–2000 which provides evidence of a break in the model.[18] We select 1980 as the break-point as it corresponds to the maximum value of the break-point and split-sample test statistics. Importantly, while we find evidence of a break in 1980, we do not reject the possibility of a second break later in the sample.[19] Therefore, we check the robustness of our results to the choice of sub-sample and the frequency of the data by conducting SVECM analysis over 1996–2015 with quarterly data (discussed below). As is shown below, our results are quite robust to the choice of sub-sample.

With evidence of a break point in 1980, we re-estimate Model 3 in y_t, gi_t, and pi_t over 1980–2012. The estimated loading and cointegrating vectors are reported in row 3 of Table 3 and the short and long run matrices are reported in row 3 of Table 4. The impulse responses are shown in Fig. 3, column 3. The graphs show that the response of public and private investment to productivity shocks, and the output response to a public investment shock, are very similar to Model 1 (column 1). However, the response of private investment to public investment differs significantly from earlier specifications. In this specification, a policy-induced increase in public investment significantly *crowds in* private investment in the short run. The calculated interim multipliers are 0.37, 0.16, and 0.07 after the first, second, and third years, respectively.

This exercise, therefore, underscores two important aspects of private investment in India. First, owing to the pro-business reforms and product-market liberalization, private investment increased sharply relative to public investment since 1980s (as is shown in Fig. 1). Second, apart from this trend, we show that the marginal impact of public investment on private investment ($\partial pi_t / \partial gi_t$) has also been positive since 1980s. This change can be attributed to India's large infrastructure deficit where public investment can crowd-in private investment as it increases its productivity in an environment where private sector entry in new markets is less restrictive.

Finally, Fig. 4 investigates the impact of public investment shock on private corporate and household investment separately over the periods 1950–2012 and 1980–2012. Consistent with our results above, we find that while a policy-induced increase in public investment crowds out private investment (in particular those

[17] To calculate the multipliers, we first compute the elasticities of private investment to public investment ε_{gi}^{pi} over the three years, and divide them by the average ratio of government to private investment over the whole sample.

[18] We use 2000 bootstrapped replications to compute the p-values for the tests.

[19] Conducting unit root tests with two structural breaks as discussed in Clemente, Montañés, and Reyes (1998) indeed show a second break at 1996 for output and private investment (with the first break identified between 1983–1984 for all the variables).

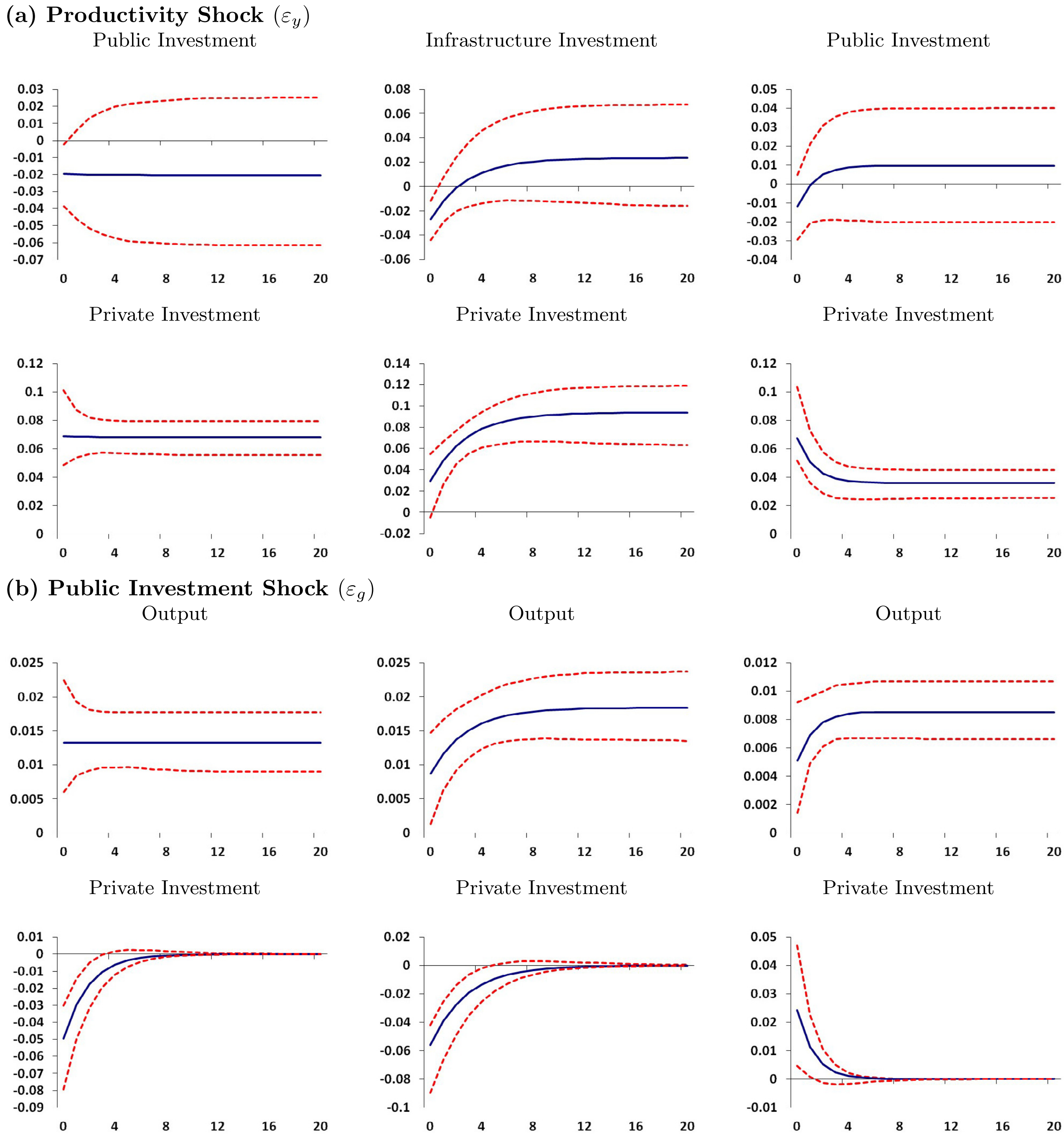

Fig. 3. Structural Impulse Responses to Productivity and Public Investment Shocks (Annual). *Note:* Figures are impulse responses to a one standard deviation shock to productivity or government investment, together with the 5th and 95th percentile bootstrapped error bands with 2000 replications. Columns 1 and 3 correspond to our baseline specification which includes output, public investment, and private investment over 1950–2012 and 1980–2012 periods, respectively. Model in column 2 is similar to that in column 1 except that we consider public infrastructure investment instead of total public investment.

of households) over the period 1950–2012, the opposite is true for private corporate investment when we restrict the sample to post 1980. The impact on household investment in the restricted sample is not statistically significant. The key reasons for this change can be attributed to the pro-business reforms, liberalization of product markets in India following the end of the license regime, and the opening up of different industries to the private corporate sector.[20]

[20] Similar results are obtained when we focus on shocks to public infrastructure investment.

4.1. Quarterly analysis using post-liberalization data

While many studies argue that the pickup in India's economic growth preceded the 1991 liberalization, there is a consensus in the literature on the role of pro-market reforms of 1990s in transforming the Indian economy. Spurred by a balance of payments crisis in 1991, Indian policy-makers began liberalizing the economy by slashing trade barriers, attracting foreign investment, dismantling the license raj regime, and beginning privatization. These reforms were pivotal in sustaining and further accelarating the high growth witnessed in the 1980s. This section, therefore,

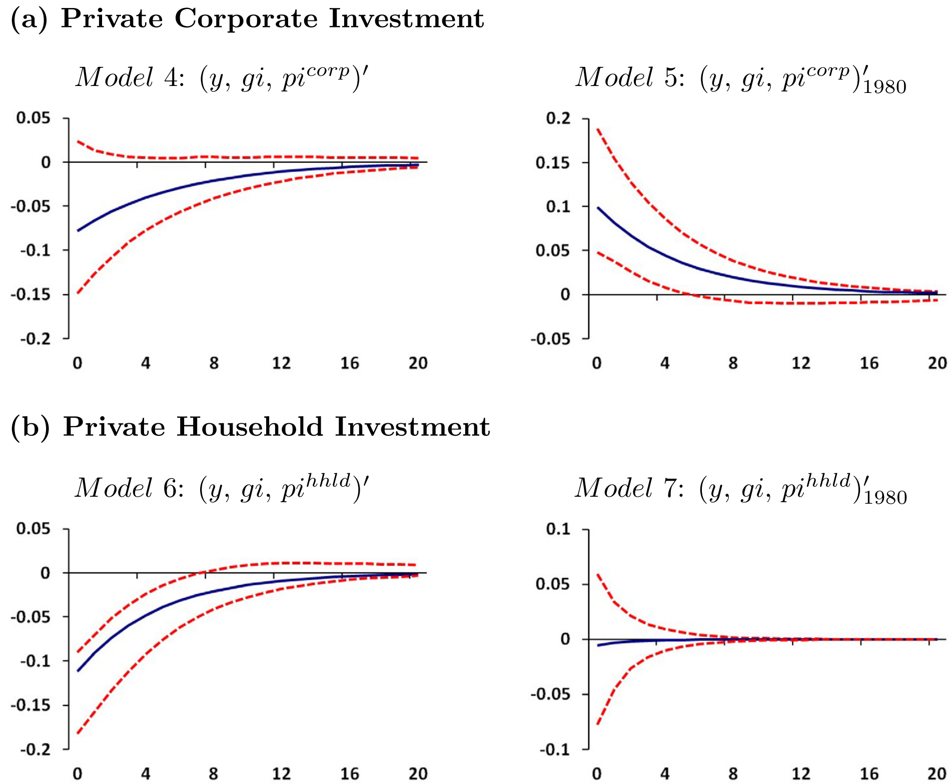

Fig. 4. Structural Impulse Responses of Corporate and Household Investment to Public Investment Shocks. *Note:* Figures are impulse responses to a one standard deviation shock to public investment, together with the 5th and 95th percentile bootstrapped error bands with 2000 replications. Parts (a) and (b) show the response of private corporate investment and household investment to a public investment shock, respectively. Column 2 plots the same impulse responses as column 1 but for the restricted sample 1980–2012.

investigates whether the relationship between public and private investment has changed after these policy reforms.

Using the quarterly series of public and private investment constructed from the CapEx-CMIE database, we estimate a range of SVECMs from 1996–2015. As discussed in the data section, we construct two alternative measures of investment: *type 1* which counts investment projects even for failed ones (*i.e.* where investment is counted until the project is either completed, shelved, or abandoned); and *type 2* which simply does not consider failed projects in the construction of the two investment series. Model 8 corresponds to the case where the investment series are constructed as type 1, gi_t^1 and pi_t^1 for public and private sectors, respectively. Model 9 considers investment series calculated as *type 2*. We treat Model 9 as our preferred specification because type 2 series abstract from making any assumptions on the investment-flow from projects that possibly never started. Finally, analogous to the exercise in annual data, Model 10 replaces gi_t^2 with $gi_t^{2,\text{infra}}$ where $gi_t^{2,\text{infra}}$ is the public investment series on infrastructure sectors.

Rows 4, 5, and 6 of Table 3 report the loading coefficients and cointegrating vectors corresponding to Models 8, 9, and 10, respectively. The signs of estimated coefficients on public and private investment in the long run relationships are broadly as expected but smaller in magnitude than those obtained in annual data estimations.[21] The estimated short and long run matrices $\mathbf{B}$ and $\mathbf{B\Xi}$ for the three models are reported in rows 4, 5, and 6 of Table 4. The corresponding impulse responses are shown in columns 1, 2 and 3 of Fig. 5. As row 1 of Fig. 5 shows, for all the 3 specifications, the response of public investment to a productivity shock is positive and statistically significant after 4–6 quarters. Similar to the impulse responses in annual data, the response of private investment (row 2) to a productivity shock is also positive and statistically significant in all the models. The response of output to a policy-induced change in public investment (panel b) is not significantly different from zero in the first 8 quarters in Model 8. However, there is a statistically significant positive impact on output from a public investment shock over the first 8 quarters in Models 9 and 10 (which continue to be small and positive in the long run).

Finally, the impulse responses of private investment to a structural innovation in government investment are reported in the last row of Fig. 5. Reassuringly and in agreement with the earlier results from Model 3, none of the three quarterly specifications predict crowding out of private investment. On the contrary, under our preferred specification, Model 9, there is evidence for a positive and significant *crowding in* of private investment by public sector investment from quarters eight to twelve. Computing interim multipliers using Model 9, we find that a one rupee increase in public investment crowds in private investment by 0.30, 1.24, and 1.07 rupees after four, eight, and twelve quarters, respectively. While the rupee on rupee impact seems large (> 1), the elasticity of private investment with respect to public investment is actually quite conservative (around 0.6 and 0.7 after eight and twelve quarters respectively).[22] The response of private investment to public infrastructure investment shocks (last graph) is very similar to the case

[21] The relatively smaller size of the coefficients in comparison to the annual results may be due to the higher frequency of data in Models 8–10. Also, the investment series constructed using investment-project announcements are only proxies for the actual investment activities.

[22] Hence, the large multipliers simply reflect that private investment (in levels) was substantially greater (around 1.7 times on average) than public investment during this period.

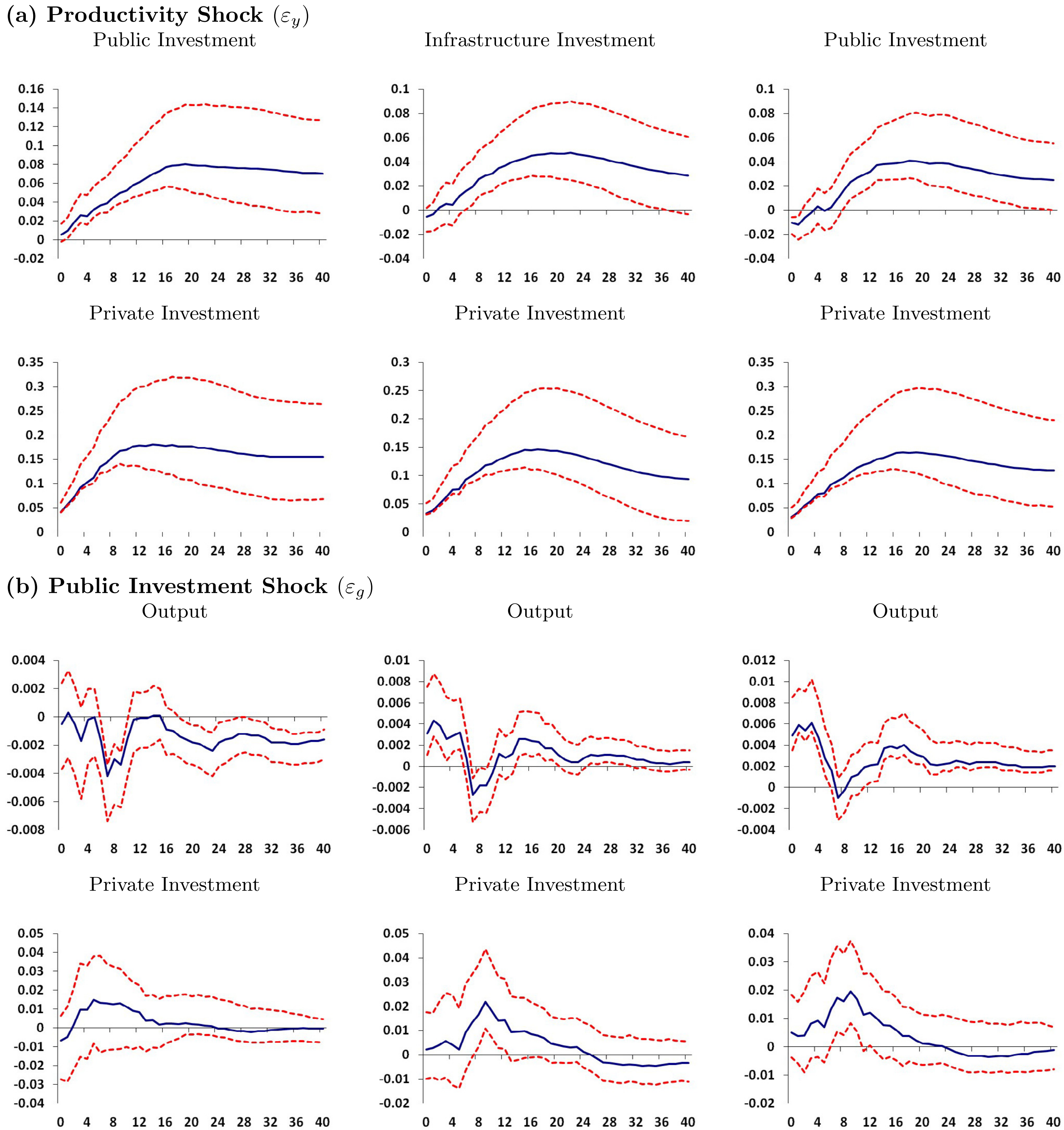

Fig. 5. Structural Impulse Responses to Productivity and Public Investment Shocks (Quarterly). *Note:* Figures are impulse responses to a one standard deviation shock to productivity or public investment, together with the 5th and 95th percentile bootstrapped error bands with 2000 replications. The impulse responses correspond to models with quarterly data on public and private investment projects constructed from CapEx CMIE database. Columns 1, 2, and 3 show impulse responses from models 4, 5, and 6 respectively. In model 4, investment is counted until a project is either completed, shelved, or abandoned. Model 5 altogether excludes shelved or abandoned projects in the construction of investment series. Model 6 is the same as model 5 except that public investment on the infrastructure sector is considered.

when aggregate public investment is considered (second graph, last row).

Overall, there is evidence for "crowding in" of private investment by public investment, once we restrict the sample post 1980. Similar responses of private investment to a public investment shock over Models 3, 8, 9, and 10 suggest that public investment has been complementary to the activities of the private sector over both 1980–2012 and 1996–2015 periods. In retrospect, the crowding in finding is not very surprising given the huge infrastructure deficit in India, but it has not been usually found previously in the Indian empirical literature, see Mitra (2006) and Serven (1999). Furthermore, the standard arguments for crowding out (assuming that the economy is operating on its production possibility frontier and has developed financial markets) do not appear to hold for emerging market economies like India. In fact, the crowding out of private investment by public investment over the full sample is likely a reflection of a state-led, inward-oriented growth strategy that existed before the 1980s, which was not supportive of private sector investment.

5. Concluding remarks

Acknowledging the key structural economic reforms in the India during 1980s and 1990s, we estimate a variety of SVECMs over different sample periods and frequencies to examine how the relationship between public and private investment in India as evolved over time. We embed a long-term relationship between output, public and private investment that is motivated by the stationarity of the "great ratio" of aggregate investment and output. We use the properties of the theory-driven long-term relationship to decompose the structural innovations into those with permanent and temporary effects to identify our SVECMs. We find public investment to "crowd out" private investment in India over the period 1950–2012. In contrast, we find support for crowding in of private investment over the more recent period of 1980–2012. This change in the relationship can be attributed to the policy reforms that started during the early 1980s and gained momentum after the 1991 balance of payments crisis. The finding of crowding-in is further supported by our quarterly model which uses investment project data by CapEx-CMIE over the period 1996–2015. Future research can exploit our novel and disaggregated dataset of public and private investment at quarterly frequency to further disentangle the region- or sector-wise relationship between public and private investment in India. Specifically, an interesting question is to examine whether, ceteris paribus, states with better institutional capacity attract greater investment by the private sector. This will have important implications for the design of macroeconomic policies for the states and central government alike.

Conflict of interest

None declared.

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Appendix A

In the spirit of the famous "Great Ratios" suggested by Klein and Kosobud (1961) in the context of economic growth, we can express the long-term relationship between investment and output as

$$i_t - y_t = \kappa + z_t \tag{A1}$$

where i_t and y_t represent total investment (public + private) and output respectively. Both variables are in per capita terms and are expressed in logs. The right-hand side of Eq. (A1) contains a constant and a mean zero I(0) random variable. Express total investment (in levels) as:

$$I_t = I_{pt} + I_{gt} \tag{A2}$$

where I_{pt} and I_{gt} represent the total public and private investment at time t, respectively. Dividing Eq. (A2) by I_{gt} and log-linearizing using first-order Taylor expansion yields

$$i_t = \tau + \beta_1 i_{gt} + \beta_2 i_{pt} \tag{A3}$$

where small letters denote variables in logs. Coefficients $\beta_1 = c/(1+c)$ and $\beta_2 = 1/(1+c)$ are both less than one, and $c = \exp(i_g - i_p)$ can be understood as the average ratio of public to private investment in the economy. τ is a linearization constant which equals $\ln(1+c) - c\ln(c)/(1+c)$. Ignoring the constant of linearization, we can use Eqs. (A1) and (A3) to express a long run relationship between public investment, private investment, and output as:

$$\beta_1 i_{gt} + \beta_2 i_{pt} - y \approx \kappa + z_t \tag{A4}$$

Eq. (A4) thus dictates that the three variables (y, gi, and pi) move together in the long run such that a linear combination of the three variables is stationary. In other words, the gap between the three variables cannot grow out of bounds over time. While this long run relation holds for economies irrespective of the growth path they follow, the difference between the level of investment and output can be quite large for a country like India (which experienced unbalanced growth during this period). While such short run 'errors' are nonetheless 'corrected' over time (since high levels of investment translate into higher output or vice versa), there is a risk that the data may fail to identify the variables as cointegrated.

However, the presence of a cointegrating vector using our data empirically validates the existence of a long run relation in our model (see Appendix B). Notwithstanding the cointegration between y, gi, and pi, the local interaction between a sub-set of these variables can still change for economies experiencing structural changes. This in fact is found to be the case for public and private investment in India.

Appendix B

B.1. Unit root tests

We first determine the order of integration of the variables y_t, gi_t, pi_t, and gi_t^{infr} over the period 1950–2012. We report the results from the Augmented Dickey-Fuller (ADF) test, ADF-GLS test as proposed by Elliott, Rothenberg, and Stock (1996), and Phillips-Perron (PP) unit root test. All three tests have a null hypothesis of individual series being a random walk against the alternative of stationarity. To preserve uniformity across tests, we select the lag order for a variable based on Ng–Perron modified Akaike information criterion (MAIC) as reported in the ADF-GLS test. Since all variables, when expressed in levels, appear to be trending, all tests on the level of variables include a deterministic time trend.[23] The results are reported in the first panel of Table 1. They indicate that we cannot reject the null of non-stationarity even at 10% level, while all the tests on the first-differenced variables strongly reject the presence of a unit root at 1% significance level. We therefore conclude that all four variables are integrated of order 1 or I(1).[24] Similarly, all variables are shown to be integrated of order one over the smaller sub-sample from 1980 (panel 2). Finally, we test for unit roots in quarterly series where we have two variants of public and private investment, as discussed in the data section. For all variables, the null of a unit root cannot be rejected even at 10% level of significance, while all variables except pi_1 and pi_2 clearly reject the null of a unit root in first differences. Although for pi_1 and pi_2, the null of unit root cannot be rejected in first differences for ADF test, the Phillips–Perron test

[23] No trend is included in the tests on first-differenced variables.

[24] As a robustness check to our unit root tests, we also conducted the Clemente et al. (1998) unit root test, which allows for one or two structural breaks in the series being tested for non-stationarity. Our results (available on request) are robust to this additional test.

strongly rejects the null at the 1% level. We therefore continue to treat pi_1 and pi_2 as I(1).

B.2. Cointegration rank tests

Table 2 reports the lag order and the number of cointegrating vectors used in various VECM models discussed in the paper. For all specifications using annual data, a VECM order of 0 (in first differences) is selected based on the Akaike Information Criterion.[25] Models 1 and 2, which are based on the full sample data confirm the presence of one cointegrating vector based on 99% trace test statistic. Although Model 3 does not confirm the presence of any cointegration between the three variables, this may be due to the loss of power of the test over a small sample of around 30 annual observations. For robustness, we conduct the Johansen trace test with structural break as discussed in Johansen, Mosconi, and Nielsen (2000) where we take y_t, gi_t, and pi_t over the whole sample, but allow for breaks in level and trend at 1980. The test strongly supports the evidence of one cointegrating vector. The results do not change even if we allow for a second break in 1991. Hence, we continue to estimate a VECM with one cointegration rank in Model 3. For VECMs using quarterly data, a lag order of 7 (in first differences) is selected based on the Akaike Information Criterion.[26] Models 4 and 6, using quarterly data, support the presence of one cointegrating relation between the three variables. Model 5 indicates the presence of two cointegrating vectors. However, we continue to proceed with one cointegrating rank which is also confirmed by maximum eigenvalue test statistic at the same significance level (not reported in the paper but available upon request).

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[25] Maximum number of lags were set to two years.

[26] Only for Model 6, AIC reports lag of 8, while FPE reports lag order 6. To maintain uniformity of lags across models 4, 5, and 6, we continue to choose lag 7 as before. Results are invariant to the inclusion of lag order 8 for model 6.