
Policy instruments to avoid output collapse: an optimal control model for India

Sushanta K. Mallick

*Department of Economics, Loughborough University, Ashby Road,
Loughborough, Leicestershire LE11 3TU, UK
E-mail: s.k.mallick@lboro.ac.uk*

This paper identifies the key policy instruments to be monitored in order to avoid output collapse in the short run for developing countries that come under the IMF-supported adjustment programmes. Changes in exchange rate and aggregate domestic credit are the standard instruments in a Fund-supported policy package used to target balance of payments (BOP) improvement and inflation reduction. Within a small macroeconomic policy-oriented model of India, this paper carries out optimal control exercises to obtain optimal policies for desired targets. The analysis thus carried out indicates that demand contraction based on domestic credit restriction leads to improvement in the BOP and reduction in inflation rather than increased output. This paper suggests using instruments such as credit flow to the private sector on the monetary side, and public spending on basic infrastructure on the fiscal side, so as to make adjustment programmes growth-oriented even in the short term.

I. Introduction

The Indian economy went through severe fiscal and external imbalances during the period 1989–1991. As a reaction to serious macroeconomic imbalances, radical policy changes were introduced in the summer of 1991. The classic goals of the macroeconomic adjustment were to achieve BOP viability and price stability as suggested by the IMF. A standard package of economic policies for developing economies (DEs) is sponsored by the Fund to overcome the BOP crisis (see IMF, 1987). The monetary restraint is one of the key channels aimed at reducing the growth of absorption and the rate of inflation. Since the focus of such tight monetary policy is the overall credit growth rather than limiting it to the public sector alone, it gives rise to the private sector being crowded out of the credit markets. Also, with a BOP

shock to the economy, the financial system can no longer do its job of channelling funds to those with productive investment opportunities partly due to fears over possible default risks, resulting in a sharp contraction of lending. Both of these factors contributed to a contraction in GDP in the first year of the IMF-supported stabilization programme (see Table 1). India had an output collapse in 1991 – the year in which the IMF's financial support was received with its usual policy advice. The aim of this paper is to look at how this macroeconomic policy problem can be optimally designed within a small macroeconomic model for India. The basic macroeconomic problem of the Fund adjustment programme is formulated here as an optimal control problem with two instruments (exchange rate and domestic credit) and two targets (inflation and foreign reserves).

Table 1. Real GDP growth (%) 1994–2001

	India	Mexico	Thailand	Korea	Malaysia	Indonesia	Philippines	Russia	Argentina
1994	6.8	4.4	9.0	8.3	9.2	7.5	4.4	-13.5	5.8
1995	7.6	-6.2	9.2	8.9	9.8	8.2	4.7	-4.2	-2.8
1996	7.5	5.2	5.9	6.8	10.0	8.0	5.8	-3.4	5.5
1997	5.0	6.8	-1.4	5.0	7.3	4.5	5.2	0.9	8.1
1998	5.8	5.0	-10.5	-6.7	-7.4	-13.1	-0.6	-4.9	3.8
1999	6.7	3.6	4.4	10.9	6.1	0.8	3.4	5.4	-3.4
2000	5.4	6.6	4.6	9.3	8.3	4.8	4.4	9.0	-0.8
2001	4.1	-0.3	1.8	3.0	0.5	3.3	3.2	5.0	-4.4

Source: World Economic Outlook, IMF, September 2002.

Low-income countries have substantial excess capacity with regard to labour, contributing to large negative output gaps,¹ and thereby require higher public investment on infrastructure to create conditions for higher private investment and sustained growth. Hence, this paper identifies policy instruments such as domestic credit to the private sector on the monetary side and government investment expenditure, especially on infrastructure on the fiscal side to avoid an output collapse in the adjustment process. A stable growth in these instruments can be financed respectively by reducing domestic credit to the government, and a cutback in government consumption expenditure. This would also ensure stabilizing the economy at a low inflation trajectory with an improvement in BOP.

Macroeconometric models are invariably used for simulation, forecast, or control purposes.² Since simulation does not provide a direct means of obtaining a policy that is *optimal* with respect to a given objective, control theory has proved to be a very efficient tool for studying dynamic economic systems for policy purposes in the last few decades. The key idea behind optimal control is precisely to derive the optimal policy in order to steer the economy to the specified targets. The economic applications of optimal control theory in the context of macroeconomic policy research have a long history both in the case of linear and non-linear models. They are extensively discussed in Pindyck (1973), Chow (1975), Holly *et al.* (1979), Kendrick (1981), Turner *et al.* (1989), and Hall and Stephenson (1991). In the case of the Indian economy, Rao and Singh (1997) derived macroeconomic stabilization policies applying

control methods within the financial programming approach of the IMF. Financial programming model – published by the IMF in 1957 – reflects the monetary approach to the BOP (Polak, 1998), integrating monetary, income and BOP analysis, and that became the basis of the conditionality applied to IMF credits. Despite being extremely simple, the model has retained its usefulness for policy purposes. Hence this paper re-examines the issue of stabilization with growth so as to look at the BOP and growth effects of credit creation by the banking system.

The second section presents a model of stabilization with growth. This model is a combination of a model of stabilization based on Mallick (2004) and a model of growth based on Mallick (2002). This section also considers the dynamic properties of the combined model. The third section discusses the design and analysis of policy feedback by using the results of the optimal control experiments. The final section summarizes conclusions.

II. The Analytical Backdrop

Macroeconomic imbalances arising from both external shocks and inappropriate domestic policies are repeatedly experienced by DEs. In order to restore domestic and external balance, adjustment programmes, often supported by the resources of the Fund are designed to simultaneously achieve both the objectives. That is the underlying rationale behind financial programming, which remains the theoretical core of nearly all IMF-supported

¹ Large negative output gap or excess capacity means low inflation. This is partially reflected in relatively low inflation rates of 10% in low-income countries, compared to 50% inflation rate in middle-income countries, while high-income countries have annual inflation of 1.5% mainly due to their policy towards containing inflation (Source: World bank for 2001). India is a low-income country as per the World Bank's definition.

² For an overview of different approaches to policy making, see Wallis (1995).

adjustment programmes. It is this IMF type of financial programming approach that Rao and Singh (1997) used in the Indian context. When an economy is in external disequilibrium, monetary and fiscal disciplines are usually imposed to reduce demand, with the expectation that these economies are growing above their potential level. Reducing domestic liquidity as a result of monetary control means reducing demand, which may stabilize prices and improve BOP.

Khan *et al.* (1990) merged the simple versions of the analytical approaches employed by the IMF and the World Bank in designing adjustment programmes that support their lending activities, with the bank model being a variant of the two-gap growth model. Several attempts have been made in the literature to extend the standard monetary and growth models by incorporating dynamics and building more economic structure. Despite these attempts, the same models continue to be used by the international financial institutions in calculating the short-run investment requirements for a target growth rate, which in turn helps to arrive at a financing gap, often filled with foreign aid or official loan arrangements (see Easterly, 1999). It is not clear whether the macroeconomic disequilibrium is caused by lack of supply or demand. But the Fund emphasizes the credit restrictions as a vehicle to improve the BOP and to generate resources to repay foreign creditors. These adjustment policies, especially credit policy, could lead to reduction in output. But the effects of such a tight credit policy are less evident in the IMF literature with regard to how it affects output. There is little investigation of the channels of transmission of monetary impulses to the rest of the economy.

The actual experience of DEs, in particular that of India, does not fit into this straightjacket approach of the financial programming of IMF. Since devaluation is also introduced to bring about an external balance, it leads to higher inflation in the short term. This will be the case when such economies depend heavily on oil imports, as the expenditure effect rather than the liquidity effect will then dominate the relative price effect. Cerra and Saxena (2002) found that current account deficits played a significant role in India's 1991 crisis. The current account deficit is caused by both excess imports and inadequate exports, and the deficit is not necessarily due to excess spending, rather it is due in part to lack of spending, particularly on investment in fixed assets, that characterizes many DEs including India. In this case, current account deficits do not reflect the idea that these countries are growing above their potential, rather that their ability to export is

weaker than their propensity to import. This requires liberalization of policies and improving product quality so as to widen the export base.

Przeworski and Vreeland (2000) estimate the effect of participation in IMF programmes on economic growth and find that governments enter into agreements with the IMF under the pressures of a foreign reserve crisis. They also found that programme participation lowers the growth rates of those countries and once countries leave the programme, they grow faster. Table 1 shows those countries which had output collapse in the first year of the IMF programme (Mexico in 1995, East Asia in 1997/98, and Russia in 1998). Argentina, however, has continued to remain in recession since 1999, despite being under the austerity programme of the IMF. The Indian economy was never part of the 'Asian economic miracle' before the Asian financial debacle. It is still dancing to a different tune, with the economy being relatively less open and capital inflows being well below other Asian economies. Other Asian economies plunged into severe output collapse in 1998 following plummeting currencies, tumbling domestic demand, diminishing external demand and fragile financial systems. In contrast, India suffered a mild slowdown in economic growth. India had an output collapse creating large negative output gap, when it encountered a BOP crisis in 1991. At a time when there is a general collapse in demand, the public sector needs to play an important role in supporting demand, if the economy remains closed and growth is driven mainly by domestic demand.

The broad concerns of monetary policy in India have been, (1) to regulate monetary growth so as to maintain a reasonable degree of price stability, and (2) to ensure adequate expansion in credit to assist economic growth (Rangarajan, 1998). Dwindling credit flows in the adjustment process has the potential to dampen economic activity. So we need to base our argument on the role of credit as a factor of production and its role in affecting the supply side of the economy. If these effects are important it seems clear that restrictive credit policy may have greater adverse effects on output growth and less effect on price inflation.

India's average annual GDP growth over the last decade (1990–2000) was 6%, in line with the average growth in the previous decade (1980–1990), during which the service sector grew much (8% in 1990–2000 from 7% in 1980–1990) faster than the industrial (6.4% from 6.9%) and agricultural sectors (3.0% from 3.1%). Agriculture accounts for just 26% of GDP, but it has strong multiplier effects especially on rural demand for industrial goods. About two-thirds

of India's one billion people live in villages and work in the agricultural sector. So consumption spending in the rural area makes up a large part of the demand for industrial products. Indeed slowing industrial growth since the middle of the 1990s has been largely due to sluggish rural demand due to volatile agriculture on the back of erratic monsoons making domestic demand cyclical. On the other hand, the share of the service sector in the economy continues to grow – from about 40% in 1990 to over 50% currently – supporting GDP growth. The service sector can also be volatile to be a reliable engine of growth for the economy, for example, the bursting of the technology bubble in 2000 and the decline in external demand. As in many other countries, high tech was no magic bullet. Old-fashioned infrastructure bottlenecks lingered, cramping private sector expansion. Hence for sustained growth, private investment must rise in the areas where there is excess capacity, primarily in rural areas.³ In order for that to materialize, there is a need to channel credit to the lower end of the private sector. We have therefore derived an independent private investment function rather than expressing it via the neo-classical mechanism of savings, and then determine the optimal level of tight credit, facilitating output growth via private investment.

Dornbusch (1990) argued that there is a possibility of stabilization resulting in stagnation because structural adjustment is only a necessary but not sufficient condition for growth. Addressing links between stabilization and growth requires the inclusion of an independent investment function that responds endogenously to current and expected future macroeconomic variables. In Fund-Bank models, investment is often either exogenous or determined by saving rate. Macroeconomic stabilization with inflation control leads to a rise in real interest rates. Such a rise in real interest rates could act to reduce investment demand, leading to output decline. The major channel via which credit policy affects the supply side is an important objective of the econometric model and optimal control experiments presented in this paper. From the fiscal side, we bring in public investment that will crowd-in private investment to the extent such spendings are on aiding capital accumulation, including the role of complementary factors such as infrastructure and human capital.

In contrast with most of the literature on this subject, Calvo (2000) endogenizes output and

discusses the channels (New Classical and Keynesian) through which a BOP crisis can result in output collapse. In the first channel, because a crisis changes relative prices, it may cause a generalized financial crash, and in the second one, it is associated with a contraction of aggregate demand. The model shows how a bad shock in a given sector could spill over to a credit crunch in the whole economy. In this context, there are two variations on the credit channel story: a balance sheet channel and a bank lending channel (Bernanke and Gertler, 1995). The first links lending to be determined by the financial health of the borrowing firms, while the second tells the supply side story originating within the banking system, which would be impacted by the monetary tightening policy advocated by the IMF in the post-crisis phase. A currency crash could lead to an increase in the foreign currency debt repayment obligations of firms, and thus cause a fall in their profits. This in turn would reduce firms' borrowing capacity and therefore investment and output in a credit-constrained economy, which in turn reduces the demand for the domestic currency, leading to further depreciation. Aghion *et al.* (2001) argue that currency crises can occur both under fixed and flexible exchange rate regimes, as the primary source of crises is the deteriorating balance sheet of private firms. Credit constraints become even more severe leading to an output collapse when the macro-economy encounters a chaotic situation following a crisis.

The econometric model

According to the IMF conditionality, external disequilibria are always a consequence of excess aggregate domestic demand, caused by excessive credit expansion. As a result, Fund sponsored stabilization programmes centre on demand contraction through a credit crunch, and establish stricter domestic performance criteria than necessary to attain the BOP objectives. But they adversely constrain growth. The standard Fund-Bank model of macroeconomic adjustment does not take into account the endogeneity/decomposition of aggregate government expenditure and total investment (into private and government investment) nor the price formation process in a DE.

The following model integrates adjustment with growth relating to the Indian economy. This model has estimated trade behaviour, inflationary process, and the determinants of long-run growth considering

³ Small- and medium-sized enterprises (SMEs) potentially constitute the most dynamic firms in an emerging economy. Lack of finance is the main obstacle to the growth of SMEs. Among other factors, key obstacles for SMEs include limited access to working capital and long-term credit, inadequate infrastructure, and high transaction costs.

the role of endogenous growth (through human and physical capital interactions) and the demand factors in growth. The novelty of this model lies in incorporating both the demand and supply side effects through an eclectic model of Keynesian–Neoclassical mix. There seems to be a general consensus that the split between public and private components of investment can exert a differential impact on economic growth (Khan and Kumar, 1997). The contribution here lies in the treatment of the crowding-in and crowding-out of private investment due to public investment and huge government borrowing from the financial system, respectively. The relationship between exports and real output has also been included. The vector error correction method is used to analyse the relationship between GDP, investment, exports, human capital and credit.

The model has 10 endogenous and 16 exogenous variables. Of the 10 endogenous variables, equations 1 to 5 have been estimated using the data from 1950–1951 to 1995–1996 employing a fully modified Phillips–Hansen method of estimation to obtain the cointegrating relations and the short-run dynamic model. Equations 8 and 9 are estimated error-correction equations, using annual data pertaining to the same period, derived from equilibrium relationships obtained through a vector auto-regressive model employing Johansen’s multivariate cointegration approach. Equations 6 and 7 are identities and Equation 10 is a definition. Equations 1 to 7 constitute the stabilization model and Equations 8 and 9 form the growth model. Expected inflation is defined as adaptive.

Variables used in a control model are classified into three categories:⁴

State variables. describe the state of the economy but can not be directly modified by policy makers: P is the price level (represented by the WPI), π^e is the expected inflation, M is the nominal money supply (M_3), $(M/P)^d$ is the desired real balances (MD), PX is the unit value of exports, X is the real export, I is the real import, R represents the foreign exchange reserves, $GDPFC$ is the real Gross Domestic Product (GDP) at constant prices, $PVTFCF$ is real gross domestic private capital formation, RIR is real interest rate.

Control variables. can be directly controlled by policy makers: E is the nominal exchange rate ($INR/US\$$), DC is total domestic credit (DCP –private and DCG –government), $PUBCF$ is real public investment expenditure.

Exogenous variables. are determined outside the system over which neither the economic system being described nor the policy makers have any control: IPA refers to international price of domestically consumed agricultural tradables expressed in foreign currency, W is the nominal wage, Q is average labour productivity, $IPRM$ is price of imported raw materials, ED is monetary disequilibrium, YM is the marketed output, IR is nominal interest rate, YW is the real GNP of trading partners, S is unit export subsidies ($INR/US\$$), T is unit import duties ($INR/US\$$), PW is world price level (in US\$), PM is the import unit value in US\$, KI refers to net foreign assets of the non-banking sector, EI is the essential imports, K is the money multiplier, $RDCP$ is real domestic credit to private sector, $SERAT$ is school enrollment rate, and $DUM79$ is oil price dummy of 1979, EC terms are error correction variables.

1. Price equation

$$\begin{aligned} \Delta \ln(P) = & -0.002 + 0.84 * (\Delta \ln(IPA) + \Delta \ln(E)) \\ & (1.12) \qquad (21.05) \\ & + 0.07 * (\Delta \ln(W) - \Delta \ln(Q)) \\ & (2.84) \\ & + (1 - 0.84 - 0.07) * (\Delta \ln(IPRM) + \Delta \ln(E)) \\ & - 0.00003 * \Delta ED + 0.06 * \Delta \ln(P(-1)) \\ & (-0.78) \qquad (0.84) \\ & - 0.35 * EC1(-1) \\ & (-3.05) \end{aligned}$$

$$\begin{aligned} EC1 = & \ln(P) - 0.828 - 0.73 * (\ln(IPA) + \ln(E)) \\ & - 0.16 * (\ln(WM) - \ln(QM)) \\ & - 0.11 * (\ln(IPRM) + \ln(E)) + 0.0003 * ED \end{aligned}$$

2. Desired real balances

$$\begin{aligned} \Delta \ln(MD) = & 0.012 + 1.45 * \Delta \ln(YM) - 0.32 * \Delta \pi^e \\ & (0.71) \qquad (4.23) \qquad (-1.08) \\ & - 0.34 * \Delta \ln(IR) - 0.26 * EC2(-1) \\ & (-3.93) \qquad (-2.31) \end{aligned}$$

$$\begin{aligned} EC2 = & \ln(MD) + 14.949 - 1.96 * \ln(YM) \\ & + 1.03 * \pi^e + 0.5576 * \ln(IR) \end{aligned}$$

⁴ A more detailed list of variables used and their definitions and sources of data are provided in Mallick (2004 and 2002).

3. Unit value of exports

$$\begin{aligned} \Delta \ln(PX) = & \frac{-0.007}{(-0.255)} + 0.048 * \frac{(\Delta \ln(P(-1)))}{(1.57)} \\ & - \Delta \ln(E(-1) + S(-1)) \\ & + 0.367 * \frac{\Delta \ln(PW(-1))}{(2.51)} \\ & + 0.55 * \frac{\Delta \ln(Y)}{(1.94)} + 0.73 * \frac{\Delta \ln(YW(-1))}{(1.399)} \\ & + 0.0002 * \frac{ED}{(1.469)} + 0.28 * \frac{\Delta \ln(PX(-1))}{(1.946)} \\ & - 0.215 * \frac{EC3(-1)}{(-2.025)} \end{aligned}$$

$$\begin{aligned} EC3 = & \ln(PX) + 11.804 - 0.027 * (\ln(P) \\ & - \ln(E + S)) - 0.657 * \ln(PW) \\ & - 1.89 * \ln(GDPFC) + 0.86 * \ln(YW) \\ & - 0.0012 * ED \end{aligned}$$

4. Export demand

$$\begin{aligned} \Delta \ln(X) = & \frac{0.07}{(3.54)} - 0.12 * \frac{\Delta \ln(PX/PW)}{(-1.08)} \\ & + 0.72 * \frac{\Delta \ln(YW)}{(1.565)} + 0.18 * \frac{\Delta \ln(X(-1))}{(1.14)} \\ & - 0.298 * \frac{EC4(-1)}{(-2.88)} \end{aligned}$$

$$\begin{aligned} EC4 = & \ln(X) + 1.6597 + 0.578 * \ln(PX/PW) \\ & - 0.683 * \ln(YW) - 1.18 * \ln(E) \end{aligned}$$

5. Imports

$$\begin{aligned} \Delta \ln(I) = & \frac{0.02}{(1.48)} - 0.12 * \frac{\Delta \ln((PM * (E + T))/P)}{(-2.74)} \\ & + 0.22 * \frac{\Delta \ln(Y(-1))}{(0.74)} + 0.06 * \frac{\Delta \ln(EI)}{(3.00)} \\ & + 0.30 * \frac{\Delta \ln(KI/PM)}{(12.39)} \\ & + 0.05 * \frac{\Delta \ln(R(-1)/PM(-1))}{(1.32)} \\ & + 0.07 * \frac{\Delta \ln(I(-1))}{(0.96)} + 0.0003 * \frac{ED}{(-2.92)} \\ & - 0.598 * \frac{EC5(-1)}{(-4.53)} \end{aligned}$$

$$\begin{aligned} EC5 = & \ln(I) + 5.20 + 0.17 * \ln((PM * (E + T))/P) \\ & - 1.00 * \ln(GDPFC) - 0.002 * \ln(EI) \\ & - 0.3186 * \ln(KI/PM) - 0.161 * \ln(R/PM) \\ & + 0.0003 * ED \end{aligned}$$

6. Balance of payments

$$R = R(-1) + X - I + KI$$

7. Money supply

$$M = k * (R + DC) \quad \text{and} \quad DC = DCP + DCG$$

8. Real output

$$\begin{aligned} \Delta L(GDPFC) = & \frac{0.23}{(1.435)} - 0.27 \frac{\Delta L(GDPFC(-1))}{(-1.809)} \\ & + 0.06 \frac{\Delta L(PVTCTF)}{(1.049)} \\ & + 0.12 \frac{\Delta L(XPG(-1))}{(1.98)} \\ & - 0.073 \frac{\Delta L(PUBCF(-1))}{(2.197)} \\ & + 0.002 \frac{\Delta(RIR)}{(2.126)} + 0.1789 \\ & \times \frac{\Delta L(RDCP(-1))}{(2.396)} \\ & - 0.087 \frac{DUM79}{(-3.038)} - 0.067 \frac{EC6(-1)}{(-3.167)} \\ & + 0.82 \frac{EC7(-1)}{(1.533)} \end{aligned}$$

$$\begin{aligned} EC6 = & \ln(GDPFC) - 0.21773 * \ln(PVTCTF) \\ & - 0.63966 * \ln(SERAT) \\ & - 0.16661 * \ln(PUBCF) \\ & - 0.083522 * RIR \end{aligned}$$

9. Real private investment

$$\begin{aligned} \Delta L(PVTCTF) = & \frac{-3.95}{(-6.174)} + 1.1 \frac{\Delta L(GDPFC(-1))}{(2.233)} \\ & + 0.47 \frac{\Delta L(PVTCTF(-1))}{(3.639)} \\ & - 1.30 \frac{\Delta L(SERAT)}{(-2.481)} - 0.0079 \frac{\Delta RIR}{(-1.867)} \\ & + 0.01 \frac{\Delta RIR(-1)}{(3.427)} + 0.5224 \frac{\Delta L(RDCP)}{(2.057)} \\ & + 1.1709 \frac{EC6(-1)}{(8.025)} - 1.216 \frac{EC7(-1)}{(-7.883)} \end{aligned}$$

$$\begin{aligned} EC7 = & \ln(PVTCTF) - 0.44751 * \ln(SERAT) \\ & - 0.013224 * \ln(PUBCF) \\ & - 0.51512 * \ln(RDCP) \\ & - 0.061383 * RIR \end{aligned}$$

10. Real interest rate

$$RIR = IR - \pi^e$$

The change in the general price level is a function of the prices of imports and the exchange rate, which is a policy (or instrument) variable. The purpose of controlling credit according to the IMF is to accommodate balance of payments situation and reduce inflationary pressure. Given reserves (R^*) and inflation (π^*) targets, the two instruments DC and E can be chosen to meet R^* and π^* . The monetary transmission mechanism focuses on the intermediate variables such as the interest rate, credit, and exchange rate to influence prices and output. In India, the output effect of money supply, stems from three major sources, namely through (1) the aggregate demand effect, (2) the impact on the stock of credit, and (3) the cost of credit. On the monetary side, domestic credit to the private sector can be an important policy instrument for growth, while the decomposition of government expenditure is crucial on the fiscal side (Mallick, 2001). Our model remains consistent with the recent literature on structural vector autoregressions that an increase in the stock of money leads to an increase in economic activity, although these real effects die out over time, as discussed in the next section.

The results do not support the export-led growth hypothesis, as India had mostly an inward-looking strategy during most of the sample period. The results show that exports have a positive but small effect on output in the short run, but the effect is not as strong as it is normally assumed that it will be increasing in the long run. Looking at the investment behaviour, this model finds a negative short-run response to public investment reflecting crowding-out of private investment through credit squeeze. But complementarity or crowding-in prevails between public and private investment in the long run, which means public investment on infrastructure (physical and social) will stimulate private economic activity. In the short run, the policymakers need to contain fiscal deficit by reducing government consumption expenditure, thereby reducing pressure on the massive market borrowing by the government. This in turn will boost the monetary liquidity in the financial system, motivating the private sector to participate actively.

Dynamic properties of the model

Since simulation analysis provides some important guidelines for optimal control analysis, we first analyse the dynamic properties of the model by introducing single shocks to the system and solving the model for the sample period. The model solutions

have been obtained using *WINSOLVE* (Pierse, 1997). The exogenous (policy) variables being analysed here are domestic credit, exchange rate, and public investment. A sustained 10% negative shock (an unanticipated shock) is introduced to DC and $PUBCF$, with a permanent 10% positive shock to exchange rate. The time path of $GDPFC$ and P is derived by means of dynamic multiplier analysis and the cumulative differences between the base and variant solutions are computed; these differences are presented in Fig. 1. These simulations suggest that the stability properties of the model are satisfactory, although in some cases there is non-decaying response, in part due to significant turbulence in the historical time series reflecting policy changes and other shocks over time.

In what follows we discuss the overall properties of the model through three standard simulation experiments, which are depicted in Fig. 1. The first experiment elicits the response of the model to a permanent negative shock in credit. Output falls sharply, and prices decline due to the shock in credit leading to demand contraction. Thus the very mode of adjustment in the Fund policy package creates serious supply-side constraints. It has been argued in the Indian context that curtailing growth in money supply might adversely affect output, because money, apart from being relevant as a means of influencing aggregate demand, also plays a crucial role as an input for the productive sectors in the economy in the form of credit (Rangarajan, 1998). BOPs improve in general due to the reduction in the domestic credit. Since output collapses as a result of reducing credit so as to stem inflation and improve BOPs, we need to make a distinction between credit to the government and to the private sector, in order to ensure that credit to the private sector remains unaffected in the process of adjustment. As the public sector borrows from the central bank, which results in an increase in money supply, the credit rationing here meant curtailing such public borrowing. Since there is no limit on government borrowing from the market, this in turn meant crowding-out of private investment resulting in output contraction.

Exchange rate depreciation by 10% reduces the level of output in the first period and as relative price effect dominates after the next period, output effect turns positive. The price response emerges more quickly in the devaluation shock and slowly settles down to a lower level in the long run. The devaluation-based adjustment policies do not help to achieve the desired effects on the balance of trade,

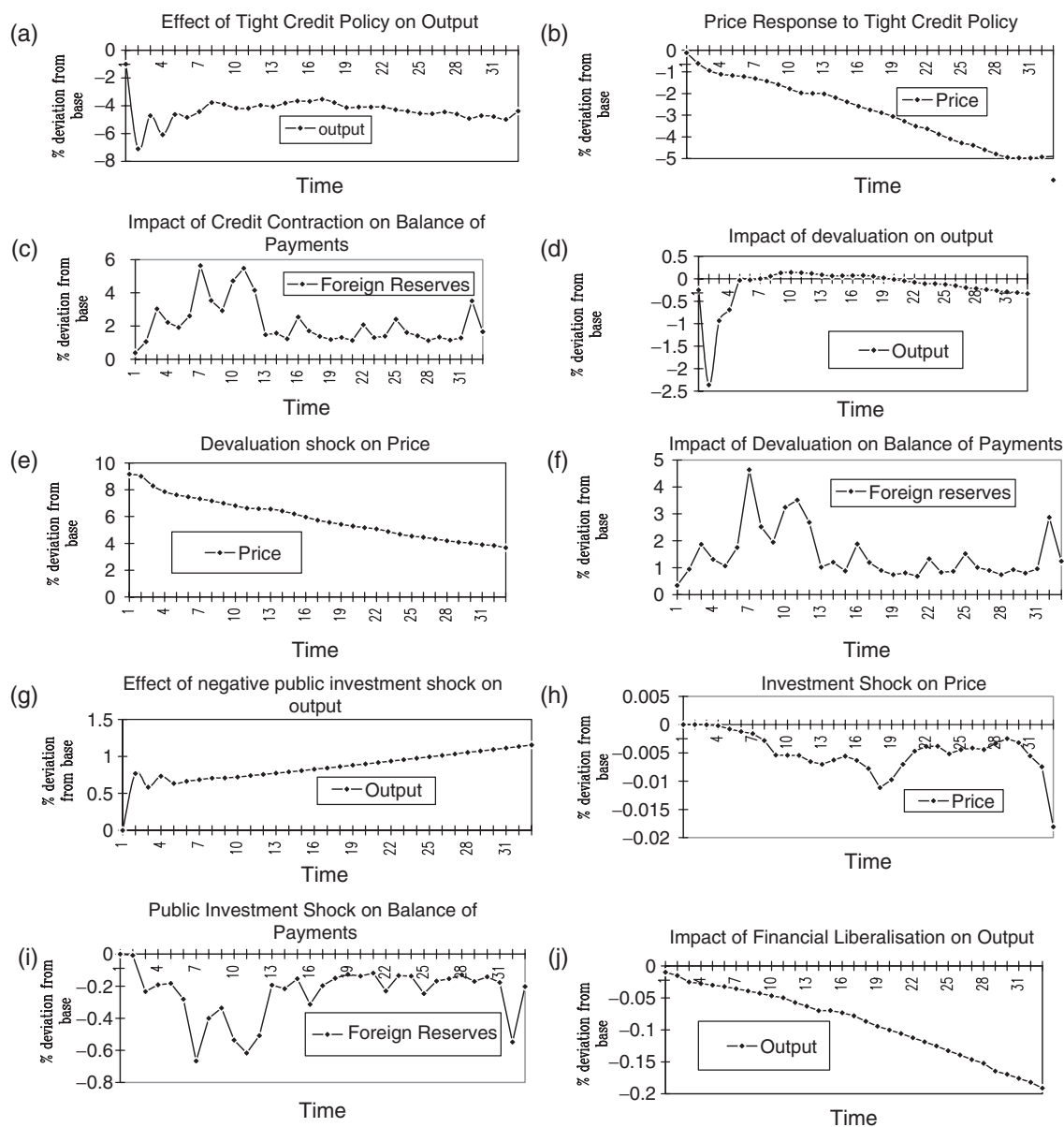


Fig. 1. Dynamic simulations of the model

since the world income plays little or no role in affecting the balance of trade in India. Moreover, despite the trade policy reforms in the early 1990s,⁵ India has not achieved a manufacturing export-led growth as yet, and export demand response remains weak, partly because of higher relative price of domestic goods and thereby running into an export-demand bottleneck. If a step-up in manufacturing

output is to contribute to a non-inflationary acceleration of GDP growth, it needs to be complemented by adequate policies aimed at raising agricultural output and income (Storm, 1997). This would require an increase in public capital formation in agriculture.

In explaining overall investment behaviour in the economy, a crucial role was generally assigned to

⁵ Chand and Sen (2002) find that the trade reform in Indian manufacturing has had a positive impact on total factor productivity growth, but it still remains a controversial issue being time- and sector-dependent (such as final- or intermediate-goods sectors). In general, with regard to the empirical evidence on a cross-country basis, the linkage between trade liberalization influencing growth has been mixed, with studies supporting the nexus (for example, Greenaway *et al.*, 2002), and others being sceptical of the relationship (for instance, Rodriguez and Rodrik, 2000).

public investment. The issue of crowding out is a well-accepted proposition that in DEs there is a close relationship between private and public investment, although there is considerable uncertainty as to whether the public sector investment raises or lowers private investment. Public sector investment can result in crowding out if it utilizes physical and financial resources that would otherwise go to the private sector. Furthermore, financing of the public sector, whether through taxes or issuance of domestic debt, in either case will lower the resources available for the private sector and thus depress private investment activity. On the contrary, public investment that is related to infrastructure and the provision of public goods can be complementary to private investment and can raise the productivity of capital, increase the demand for private output through increased demand for inputs and additional services. The overall effect of public investment on private investment will, therefore, depend on the relative strength of these various effects. The question is whether and to what extent the effect of the public investment crowds-out or crowds-in the private investment in India. The key conclusion is that the effect of public investment on the private sector investment appears to be crucial in both directions. So we analyse the output response under a reduction in public investment by 10%. Since the short-run response of output is negative in our model due to reduction in public investment, output increases moderately. The negative short-run response of 0.07 implies that there is a crowding out of private investment by the public spending in the short-run, though complementarity or crowding-in prevails between public and private investment in the long run.

For the case of financial liberalization,⁶ we investigate the effect of a 1% increase in the nominal interest rate, which leads to a negative output effect and positive price effect. So high interest rates are a disincentive for productive investment, aggravating the recession associated with the adjustment. Basu (2002) examines why financial liberalization is unable to deliver a higher growth rate and points out the role of intervention not only to maintain financial stability but also to help promote growth. As the process of liberalization raises the interest rate, Basu argues that it will cause a rise in the bank's credit standard requirements in order to minimize credit risks. That in turn is more likely to push small and medium sized firms out of the credit market.

The situation is exacerbated if a tight credit policy is adopted following a BOP crisis.

III. The Design of Optimal Control Exercise

As the purpose of this paper is to undertake an optimal policy formulation for India keeping in view the adjustment strategies, it is worthwhile to survey briefly the literature on the method of optimal control. Since a large number of economic problems are naturally described as dynamic systems, which can be influenced by policies in an attempt to improve their performance, control theory has gained widespread application by economists. Tinbergen (1952) defined the concept of a 'Policy Model', which predicted the effect of 'instruments' on 'targets'. Tinbergen's approach to quantitative economic policymaking involves the following elements:

- a criterion or welfare function that depends on output growth, inflation and change in reserves;
- a classification of endogenous variables into two categories, targets as above and irrelevant variables, and classification of exogenous variables into instruments such as exchange rate, domestic credit and public investment, and data variables;
- an econometric model involving relationships between endogenous and exogenous variables as outlined in the first part of Section II;
- a set of boundary conditions and constraints on the target and instrument variables.

In Tinbergen's approach, the policy model may be a fixed or a flexible target; in the former, the welfare function contains fixed target values, but in the latter, such target values are chosen as to optimize the welfare function. The work initiated by Tinbergen was limited to static or comparative static models such as Keynesian macroeconomic models. Tinbergen's approach with static and comparative static models required methods of Linear Algebra for fixed target problems or mathematical programming for flexible target problems. Tinbergen's approach was extended to dynamic economic policy problems such as those that confront developing economies in Kumar (1969). Kumar's extension made use of the then emerging mathematical tools of optimal control theory.

⁶ Real interest rates tend to be relatively high in DEs undertaking adjustment programs involving monetary stringency. Since it is not our purpose in this paper to model the impact of financial liberalization, we would like to be modest with regard to our results.

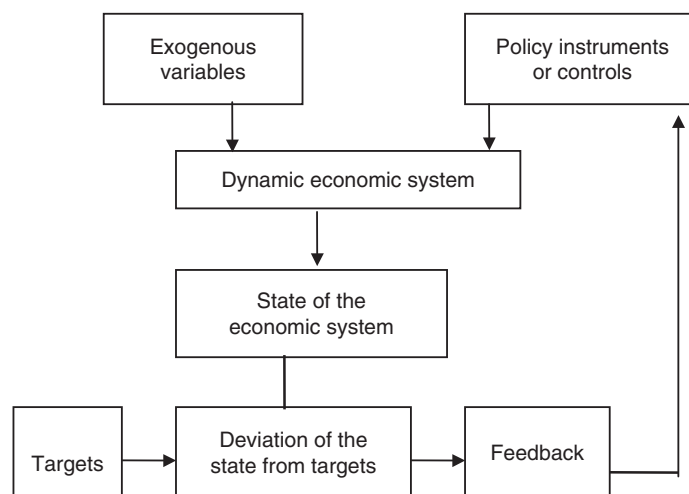


Fig. 2. Mechanism of feedback control policy

Recently there has been a revival of interest in the applications of optimal control in economic policy. The basic concept in the field of optimal control is the concept of the welfare loss function or simply the loss function. The use of modern control theoretic approach along with various dynamic economic models provides an operational procedure for the optimal policy instruments to achieve the desired targets over time for a deterministic or stochastic system. When feedback is used to determine macroeconomic policy, then the levels of policy instruments depend on the state of the economy at that time. Papers in Britton (1989) attempt to derive explicit feedback rules that approximate the fully optimized solution in large non-linear models. Feedback control is an optimization technique for quantitative macroeconomic policymaking (Livesey, 1979) which involves:

- A dynamic system
- A set of controllable inputs
- A set of measurable outputs
- A policy objective function
- A formula or set of formulae that link the level of controllable inputs to the deviation of the outputs from the desired level.

Here there are three types of adaptive policies. They are: (i) proportional control, where the correction is proportional to the difference between observed and desired state of the system, (ii) derivative control, where the correction is proportional to the difference between rate of change of the observed state and the rate of change in the desired state, and (iii) integral control, which is

proportional to the cumulative difference between the observed and the desired states. A combination of all three types could be ideal to approximate the optimal control policy by adaptive policies (Kumar, 1969).

However, the feedback control policy could be interpreted as an error-correction mechanism in which the error-correction, or feedback, leads to a simple method for determining optimal control actions based on the deviation of target variables from their desired values. Thus the condition of the economy, i.e. growth rate or inflation rate, is fed back to determine the policy setting, i.e. exchange rate or domestic credit respectively. Figure 2 shows a block diagram representation of the feedback control policy mechanism.

Any dynamic system is designed to reach a target or to follow a desired path through time. A special case of a policy target problem is the *Type II fix* in British terminology – a form of control in which the instrument is adjusted period by period by exactly the amount needed to contemporaneously eliminate any deviation of the target variable from its desired value (Church *et al.*, 1996). This type of control will be used in the policy experiments in the following section.

Policy experiments using optimal control

Traditionally, optimal control problems in economics are solved as quadratic linear programming problems where the objective function, which is a quadratic function, is minimized, subject to a set of linear equations, called the system equations. The objective function is specified as a scalar function of the values of the endogenous variables (targets) and policy instruments over the planning period. The optimal

control problem is then to find the values of the policy instruments that, together with the resulting predicted values of the endogenous variables, minimize the objective function, penalizing squared deviations of the state variables from its target values, and penalizing changes in the instruments. The loss function:

$$J = \sum_{t=1}^T k_{1t}[x_t - x_t^*]^2 + k_{2t}[u_t - u_{t-1}]^2$$

is minimized subject to the system equations:

$$x_{t+1} = A_t x_t + B_t u_t + C_t z_t + c_t$$

where x = state variables, u = control variables, x^* = desired paths for state variables, k_1 = penalty weights for state variables, k_2 = penalty weights for control variables, z = exogenous variables, c = constant terms.

In the cost function, relative penalties are attached to the deviations of actual values of endogenous variables from their desired values to reflect the policymaker's priorities. Relative weights applied to the presence of the path of the instrument variables in the objective function may reflect the extent to which certain policy instruments can be used, or the desirability of relatively smooth changes in policy instruments. The k_1 coefficients give the relative costs of deviating from the desired paths of each state variable to be tracked, while the k_2 coefficients give the relative costs of changing the control variables from one period to the next. Where the loss function is quadratic and the dynamic system is linear, the solution gives a control policy in the form of a linear feedback rule, i.e. the optimal policy is a linear function of lagged endogenous variables and the exogenous factors including the desired values of the target variables. The estimated model is then used to trace the optimal control trajectories and the associated trajectories of the endogenous macroeconomic aggregates (state variables). The path that the adjustment programmes take can be seen in the context of policy experiments that we undertake using the estimated macroeconomic model.

One way of specifying the penalty weights to each of the elements of the cost function is to set what are known as 'equal priority values', which are typically inversely proportional to the scale of the terms involved. While this method of assigning equal priority values determines the scales of weights, the actual levels of the weights (constants of proportionality) must still be determined carefully and any differences in weights will give rise to differences in optimal policies. We have calculated the value of the loss function by fixing the weights by choosing equal

priority values such that each term in the loss function leads to equal cost for all variables after optimization. The optimal control solutions have been obtained using Program SLIM for the solution of large macromodels developed at the Macroeconomic Modelling Bureau of the University of Warwick.

The deterministic optimal control problem is to find u_t that minimizes the welfare loss function (J), given the dynamic system. We compare the optimal solutions with the historical data over an experimental period of 5 years between 1991 and 1995. We chose the period 1991–1995 to reflect the important change in policy regime. In the year 1991, the Indian economy had BOP deterioration and there was exchange rate devaluation, which led to a sudden jump in the price level in 1991. In order to improve the foreign reserve position, India had to go for both devaluation and tight domestic credit policy in line with IMF conditionality. Since the mix of these two policies (devaluation and tight credit policy) has been used to achieve both the targets from 1991 onwards, this period for our control exercise would enable us to examine the policy trade-off. The desired trajectories of the target variables are set at 1 percentage point fall in inflation rate, 2 percentage point rise in output growth rate and 3% increase in change in international reserves.

Experiment 1. In the first run we are mainly concerned with examining how well the optimal paths of the state and control variables track their paths within a two-target and two-instrument problem usually embodied in a Fund-sponsored stabilization package for DEs. The key macroeconomic instruments that are often present in the discussion of stabilization policies are the credit restrictions and the exchange rate policy to control BOP deficit and inflation. In other words, the IMF stabilization arrangement is based on a Tinbergen type of static or comparative static fixed target model. In such models it is almost always desirable to choose two instruments for two targets. Given a desired increase in BOP of 3% and reduction in inflation of 1 percentage point, the two instruments exchange rate and domestic credit, can be chosen to meet the targets.

In a flexible target dynamic economic model we use a quadratic objective function – a loss function to be minimized, where the loss is measured in terms of deviation of the state variables from the target values and a quadratic cost function associated with the use of instruments. Weights assigned in the objective function to the various components of the loss are

Table 2. Specification and value of the objective function

	Desired value	Weight	Value of the loss function J	Change in J (%)
Targets:			2.6247	2.25363
Inflation	1%	1		
Change in reserves	3%	3.81×10^{-5}		
Instruments:				
Exchange rate	Base	8.94×10^{-6}		
Domestic credit	Base	3.45×10^{-14}		

Table 3. Trajectories of price and balance of payments: differences from base solution

	Actual INF	% diff	Actual ΔR	% diff
1991	12.87	-1.01	12433.72	0.02
1992	9.58	-0.99	6894.75	3.03
1993	8.02	-0.99	29675.75	2.99
1994	10.31	-0.98	19359.88	2.99
1995	7.40	-0.92	-5395.51	2.74

chosen according to the equal priority values, which are presented in Table 2.

The time paths of the targets with differences from the base solution that minimize the loss function are presented in Table 3, and the optimal controls are displayed in Table 4.

Tables 3 and 4 suggest that there is a trade-off between the two instruments in order to achieve the targeted change in reserves and inflation. Among these two different policy objectives, the objective of low inflation can be achieved at the expense of deterioration in the reserve position. Here we analyse the trade-off relations between inflation and a change in reserve position. Given the targeted rates of increase in foreign reserves, an improvement in the BOP in 1991 requires a choice of instrument with a direct impact, i.e. devaluation in exchange rate, which could help improve BOP. Since the exchange rate has a direct impact on price level and when inflation reduction is targeted, exchange rate appreciated in 1991. This exchange rate appreciation reduces export demand and hence we cannot achieve the BOP target, which is precisely the reason why change in R is off-target in 1991. The other instrument which can influence reserve change is domestic credit, which declined by 1.69% in order to increase R by 0.02%. However it is off-target, and in the next year since DC influences P with a lag in the excess demand term (which also enters export price and import demand equations), the two instruments together

Table 4. Trajectories of instruments: differences from base solution

	Actual E	% diff	Actual DC	% diff
1991	24.47	-0.91	293199	-1.69
1992	30.65	-1.39	336080	-4.64
1993	31.37	-0.96	373987	-3.56
1994	31.39	-2.20	451646	-3.16
1995	33.45	-4.21	538562	-0.0002

Table 5. Trajectories of output and investment: differences from base solution

	$GDPFC$ (% diff)	$PVTCF$ (% diff)
1991	-0.37	-2.71
1992	-1.07	-7.21
1993	-1.07	-7.77
1994	-1.09	-2.76
1995	-0.45	1.76

bring down inflation and the foreign reserve target is achieved.

There was a 1.69% credit contraction and 0.91% appreciation in exchange rate in 1991. In the following year there was 1.4% appreciation and 4.64% credit contraction to achieve a 1% reduction in inflation and 3% rise in reserves, relative to base-run values. A cut in domestic credit reduces money supply, lowers price levels, and increases foreign reserves. In reality, what the monetary authorities usually do is to manipulate available monetary policy instruments to control the amount of net domestic credit in order to attain the desired amount of domestic liquidity, derived from the money demand function. If the foreign reserves exceed the required domestic liquidity, there has to be some degree of currency appreciation in order to achieve the 3% increase in reserve change.

However, credit control and exchange rate changes are not sufficient to achieve multiple economic targets. The effect of credit restrictions often leads to drastic declines in private investment, which has an adverse consequence upon output growth. As the credit restraints raise the rates of interest, it increases firms borrowing costs, which in turn inhibit investment. Table 5 shows the responses of output and investment to the policy obtained above. Since output is not targeted in this kind of stabilization exercises, output tends to decline during the adjustment process, which is obvious from Table 4. This, of course, is the real side of the picture, where the transmission mechanism leads to output contraction as a result of tighter credit policy. We conclude that the IMF's financial programming model is

Table 6. Specification and value of the objective function

	Desired value	Weight	Value of the loss function J	Change in J (%)
Targets:			18.9085	0.561297
Inflation	1%	1		
Output growth	2%	0.249999		
Change in reserves	3%	3.81×10^{-5}		
Instruments:				
Exchange rate	Base	8.94×10^{-6}		
Domestic credit	Base	3.45×10^{-14}		
Public investment	Base	2.30×10^{-11}		

Table 7. Trajectories of three targets and three instruments: differences from base solution

	INF (%diff)	ΔR (% diff)	Growth (%)	E (% diff)	DC (% diff)	$PUBCF$ (% diff)
1991	-0.38	0.002	0.015	-0.344	-0.81	-15.42
1992	-0.24	0.988	0.821	-0.316	-2.87	-34.89
1993	-0.45	1.125	0.823	0.427	-2.96	-50.81
1994	-0.21	0.679	1.874	0.793	-3.03	-47.27
1995	-0.15	10.349	0.813	0.972	2.76	0.04

incomplete as a growth-led model and hence inadequate as a framework for policy formulation. But that may be because of the fact that policy objective function is not sufficiently general.

Experiment 2. In this run we also include a growth objective and try to derive macroeconomic policies with the following targets: a 2 percentage point increase in growth trajectory, a 1 percentage point fall in inflation trajectory, and a 3% rise in foreign reserves. In a policy package, it is co-ordination rather than specialization of policies among the authorities that is important. When the number of targets exceeds the number of instruments, not all targets can be attained simultaneously by optimal control.⁷ Besides change in domestic credit and exchange rate, we consider public investment expenditure as an additional policy instrument (fiscal) to target output, because $PUBCF$ not only constitutes a component in the aggregate demand but also adds to the productive capacity of the economy in mitigating the demand pressure. These three policy instruments must be determined jointly in order to achieve the targets set in a financial programme of growth-led adjustment, since various sectors interact with one another in the economy. The penalty weights associated with the objective function are given in Table 6.

We draw the conclusion from Table 7 that it is not possible to attain the objective of low inflation, high growth and BOP improvement simultaneously (as reflected by the percentage deviations for these variables coming in under target). The target growth path is 2 percentage points higher than base. Output along the optimal path is less than the target path except for the year 1994, when the growth target of 1.87% is achieved. Optimal inflation is always less than is indicated by the target path. Optimal output growth increased by about 2 percentage points in 1994. The departures from target path can be explained by a number of variables influencing the output. The impact of monetary policy on output can be seen from the credit availability to the private sector, as credit forms an important input in the production system. The credit channel of monetary policy transmission on growth also raises the question of sustainability of such financing from the point of view of its implications for inflation, which would require reducing credit flow to the government so as to contain the monetized deficit.

There is an important policy lesson to be learned from Table 7. As there are policy trade-offs and we cannot target all three variables using the three instruments all the time, one could consider time phasing the policies, so as to target two targets for a few years and two other targets in subsequent years. This will require choosing time-varying policy

⁷ It should, however, be noted that in a model with a quadratic objective function only the necessary conditions, or first-order conditions, give rise to a system of simultaneous linear equations that will have unique solutions only if this condition is satisfied. If the objective function is in general non-linear and not quadratic, this condition may not hold.

weights in the policy objective function. In fact in policy debates, there have been discussions about sequencing and phasing of economic reforms. This could be demonstrated by choosing different time sequences of policy weights for different phases of economic reforms and examining the state variable part of the objective function alone, leaving the cost of controls aside.

Notwithstanding, the model as demonstrated in the simulation suggests that there is a crowding-out effect of public investment being fed back through the error correction mechanism. In our control simulations, public investment declined by about 51% in 1993 to achieve the 2 percentage point rise in output growth in 1994. This essentially implies that the government should get rid of activities that are more efficiently undertaken in the private sector. Moreover, as upgrading of the infrastructure and human capital base cannot be financed by domestic credit to government due to its monetization effect,⁸ it would be preferable to adopt a non-inflationary means of financing, such as privatization of the inefficient public sector enterprises (PEs). Due to the poor performance of the majority of PEs and increasing financial burdens and constraints, almost all countries (both developed and developing) continue to implement privatization programmes.⁹ Historically India has a track record of overestimating the amount it would receive from privatization.¹⁰ As the proceeds from privatization come in under target, fiscal deficit is financed by higher market borrowing thereby crowding-out the private sector from the debt market in the short term and creating a tight liquidity situation. In the long term, such growing deficit¹¹ has the potential to harm the growth prospect of the private sector in India.

Exchange rate policy affects prices quite significantly in the sense that a 10% devaluation influences price level by 9% as it has a direct impact through traded goods prices and prices of imported raw materials.¹² When devaluation induced price increase in 1993, a tight credit policy brought it down. It is conceivable that depreciation in the exchange rate first increases import prices relative to domestic prices and decreases export prices relative to the

world price level. These in turn tends to increase foreign reserves via rise in export earnings. Since there is an exchange rate appreciation to reduce inflation in 1991, foreign reserve target was not achieved. Furthermore, any attempt to raise rate of growth of output translates into an increase in imports, for imports being determined by income. Due to devaluation in later periods, the increase in foreign reserves becomes a source of monetary expansion unless domestic credit is further restricted. This is the general rule about the channel through which a change in the exchange rate affects the BOP and domestic prices. However, using all three instruments simultaneously and optimally, it has not been possible to attain our target values for each of the target variables due to their differential effects on the targets. Monetary policy instrument (*DC*) has a comparatively stronger effect on *R*, and the fiscal policy instrument (*PUBCF*) has a relatively stronger effect on *GDPFC*. Output growth achieves its target level in 1994. The reasons why output does not respond to the policy instruments more vigorously include the increased cost resulting from exchange rate changes and credit constraints. The latter arising from the restrictions imposed on bank credit to control monetary aggregates for an increase in reserve change. The contractionary impact of tight monetary policy on output (as shown in Table 7) can be offset by a reduction in credit to the government.

The welfare loss from control using three targets and three instruments is very high, essentially because it is difficult to achieve the targeted low inflation with high growth and hence there are no potential gains for control. It may be desirable to control the economy with alternative instruments to stimulate growth. The crucial instrument on the monetary side would be to ensure that domestic credit to the private sector is not affected, especially when there is a general collapse in domestic demand. Similarly, on the fiscal side, it is necessary to ascertain that the public investment especially on infrastructure does not get hammered in the adjustment process.

Rao and Singh (1997) executed one-period optimal control solutions involving (i) the growth rate,

⁸The fiscal deficit continues to overshoot the budget assumptions by a large margin, which remains a cause for serious concern, as it is squeezing liquidity in the market. And, structural rigidity in government current spending makes it difficult to slash the deficit as targeted in each year's budget.

⁹The government of India has placed a high priority on market-driven policy reforms. At the same time there has been a gradual withdrawal of budgetary support to PEs encouraging such enterprises to tap the capital market.

¹⁰In the decade 1991–2000 the government could manage to get 40% of what it targeted in privatization proceeds so as to contain the fiscal deficit (Source: CMIE).

¹¹The combined central and state government deficits currently exceed 10% of GDP, threatening a broader economic crisis.

¹²This feature of 'exchange rate pass through' phenomenon has also been examined in a recent disaggregated trade model by Krishnamurty and Pandit (1997).

inflation rate, interest rate and foreign exchange reserves as the primary targets; and (ii) the exchange rate, tax rates, domestic credit allocation and market borrowings as the primary instruments. But they neither took into account the importance of exchange rate as an argument in the price equation nor considered the implied trade-offs between targets. They predicted a 5.4% real growth rate and a 10.9% inflation rate for 1994–1995, whereas we obtain 8.2% real growth rate and 10.1% inflation rate for the year 1994–1995. Their objective function evaluated the loss incurred as a result of any deviations between the actual values of the instruments and targets from their desired values, associated with each policy, rather than tracking the changes in instruments as in our objective function.

The results from this exercise suggest that in the period 1991 to 1995, it would have been better, in terms of improving growth, if there had been more emphasis on both demand and supply side policies for the goal of higher growth. So the results show that the most effective policy instrument would be the manipulation of the domestic credit and public investment. Any optimal policy required to accommodate stabilization with growth needs to have a greater allocation of domestic credit to the private sector and, by creating space in the public sector budget (through reduction in public investment in sick industrial units) to increase public investment on infrastructure. This should raise private sector investment in the long run thereby resulting in higher output growth.

IV. Conclusion

An attempt has been made in this paper to develop a policy framework to avoid output collapse, while designing a growth-oriented adjustment programme in order to stabilize the economy at a low inflation and high growth within a macroeconomic system, which ignores uncertainties in the parameters and regression equations. Carrying out dynamic simulation and optimal control exercises, this paper finds that policies such as pursued under an IMF-supported adjustment programme tend to lower inflation and improve external balance, but does not lead to higher growth. This paper solved a multi-target and multi-instrument optimal control problem and finds that the two-target two-instrument problem of a standard policy package is not growth-inducive. Output growth needs to be targeted while designing a growth-oriented adjustment programme. An explicit focus on the credit channel in monetary policy

transmission (improving the credit delivery system to the private sector), and public investment on infrastructure, are better for growth and price stability rather than resorting to excessive devaluation. This is one of the several significant policy conclusions that depart from the traditional views held by reformers. In an attempt to improve fiscal prudence in India, there has been a drastic fall in the government's capital expenditure without any cut back in government's consumption expenditure, partly due to structural rigidity in government's spending pattern. This raises concerns about the sustainability of India's long-term growth potential.

Control experiments revealed that with equal priority penalties on the state and control variables using welfare maximization, it was possible to attain a 2 percentage point rise in growth only in the year 1994 during a five-year control horizon with a lower percentage point reduction in inflation. But the optimal trajectory of inflation turned out to be about its desired level, and reserves at its desired level, within the IMF's policy framework, though not in the extended framework where output is used as an additional target. It would be desirable to consider alternate sets of target and instrument variables, two each at a time to see what would happen to the third target variable in each case. Also the policy weights are based on a particular criterion of equal priority values. If the criterion of equal priority is altered, the optimal solution could be sensitive to changes in these weights.

Although the essential purpose of any optimal control model is to plan for the future, we have carried out the experiments over a historical period in order to avoid the difficulties that arise in the choice of the future paths of the exogenous variables. In effect, this is a counterfactual exercise showing how things could have been done differently in the past, which has a long tradition in control exercises. However, in order to have adjustment with growth, we need to target output growth using other instruments in addition to the two-targets-two-instruments policy framework of IMF. Surely the point is that the 2–2 framework neglects other variables, and when these are taken into account the true costs of these policies are observed. The question that remains to be answered is what could be a more realistic objective function. Besides providing some ideas of the optimal paths for various policy strategies, the control technique is complementary to the traditional simulation procedures in macroeconomic modelling. Thus macroeconomic model simulation and optimal control techniques could be

effectively used for policymaking in an alternative manner.

Acknowledgements

This paper has been derived from the Author's Ph.D. research at the University of Warwick. The author thanks Kenneth F. Wallis, T. Krishna Kumar and Santonu Basu for their useful comments and Peter R. Mitchell for his help on optimal control solutions. Any remaining error is the author's alone.

References

- Aghion, P., Bacchetta, P. and Banerjee, A. (2001) Currency crises and monetary policy in an economy with credit constraints, *European Economic Review*, **45**, 1121–50.
- Basu, S. (2002) Financial fragility: Is it rooted in the development process? – An examination with special reference to the South Korean experience, *International Papers in Political Economy*, **9**, 1–50.
- Bernanke, B. S. and Gertler, M. (1995) Inside the black box: the credit channel of monetary policy transmission, *The Journal of Economic Perspectives*, **9**, 27–48.
- Britton, A. (Ed), (1989) *Policymaking with Macroeconomic Models*, Gower, Aldershot.
- Calvo, G. A. (2000) Balance of payments crises in emerging markets: large capital inflows and sovereign governments, in *Currency Crises* (Ed) P. Krugman, University of Chicago Press, Chicago.
- Cerra, V. and Saxena, S. C. (2002) What caused the 1991 currency crisis in India? *IMF Staff Papers*, **49**, 395–425.
- Chand, S. and Sen, K. (2002) Trade liberalization and productivity growth: evidence from Indian manufacturing, *Review of Development Economics*, **6**, 120–32.
- Chow, G. C. (1975) *Analysis and Control of Dynamic Systems*, Wiley, New York.
- Church, K. B., Mitchell, P. R., Smith, P. N. and Wallis, K. F. (1996) Targeting inflation: comparative control exercises on models of the UK economy, *Economic Modelling*, **13**, 169–84.
- Dornbusch, R. (1990) Policies to move from stabilization to growth, in *Proceedings of the World Bank Annual Conference on Development Economics*, World Bank, Washington, DC.
- Easterly, W. (1999) The ghost of financing gap: testing the growth model used in the international financial institutions, *Journal of Development Economics*, **60**, 423–38.
- Greenaway, D., Morgan, W. and Wright, P. (2002) Trade liberalization and growth in developing countries, *Journal of Development Economics*, **67**, 229–44.
- Hall, S. G. and Stephenson, M. J. (1991) Optimal control of stochastic non-linear models, in *Dynamic Modelling and Control of National Economies* (Ed) N. Christodoulakis, Pergamon Press, Oxford.
- Holly, S., Rustem, B. and Zarrow, M. B. (Eds), (1979) *Optimal Control for Econometric Models*, Macmillan, London.
- International Monetary Fund, (1987) Theoretical aspects of the design of fund-supported adjustment programs. Occasional Paper, IMF Washington, DC, September.
- Kendrick, D. A. (1981) *Stochastic Control for Economic Models*, McGraw-Hill, New York.
- Khan, M. S. and Kumar, M. S. (1997) Public and private investment and the growth process in developing countries, *Oxford Bulletin of Economics and Statistics*, **59**, 69–88.
- Khan, M. S., Montiel, P. and Haque, N. U. (1990) Adjustment with growth: relating the analytical approaches of the IMF and the World Bank, *Journal of Development Economics*, **32**, 155–79.
- Krishnamurty, K. and Pandit, V. (1997) Exchange rate, tariff and trade flows: Alternative policy scenarios for India, *Journal of Asian Economics*, **8**, 425–54.
- Kumar, T. K. (1969) On the existence of an optimal economic policy, *Econometrica*, **37**, 600–12.
- Livesey, D. A. (1979) The role of feedback in macroeconomic policy, in *Optimal Control for Econometric Models* (Eds) S. Holly, et al., Macmillan, London.
- Mallick, S. K. (2001) Dynamics of macroeconomic adjustment with growth: some simulation results, *International Economic Journal*, **15**, 115–39.
- Mallick, S. K. (2002) Determinants of long-term growth in India: a Keynesian approach, *Progress in Development Studies*, **2**, 306–24.
- Mallick, S. K. (2004) A dynamic macroeconometric model for short-run stabilization in India, *Applied Economics*, **36**, 261–76.
- Pierse, R. (1997) WinSolve Version 2.42: A computer package for solving nonlinear macroeconomic models. Department of Economics, University of Surrey, UK.
- Pindyck, R. S. (1973) *Optimal Planning for Economic Stabilization*, North-Holland, Amsterdam.
- Polak, J. J. (1998) The IMF monetary model at 40, *Economic Modelling*, **15**, 395–410.
- Przeworski, A. and Vreeland, J. R. (2000) The effect of IMF programs on economic growth, *Journal of Development Economics*, **62**, 385–421.
- Rangarajan, C. (1998) Development, inflation, and monetary policy, in *India's Economic Reforms and Development: Essays for Manmohan Singh* (Eds) I. J. Ahluwalia and I. M. D. Little, Oxford University Press, Delhi, pp. 48–72.
- Rao, M. J. M. and Singh, B. (1997) Liberalization and growth-oriented structural adjustment programs: a financial programming approach for India, in *Dynamics of Globalization and Development* (Eds) S. D. Gupta and N. K. Choudhry, Kluwer Academic Publishers, London.
- Rodriguez, F. and Rodrik, D. (2000) Trade policy and economic growth: a skeptic's guide to the cross-national evidence, *NBER Macroeconomics Annual*, **15**, 261–325.
- Storm, S. (1997) Domestic constraints on export-led growth: a case study of India, *Journal of Development Economics*, **52**, 83–119.
- Tinbergen, J. (1952) *On the Theory of Economic Policy*, North-Holland, Amsterdam.
- Turner, D. S., Wallis K. F. and Whitley, J. D. (1989) Using macroeconometric models to Evaluate Policy Proposals, in Britton (1989).
- Wallis, K. F. (1995) Some recent developments in policy making with macroeconometric models, in *Time Series Analysis and Macroeconometric Modelling: The Collected Papers of Kenneth F. Wallis*, Edward Elgar, Cheltenham, pp. 385–406.