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# Revisiting policy combinations under IS–LM–EE framework introducing capacity utilization

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**Abstract**
The study introduces the capacity utilization factor into the existing works on the effect of technological progress towards environment friendly capital formation to analyse the impacts of fiscal and monetary policies in an IS–LM framework and concludes that the effects of fiscal and monetary policies on conservation capital and permit cost in the presence of technological progress cause increases in output, but these increases will centre around the full capacity utilization level. Further, the empirical exercise in a pooled regression model involving the income-influencing factors through fiscal and monetary policies shows that technological progress endowed with emission intensity and capacity utilization dummy for the world's 28 countries, confirms the theoretical results in most circumstances. The study signifies the role of institutions and technological progress as the backbone to frame fiscal and monetary policies as an effective instrument for getting green growth.

**Keywords** IS–LM · EE · Sustainability · Technological progress · Permit cost · Capacity utilization · Pooled regression

## 1 Introduction

The necessity of analysing the standard macroeconomic demand side equilibrium, the IS–LM model, with the incorporation of the concept of environmental sustainability, has been primarily felt in the later part of the twentieth century. Its latest development is the introduction of the effects of technological progress on environmental capital, also known as conservation capital, in the presence of a permit market that analysed the fiscal and

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monetary policy effects upon economic growth maintaining environmental stability. The Introduction of environmental aspects into the aggregate economic activity has been first considered by Daly (1991a, 1991b).[1] He proposed the treatment of environmental factors as the crucial elements of macroeconomics, besides all of the microeconomic attention to the environment paid by Pigou (1920), Baumol and Oates (1992), Pearce and Turner (1991), among others. Till date there have been developments in the subject under different specifications of the related factors. The work of Heyes (2000), probably the first after Daly (1991a, b), tries to incorporate the environmental sustainability function into the traditional goods and money market equilibrium (IS–LM), under the assumption that man-made physical capital and natural capital are substitutes for each other, and so the interest sensitivity of the natural capital to the rate of interest is positive since the sensitivity of the physical capital to rate of interest is negative. Further, the study considers that the relative magnitude of interest sensitivity of the natural capital is lesser than that of physical capital, which leads the IS curve to be flatter than the environmental sustainability curve (EE curve). The EE curve stands for sustainability of the use of environment in the sense that the amount of pollution generated by any economic activity should be exactly equal to the rate of renewal or regenerative capacity of nature. Heyes (2000) concluded that expansionary fiscal policy should be accommodated by contractionary monetary policy, and expansionary monetary policy should be accommodated by contractionary fiscal policy if the objective of the planner is to maintain environmental sustainability. Both of the policy parameters were considered to be exogenous. Further, it is also assumed that expansionary monetary policy is a better and more acceptable policy compared to the fiscal one, as it obtains the result of expansion in output along the line of optimal use of nature. In his work Heyes (2000) did not consider the effects of technological innovation on the conservation of capital, the role of pollution permits and the complementarity relation between physical and natural capitals. Lawn (2003a, b) has tried to extend the Heyes (2000) model by considering the role of pollution permit and technological progress in the conservation of capital. Lawn (2003a, b) showed that exogenous expansionary or contractionary monetary policy in response to expansionary fiscal policy may not be required to maintain sustainability of the economic activity if continuous progress is made in favour of greener technologies. In the next phase, Sim (2006) extends the IS–LM–EE framework of Heyes where exogenous fiscal or monetary shocks are needed so that the intersection of all three schedules is reached through a naturally adjusting process. Decker and Wohar (2012) denied the hypothesis of the substitution of the environmental capital for the physical capital, and argued instead for the complementariness of the environmental capital and the physical capital, and showed that the EE schedule with the positive slope was steeper than the LM schedule. They also recommended a tight monetary and expansionary fiscal policy be adopted to promote economic growth and maintain the equilibrium of the environmental schedule. In the recent past, Zhang and Lee (2017) revised the IS–LM–EE schedule model in the existing literature and discussed the stability conditions and the policy significance of the equilibrium point of the IS–LM–EE model under the complementary relationships between physical and natural capital.

A few works have been surveyed further to support the justification of using the factor ‘capacity utilization’ in the earlier models in order to explain inflation rates to link up with pollution permit costs. First, the study of Hamberg (1952), clearly distinguished between the full employment level of growth and the full capacity level of

[1] In this context one can also read some recent articles like Halkos and Paizanos (2015) and Rezai and Stagl (2016).

growth. The shortfall of full employment level compared to the full capacity level is the phenomenon of the present world economy. According to Gittings (1989), there have been inverse relations of one period lag between capacity utilization and inflation for the US economy for the period 1972–1988. In the late '80s, capacity utilization increased and the inflation rate decreased. This is a crucial observation so far as the effect of permit cost on product prices is concerned in the present study. A similar inverse relationship between the two was also observed by Finn (1996) for the period 1953–1995. Moreover, the study found a positive relation between low capacity utilization and high inflation during the periods of the energy crisis of the 1970s. In another research de Kock and Nadal-Vicens (1996) analyse whether capacity utilization in the manufacturing sector is a suitable indicator of inflation across countries for data from 1970 onwards. Through different variants of Granger causality tests, the study found that manufacturing capacity utilization has marginal predictive power for inflation in some OECD countries. But in the case of the US, there had been strong evidence that change in manufacturing activity had impacts on inflation through increases in the labour cost. Dotsey and Stark (2005) observed that the relationship between utilization and inflation for the US manufacturing industries could be tricky or unusual because it was sensitive to which fundamental factor is driving the economy and how monetary policy responds to those fundamentals; this makes the relationship quite complex and conditional to economic circumstances. Concerning the role of imperfect competition on capacity utilizations, Dixon and Savagar (2017) claim that firms' entry causes endogenous fluctuations in macroeconomic productivity through its effect on the capacity utilization of the incumbent firms, and show that imperfect competition causes long-run excess entry, leading to the presence of many small firms, each with excess capacity.

### 1.1 Motivation and contribution of the study

The study starts with the work of Heyes (2000) and Lawn (2003a, b) to examine theoretically and empirically the fiscal and monetary policy combinations upon green growth coupled with capacity utilization in a standard IS–LM model incorporating environmental sustainability as considered in the earlier two studies. The existing literature supports the idea that there should be a linkage between capacity utilization and inflation, and that this leads to endogenous monetary policy shifts, rather than exogenous policy shifts, which the present study seeks to apply.

The present study contributes to the existing literature on the IS–LM–EE framework by incorporating the capacity utilization factor. We conclude that the effects of the fiscal and monetary policies on the income or output of the economies are not perpetual to the extent of the full technological progress; rather, they stick to the level corresponding to the full capacity utilization. We offer a theoretical analysis and empirical verifications to justify our conclusion.

The paper is structured as follows. Section 2 reviews the existing literature on the IS–LM–EE framework and presents research gaps. Section 3 describes the background story behind ecological macroeconomics augmenting with capacity utilization, and Sect. 4 illustrates the dynamic model. Empirical validation of our theoretical model and conclusions are made in Sects. 5 and 6 respectively.

## 2 Brief review of the literature on IS–LM–EE

Ecological macroeconomic models often start with a Keynesian flavor by considering that the production may remain below the productive capacity of the representative economy. Daly (1991a) has been the first to adopt ecological macroeconomics to illustrate the significance of the environment when dealing with macroeconomic issues. Daly (1991a) illustrated the macroeconomic issues raised by Pigou (1920), Baumol and Oates (1992) in the presence of the environment. Later Heyes (2000) modified the Daly's (1991a, b) text book version of ecological macroeconomics by incorporating the environmental equilibrium curve or EE curve within the standard IS–LM model. The institutional argument is adopted in Heyes (2000), and it shows shifts in the EE schedule following any change in the institutional parameters of a society. Again, Daly and Farley (2011) have suggested enforcing an external constraint on an IS–LM model and framed the IS–LM–EC structure to illustrate the biophysical limits of ecosystems. By advancing over earlier works on ecological macroeconomics, Lawn (2003a, b) and Sim (2006) have attempted to make the IS–LM–EE framework a more policy-effective in terms of the IS–LM model. Lawn (2003a, b) has used the same IS–LM–EE model adding the technological parameter. Lawn (2003a, b) has used IS–LM–EE and illustrated that monetary policy of either form in response to expansionary fiscal policy may not be required to maintain the sustainability of the economic activity if continuous progress is made in favour of greener technologies. Unlike Lawn (2003a, b), Sim (2006) has proposed a model of IS–LM with EE to derive a socially optimum solution. Sim (2006) has showed that fiscal or monetary shocks are required to reach the simultaneous intersection of all three schedules reached through a naturally adjusting process. Moreover, Sim (2006) has shown that the expansionary fiscal policy may lead to poor environmental quality and lower planned expenditure. Under such circumstances Sim (2006) has proposed strict environmental regulatory standards to reach higher output levels in the long run. Later, Moraes and Serra (2011) extended the IS–LM–EE model by incorporating the international trade argument within ecological macroeconomics. In their article, Moraes and Serra (2011) found that developing countries would export resource-intensive products, while developed countries mainly export manufacturing products by imposing more strict environmental regulations. So far we have dealt with models which are built on the basis of a common assumption—that physical capital and natural resources are substitutes for each other. However, Decker and Wohar (2012) have assumed that physical capital and natural resources are complementary, and following this they have found a positively sloped EE schedule. The new EE schedule gives new results following fiscal and monetary policies (Decker and Wohar 2012). In addition to Decker and Wohar (2012), Zhang and Lee (2017) have also considered the complementarity between physical capital and natural capital under the IS–LM–EE structure to justify the stability and policy significance of the equilibrium point.

From this short review of the literature on the IS–LM–EE framework of ecological economics we find that even though the existing literature has dealt with some macroeconomic and trade related issues within the IS–LM–EE periphery, however, none of these studies has tried to capture the significance of capacity utilization in order to determine the macroeconomic equilibrium. This departure from the existing literature makes our study a novel one. Additionally, we also explore the research gap regarding the stability and policy significance of the long run equilibrium point in the presence of a capacity utilization vector, thus providing our second contribution to the literature.

## 3 Environmental macroeconomic background and rationale of the present study

The present study reviews the existing studies and tries to extend the core studies. First, we point out the limitations of the above studies by dividing them on two grounds—whether physical capital and natural capital are considered substitutes or complements. The studies by Heyes (2000), Lawn (2003a, b) and Sim (2006) consider the substitutability relation, while Decker and Wohar (2012) and Zhang and Lee (2017) choose the complementary relation. Which of the two relations should be considered is an empirical question and the present study has attempted to answer it. We considered the world's top three countries in a quantity of $CO_2$ emissions—China, the USA and India. On the one hand we relate the total $CO_2$ emissions as a share of the gross domestic product (GDP) of the countries with the rate of interest and, on the other hand, the physical capital investment with the rate of interest. The first one stands for the sensitivity of environmental intensity to the rate of interest ($E_r$) and the second one as the sensitivity of physical investment to the rate of interest ($I_r$). Taking the data of the World Bank (www.worldbank.org) on $CO_2$ emissions and gross capitalformation for the period 1980–2017, it is derived that, on average, $I_r < 0$ and $E_r > 0$ for the said period (Table 1). Further, to examine whether the environmental curve is steeper than the IS curve. We calculated their relative magnitudes and found that the magnitude of $E_r$ is lesser than that of $I_r$, which means that the EE curve will be steeper than the IS, not the reverse. Therefore, we consider the substitute relation between the two types of capital and so, we decide to extend the studies of Heyes (2000) and Lawn (2003a, b). We did not consider the similar model of Sim (2006) as it did not consider the effect of technological progress and permit cost, as done by Lawn (2003a, 2003b).

The study of Lawn (2003a, 2003b) is considered to be more advanced than that of Heyes (2000), as the former included the effect of technological innovations in favour of natural capital in the presence of pollution permits. Positive cost of permit provides incentives to the industrial houses to go for low pollution or low entropy energy use state through investment in conserving natural capital. Therefore, our main focus hinges upon the critical analysis of the work of Lawn (2003a, b).

The role of technological progress in producing greener capital goods to maintain long run or sustainable growth of income has been well documented by Lawn (2003a, b) in the IS–LM framework. The idea is a novel one in the sense that it may provoke governments and private production units to invest in conservation capital to achieve green or sustainable growth of income. Exogenous expansionary fiscal policy is accommodated with endogenous monetary policy (through changes in real money balance), and exogenous monetary policy is accommodated by endogenous changes in real money balance due to the increase in product prices induced by the increase in pollution permit cost, which further leads to the reduction of sustainable output. Introducing technological progress would lead to low pollution, low demand for permit, low cost of permit and hence low general price levels, which ultimately results in an increase in real money balance and output. Hence, the increase in the permit cost and goods prices are crucial factors in determining whether real money balance will change and technological progress will be required. But, as the present study shows, the magnitude of an increase in goods price due to an increase in permit cost depends also on the capacity utilization of the industries in particular and the economy in general. The classic work of Hamberg (1952) has clearly shown that full capacity utilization may not be identical to full employment. He defined a ratio—the coefficient of required growth—with $a = Y_f/Y_c$, where $Y_f$ stands for the full employment growth rate and

**Table 1** Case study for China, USA and India (World's three largest emitters of $CO_2$), sensitivity of I w.r.t rate of interest (dI/dr). Source: Computed by the author upon World Bank data

| Year | China | USA | India | China | USA | India |
|---|---|---|---|---|---|---|
| 1980 | | | | | | |
| 1981 | −0.44 | 0.55 | | 0.0135 | 0.0031 | |
| 1982 | | −0.04 | | | 0.0023 | |
| 1983 | | 2.28 | | | −0.0069 | |
| 1984 | 6.64 | 0.43 | | −0.0883 | 0.0035 | |
| 1985 | −132.28 | 0.28 | | 5.1711 | 0.0034 | |
| 1986 | | 0.93 | | | 0.0129 | |
| 1987 | 1.64 | −0.71 | | −0.0472 | −0.0028 | |
| 1988 | −0.86 | −0.20 | | −0.0279 | −0.0036 | |
| 1989 | 1.60 | 1.14 | | 0.0079 | 0.0021 | |
| 1990 | −1.57 | 0.92 | −3.38 | 0.0117 | 0.0023 | 0.0376 |
| 1991 | | 0.01 | 1.31 | | 0.0014 | −0.0007 |
| 1992 | 1.88 | −1.26 | 0.35 | 0.0065 | 0.0091 | −0.0062 |
| 1993 | | 0.78 | −1.86 | | −0.0028 | 0.0171 |
| 1994 | −1.17 | 0.00 | 0.85 | −0.0823 | −0.0015 | −0.0119 |
| 1995 | 0.66 | −0.77 | −3.50 | 0.0252 | 0.0027 | −0.0031 |
| 1996 | 1.41 | 4.14 | −0.98 | 0.0274 | −0.0187 | 0.0017 |
| 1997 | 0.29 | −6.27 | 5.15 | 0.0168 | 0.034 | −0.0053 |
| 1998 | 1.32 | −1.28 | −2.67 | 0.0362 | 0.0081 | 0.0047 |
| 1999 | | 0.21 | 10.43 | | −0.0016 | −0.0118 |
| 2000 | | 0.65 | 0.10 | | 0.0012 | 0.0315 |
| 2001 | −1.21 | 0.21 | −3.34 | −0.0026 | 0.0006 | 0.0602 |
| 2002 | | −0.06 | −4.99 | | 0.0038 | 0.0526 |
| 2003 | 8.38 | 4.21 | −12.15 | −0.0223 | −0.0106 | 0.0339 |
| 2004 | | 0.39 | −11.93 | | −0.0016 | 0.0847 |
| 2005 | −0.85 | 0.09 | 1.88 | −0.0384 | −0.0018 | −0.0223 |
| 2006 | 0.41 | −10.23 | 1.65 | −0.0286 | −0.0144 | −0.0132 |
| 2007 | −0.84 | 0.50 | −13.99 | 0.0152 | 0.0007 | 0.0503 |
| 2008 | | 1.80 | −2.01 | | 0.0012 | 0.0004 |
| 2009 | 2.40 | | −0.03 | −0.025 | | 0.0071 |
| 2010 | 0.14 | | −0.34 | −0.0205 | | −0.0016 |
| 2011 | 0.76 | | −2.84 | 0.0204 | | 0.0203 |
| 2012 | | | 13.84 | | | 0.003 |
| 2013 | 0.91 | | −5.87 | 0.0207 | | −0.0158 |
| 2014 | 1.28 | −28.64 | 8.90 | 0.0047 | 0.2039 | −8E−05 |
| 2015 | | −2.62 | 5.67 | | −0.0281 | 0.0048 |
| 2016 | | 0.46 | −4.44 | | −0.013 | 0.0073 |
| 2017 | | 0.43 | −6.77 | | −0.0094 | 0.0252 |
| Average | −4.76 | −0.99 | −1.11 | 0.22 | 0.01 | 0.01 |

The blank cells show zero values as there were no changes in interest rates in these years. The values of dE/dr > 0 and dI/dr < 0, and the absolute values of dE/dr are smaller than dI/dr which means the EE curve is steeper than IS curves

$Y_c$ for the rate of growth required for the full utilization of capital. So, when a = 1, the two growth rates are equal, and the income growth which will ensure the capacity use of a growing capital stock will also suffice to ensure full employment. This situation represents the ideal growth pattern. When 'a' is more than one (a > 1), the full capacity growth rate is not sufficient to produce the results corresponding to the full employment level. Finally, when 'a' is less than one (a < 1), the situation is typically represented as secular stagnation. Full capacity growth cannot be obtained, because it lies above the full employment growth ceiling. This means that actual or realized growth falls short of the full capacity rate. The result is idle fixed capital and excessive stocks, that is, too much is being saved relative to the economy's capacity to absorb these savings.

Following Hamberg (1952), the present study proposes that if an economy has near the full capacity level of operations, an increase in permit cost may not increase product cost, and hence shifting of the LM curve may be bounded. On the other hand, if there is excess capacity—that is, the imperfectly competitive firms are underutilizing their capacity to influence prices (this is today's phenomenon to decide prices which is claimed by the new Keynesian school)—then an increase in permit cost will greatly influence products costs and the LM will be very much free to shift.

Grounded upon the principal model of Heyes (2000) and the cutting-edge model of Lawn (2003a, b), the present study aims to introduce the concept of Capacity Utilizations into Lawn's structure. We try to show that shifting of the LM curve due to the endogenous changes in the real money balance caused by the changes in permit cost will not be free as in Lawn's model. Instead, the shifting of the LM curve will centre around the optimum capacity utilization.

### 3.1 Conceptual notes on green macroeconomics and capacity utilization linkages

With the substitute relationship between physical and natural capital (as empirical evidence shows), an expansionary fiscal policy (FP) may not be accommodated with exogenous contractionary monetary policy (MP)—as it happens under Heyes—but there will be endogenous contractionary MP due to permit cost which will contract output to ensure environmental sustainability (Naqvi 2015). Introducing technological progress in favour of conservation capital, Lawn showed that there would be a reduction of the permit as well as product costs. As a result, there would be a continuous rightward shifting of LM depending on continuity in technological progress, and output would increase till the maximum capacity of technological progress is reached. Now we consider the case that the economies are not maintaining their full capacity of operation. Expansionary FP-led increase in permit cost and leftward shifting of the LM will then depend upon whether the economies are away from the full capacity level and on how far they are away from the full capacity level. Being away from the full capacity level means the increase in product cost will be magnified due to an increase in permit cost. As a result, LM will shift to a greater extent than the EE curve, and reach equilibrium with the goods sector (or make an intersection with IS). If now technological progress is allowed (as in Lawn), then LM will shift rightward due to low product price, and the shifting will continue till the full capacity level is reached. Hence, the magnitude of technological progress and shifting of LM are limited by the position of the full capacity level. Any further increase in technological progress and rightward shifting of LM will move the economies to the right to the level of optimum capacity, which will again push up the price of the goods and LM will shift back. This result does not match that of Lawn. There is no scope of continuous technological progress in favour of the environment after the full capacity level because that could not increase the capacity of the industries or economies.

A similar logic can also be applied when there is exogenous expansionary MP. The shifting of LM due to continuous technological progress will then be barred by the level of optimum capacity utilization. Hence, there will be a critical level of technological progress and position of LM as predicted by the present study.

### 3.2 Structure of the present study

In the traditional aggregate demand side model, the popular IS–LM model, representing the combination of the goods sector and monetary sector (Hicks 1937, 1981), income and rate of interest were determined without accommodating the optimal use of environmental or natural capital (Jackson et al. 2014). Further, the equilibrium output, employment, rate of interest and price level were determined by combining the aggregate demand side and aggregate supply side. However, the attainment of full employment of all the economic resources was a matter of debate among different schools, starting from the classical Keynesian to today's new Keynesian thinkers (Jackson 2009; Schneider et al. 2010; Røpke 2013, 2016). Full employment is generally explained by the number of people who want the job in the existing wage rate in particular, and factor prices in general, and do get the job (Patinkin 1948; Azam & Feng 2022). Yet, the attainment of full employment of the factors does not necessarily imply that the producing units (private or public) use all of their productive resources at their full capacity levels (Marris 1964; Winston 1974; Betancourt & Clague 1981). In other words, the degree of capacity utilization may not be at par with the full employment level (as evidenced by Hamberg 1952). If capacity utilization is less than the available full employment (or maximum potential output level), then the price of the goods will increase as fewer goods are produced. The gap between maximum potential output and actual capacity output is known as excess capacity, which is one of the important sources of social cost (Franz & Gordon 1993; Gordon 1994; Cecchetti 1995; McCallum 1994; Tinsley & Krieger 2007; Taylor et al. 2016). Such phenomenon is usually noticed with the imperfectly competitive producers, which the New and post Keynesians reveal as the source of unemployment and rigid wages (Kalecki 1935, 1971; Kaldor 1940; Goodwin 1951; Rezai et al. 2013; Fontana & Sawyer 2013, 2016).

Empirical data on average capacity utilization rate as per 2003–04 (unless otherwise specified) shows that the major developed countries use 80–87% of their total capacity in production, while the major developing countries use about 60–70% of their installed capacity (Table 2).

The information on the average capacity utilization thus confirms the claim of the new Keynesians, and it also justifies the proposal of the present study. We can then proceed with our objectives as stated above on the basis of the justifications provided by the existing empirical data.

## 4 Revisiting the IS–LM–EE model in the wake of capacity utilization

In general, the production side uses inputs to produce outputs and meet the existing demand in terms of supply generation. In fact, the possible output or supply of a production unit, mainly determined from the level of capacity, is utilized by the corresponding unit.

**Table 2** Average capacity utilization of major countries. Source: https://en.wikipedia.org/wiki/Capacity_utilization

| |
|---|
| 1. United States 79.5% (April 2008—Federal Reserve measure) |
| 2. Japan 83–86% (Bank of Japan) |
| 3. European Union 82% (Bank of Spain estimate) |
| 4. Australia 80% (National Bank estimate) |
| 5. Brazil 60–80% (various sources) |
| 6. India 70% (Hindu business line) |
| 7. China perhaps 60% (various sources) |
| 8. Turkey 79.8% (September 2008—Turkish Statistical Institute) |
| 9. Canada 87% (Statistics Canada) |

Information in the parentheses indicates the sources of the data

Hence, from the macroeconomic perspective of an economy the capacity utilization ($U$) augmented aggregate supply of commodity market ($Y^S$) equation can be represented as

$$Y^S = f(L) + \gamma U \tag{1}$$

where $Y = f(L); f^{/} > 0$.

Following Keynesian arguments, the ex-ante or planned aggregate expenditure in terms of consumption expenditure ($C$), private investment expenditure ($I$) and public expenditure ($G$) can be represented as the aggregate demand of the goods market ($Y^D$) of the economy with usual interpretations

$$Y^D = C(Y - T) + I(r) + G \tag{2}$$

where $0 < C_Y < 1; I_r < 0$.

Following Eqs. (1) and (2) the excess demand of the commodity market ($EDC$) can be expressed in the following form

$$EDC = Y^D - Y^S = V(Y, r, U) \tag{3}$$

Again, expression (3) can be illustrated alternatively

$$V(Y, r, U) = C(Y - T) + I(r) + G - Y - \gamma U \tag{4}$$

Here, $V_Y = C_Y - 1 < 0; V_r < 0; V_U < 0$.

The dynamic equilibrium of commodity market is attained at

$$\left.\frac{dY}{dt}\right|_{CM} = \dot{Y} = [V(Y, r, U)] \tag{5}$$

By deriving the combinations of Y and r for which such dynamic equilibrium of commodity market (that is, $\dot{Y} = 0$) is satisfied, we obtain the IS schedule, and its slope can be expressed as

$$V_Y dY + V_r dr = 0 \tag{6}$$

$$\left.\frac{dr}{dY}\right|_{IS} = -(\underset{-}{V_Y} / \underset{-}{V_r}) < 0 \tag{6.1}$$

The financial sector is usually described in terms of money market. Money supply in real terms ($M^S$) is often referred to as real balance and is expressed as

$$M^S = (\overline{M}/P) \tag{7}$$

Unlike the IS–LM model, under the IS–LM–EE structure we assume the presence of environmental permit cost ($PM_C$) and its association with the general price level ($P$). In fact, $P$ is dependent upon the permit cost, i.e.,

$$P = \psi(PM_C);\ \psi^{/} > 0 \tag{7.1}$$

Again, whether $PM_C$ influences $P$ depends on the level of capacity utilization ($U$), where the gap of capacity utilization is defined as the difference between actual use of capacity ($Y_A$) and maximum or potential use of capacity ($Y_C$). The dynamics behind the above statement can be represented in the following form

$$\dot{P} = \alpha\left(Y_C - Y_A\right) \tag{7.2}$$

Expression (7.2) further tells us that the sign of $\psi^{/}$ depends upon the gap between $Y_A$ and $Y_C$, i.e., $\psi^{/} > 0$ if $Y_A > Y_C$ or $Y_C > Y_A$, and $\psi^{/} \to 0$ if $Y_A$ is close to $Y_C$. Hence, $\alpha_Y > 0$ if $Y_A > Y_C$ or $Y_C > Y_A$ and similarly to the earlier one $\alpha_Y \to 0$ if $Y_A$ is close to $Y_C$. Hence, by using a similar logic we find $\dot{P} \to 0$ if $Y_A$ is close to $Y_C$. Intuitively this reveals that full capacity utilization makes maximum quantity of production, which leads to the product prices being the lowest possible.

Similarly, demand for money in real terms ($M^D$) can be captured in the following manner

$$M^D = L_1(Y) + L_2(r) = M^D(Y, r);\ M_Y^D > 0, M_r^D < 0 \tag{8}$$

Following Eqs. (7) and (8) the excess demand of the money market ($EDM$) can be expressed in the following form

$$EDM = M^D - M^S = H(Y, r) \tag{9}$$

Again, expression (9) can be illustrated alternatively

$$H(Y, r) = M^D(Y, r) - (\overline{M}/P) \tag{10}$$

here, $H_Y > 0; H_r < 0$.

The dynamic equilibrium of the money market has attained at

$$\left.\frac{dr}{dt}\right|_{MM} = \dot{r} = [H(Y, r)] \tag{11}$$

Deriving the combinations of Y and r for which the above-stated dynamic equilibrium of money market (that is, $\dot{r} = 0$) are satisfied give us the LM schedule and the slope of it can be expresses as

$$H_Y dY + H_r dr = 0 \tag{12}$$

$$\left.\frac{dr}{dY}\right|_{LM} = -(\underset{+}{H_Y} / \underset{-}{H_r}) > 0 \tag{12.1}$$

The other part of the present study on environmental activities gives us the famous EE schedule. In fact, we follow Heyes' (2000) idea in this regard. The economic activity requires the environment ($E$) as an additional input for the accommodation of production residues like smoke, solid waste, noise etc. Again, the environment has its own assimilative or renewable capacity, which is termed the carrying capacity of the environment. Hence aggregate economic activity will be viable only when the total use of the environment is identical to its total regenerative capacity.

Let '$e$' be the environmental intensity of the economic activity (e.g. Emission/GDP) which is treated as one type of factor intensity and can be determined by the aggregate choice of techniques. The environment, being the natural capital, has a substitution possibility with the physical capital or investment, such that $I_r < 0$ leads to $e_r > 0$, i.e. when physical capital is costlier, the producer will go for a decreased pollution abatement activity and use more natural capital. Again '$e$' can be induced by the institutional factor '$\Delta$' which captures environmental regulation (Heyes 2000), and by the technological progress factor, $\beta$ (Lawn 2003a, b), for generating low pollution and energy saving production inputs. To control environmental degradation, the authority can apply unit tax on the polluters, or it can impose a pollution quota on the sources, etc. Therefore, the range of $\Delta$ will be $0 \le \Delta \le 1\,0$. Further, as the value of $\beta$ increases, '$e$' falls, and as a result $Y$ increases. Hence, the factor intensity function will be $e = e(r, \Delta, \beta)$, where, $e_r > 0$, $e_\Delta < 0$ and $e_{r,\Delta} < 0$ and $e_\beta < 0$. The environment intensity economic activity is increasing in the cost of capital (r) and decreasing in the extent to which environmental costs are internal to the user and technological progress. Total employment of environmental services by the economy is, therefore, $e(r, \Delta, \beta)Y$.

Let '$E$' be the physical stock of environment as capital at the time '$t$' and let assume that it self-renews by the amount $sE$, where '$s$' is the rate of renewal. So, the total environmental degradation is expressed as –

$$-(dE/dt) = -\dot{E} = e(r, \Delta, \beta).Y - s.E \tag{13}$$

The steady state environment or the long run environmental stability requires $\dot{E} = 0$

$$Or,\ e(r, \Delta, \beta).Y = s.E \tag{13.1}$$

Therefore, the steady state environment curve (EE) depends upon 'y' and 'r' like IS–LM, and the parameter of our concern, β.

Environmental capital market dynamic equilibrium claim

$$\dot{E} = sE - e(r, \Delta, \beta)Y = F(Y, r, \Delta, \beta) \tag{13.2}$$

Here, $F_Y = -\underset{+}{e(\cdot)} < 0, F_r = -Y \underset{+}{e_r} < 0, F_\Delta = -Y \underset{-}{e_\Delta} > 0, F_\beta = -Y \underset{-}{e_\beta} > 0.$

By deriving the combinations of Y and r for which such dynamic equilibrium of environmental capital market (that is, $\dot{F} = 0$) is satisfied, we obtain the EE schedule, and its slope can be expressed as

$$F_Y dY + F_r dr = 0 \tag{14}$$

$$\left.\frac{dr}{dY}\right|_{EE} = -(\underset{-}{F_Y} / \underset{-}{F_r}) > 0 \tag{14.1}$$

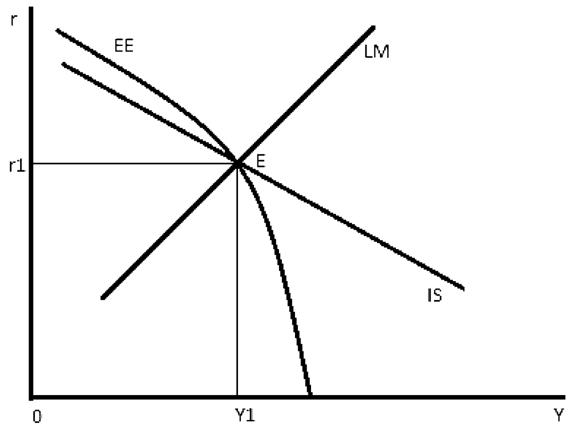


**Fig. 1** IS–LM–EE equilibrium. Source: Drawn by the authors based on the approach of Heyes (2000)

The slope of the EE curve is negative since $e_r > 0$. Along the EE curve, there is a steady state condition prevailing in nature's system, in the sense that the total use of environmental services by economic activity is just equal to the renewal of the environmental services by the natural process (or, $\dot{E} = 0$). There is no need to invest in conservation capital and hence the role of $\beta$ becomes zero. The economic position outside the EE curve means there is a disequilibrium in the environmental services. The right of EE curve means degradation of environment (or,$\dot{E} < 0$) and left of it means environmental upgradation (or,$\dot{E} > 0$). Hence, economic activities should match with any point on the EE curve that gives the IS–LM–EE model. Both IS and EE curves have the same signs in their slopes. In the work of Heyes, it is considered that the EE is steeper than IS i.e. the sensitivity of investment to '$r$' is higher than the sensitivity of the environment to '$r$'. But the reverse case may also arise. However, the present study focuses on the former case, where EE is steeper than IS as it becomes necessary to get stable IS–LM–EE long-run equilibrium.[2]

### 4.1 Environmental macroeconomic equilibrium

The aggregate economic activity will be sustainable in terms of long run condition of the environmental capacity when all three curves (IS, LM & EE) intersect each other. Figure 1 presents the equilibrium.

E is the point where there are balances in the commodity market, money market and sustainability in the environment. This point is called the IS–LM–EE equilibrium which generated Y1 and r1 levels of income and rate of interest respectively. Any activity beyond the ecological carrying capacity creates environmental degradation and reduces the long run sustainable development potential of the economy (Alaimo et al 2021).

### 4.2 Policy effectiveness: present study vis-à-vis lawn

Let us come to the discussion on the comparison of results of fiscal policy (FP) and monetary policy (MP) between Lawn's approach and the approach of the present study. Our mode of analysis is based on the consideration of capacity utilization, which was absent in

[2] Detailed derivations of stability of IS-LM-EE model are illustrated in the appendix.

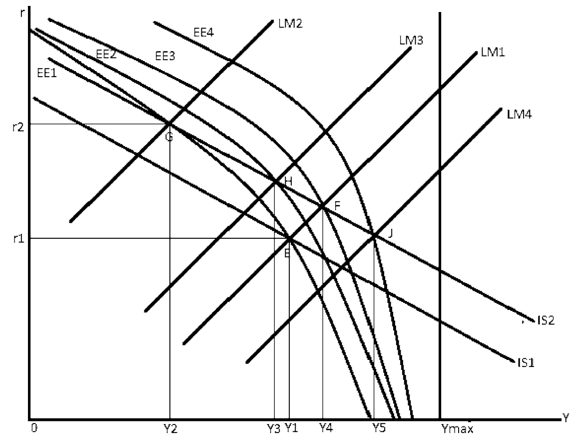


**Fig. 2** Expansionary fiscal policy under Lawn's approach. Source: Drawn by the authors

Lawn's approach. Further, recall that the effect of technological progress on conservation capital is considered in the present study, as well as in Lawn's. In the following paragraphs, we focus first on exogenous expansionary fiscal policy and then on exogenous monetary policy.

### 4.2.1 Expansionary fiscal policy

Figure 2 presents the expansionary FP effects under Lawn's approach. There are different positions of the EE curve depending on the level of technological progress measured by the values of the parameter, β. As the value of β increases the EE curve shifts rightward, generating more output in the long run and becoming inelastic. $Y_{max}$ is the vertical line depicting the maximum output that can be obtained by using all of the technological progress endowed with the economy. This is the limit to technological progress with the available scientific knowledge. E is the initial sustainable equilibrium with IS1 and LM1. Adopting exogenous expansionary increases in public expenses with unchanged monetary instruments, the new equilibrium of the goods and money sector becomes F, which generates more output. However, that extra output is not sustainable as there is environmental degradation through high entropy generation. Such environmental degradation will require demand for pollution permits, which will push up the cost of production and general price level through inflationary effects. As a result, the real money balance (M/P) will go down, leading to a leftward shifting of LM to LM2, where sustainable equilibrium is reached at G, but this is accompanied by a low level of output. Lawn then proposed that technological progress in favour of green technology, in place of paying permit costs, would reduce the cost of production and price of the goods. This, in turn, would increase real balance and result in LM shifting rightward to LM3, LM4…. depending on the level of technological progress. Once it may reach that the price level goes down below the initial value as represented through LM1.

Hence, exogenous expansionary FP will be accommodated first by contractionary endogenous monetary policy, and then by the expansionary endogenous monetary policy until Ymax is reached. There is no limit to this expansion till Ymax.

In our study, we first focus on the expansionary fiscal policy in terms of the expansion of government expenditure (G). To check this, we use comparative steady-state analysis following a change in $G$, and using Eqs. (4), (9) and (13), we get the following expressions. It is to be noted that interactions between IS and LM, and IS and EE give us the overall effect of change in $G$ on Y and r. Following the IS and LM interaction and by using Eqs. (4) and (13) we obtain

$$\frac{dY^*}{dG} = -\frac{\underset{+}{V_G}\underset{-}{H_r}}{\underset{+}{|J_{IS-LM}|}} > 0 \tag{15}$$

$$\frac{dr^*}{dG} = \frac{\underset{+}{H_Y}\underset{+}{V_G}}{\underset{+}{|J_{IS-LM}|}} > 0 \tag{16}$$

Again, to get the impact of an increase in G from the IS–EE model we use Eqs. (9) and (13) and we find

$$\frac{dY^*}{dG} = -\frac{\underset{+}{V_G}\underset{-}{F_r}}{\underset{+}{|J_{IS-EE}|}} > 0 \tag{17}$$

$$\frac{dr^*}{dG} = \frac{\underset{+}{V_G}\underset{-}{F_Y}}{\underset{+}{|J_{IS-EE}|}} < 0 \tag{18}$$

***Remarks 1***

(1) Enhancement of public expenditure augmented with capacity utilization in the form of expansionary fiscal policy leads to an increase in both Y and r following a new dynamic equilibrium. However, such an increase in Y may dominate over an increase in r iff $|H_r| > |H_Y|$.

(2) Enhancement of public investment augmenting with capacity utilization leads to an increase in Y and fall in r following a new dynamic equilibrium under IS–EE model iff $\left|\frac{V_Y}{V_r}\right| > \left|\frac{F_Y}{F_r}\right|$.

Intuitively we can explain the outcomes of expansionary fiscal policy on stationary equilibrium values of Y and r in terms of Eqs. (15) to (18). First, we focus only on the IS–LM structure and hence expressions (15) and (16) tell us the story. An increase in G in the form of expansionary fiscal policy leads to an increase in Y to clear the commodity market. Such increase in Y leads to an increase in partial demand for money; however, other things remain the same, in order to clear the money market speculative demand for money may fall following a rise in r. An increase in r leads to a contractionary effect on private investment, which results in a slight fall in Y, even though overall Y increases owing to a rise in G. We refer to this as the First Crowding Out Effect (FCOE). Moving to the second part we now consider the IS–EE structure to examine the effect of G on Y and r, using expressions (17) and (18). An increase in G produces more Y in order to maintain goods market equilibrium. Again, environmental capital market equilibrium insists to reduce e following a rise in Y. Now for a given r, fall in e is possible if either Δ increases or $\beta$ increases. Let us start with a high value of Δ or strong environmental regulations scenario. Hence, for a given $\beta$, an increase in Δ claims a rise in $PM_C$ and consequently Eq. (7.1) reveals an increase in P as $\psi^{/} > 0$. Note that in this connection Eq. (7.2) reveals the implicit part of the same story in terms of capacity utilization arguments. In fact, $\alpha_Y > 0, \psi^{/} > 0$ and $\gamma < 0$ ensure the short fall of aggregate supply ($dY^* = [-V_U \underset{(-)}{V_Y} / \left|J_{IS-EE}\right|]\, dU$) from the aggregate demand, and consequently generate upward pressure on P. Such a rise in P deteriorates the real money balance (M/P) for a given M. It creates an excess demand situation in money market and to clear it an increase in r becomes necessary. However, such an increase in r ($dr^* = [-V_Y \underset{(+)}{F_\Delta} / \left|J_{IS-EE}\right|]\, d\Delta$) leads to a fall in Y ($dY^* = [V_r \underset{(-)}{F_\Delta} / \left|J_{IS-EE}\right|]\, d\Delta$) following a reduction in private investment to clear the commodity market. Here again we get a short fall of increase in Y following expansionary fiscal policy, mainly due to strong Δ augmented with under utilization of capacity. We refer to this as the Second Crowding Out Effect Augmented with Capacity Utilization (SCOEACU). Again, if we start with a low value of Δ or weak environmental regulations scenario, for a given $\beta$ an increase in Δ augmenting with under utilization leads to a rise in $PM_C$ at a moderate level—or lower compared to the previous scenario. Following this, a moderate level of increase in P may be experienced. Hence, for a given M, such rise in P deteriorates the real money balance (M/P) at a moderate level. It creates an excess demand situation in the money market, and to clear it an increase in r becomes necessary. However, such an increase in r leads to a fall in Y also at a moderate level, owing to a reduction in private investment to clear the commodity market. Compared to the previous scenario here, the volume of SCOEACU will be lower and hence the expansionary fiscal policy will be more effective under a weak Δ regime compared to a strong Δ regime. In fact, it is the value of $F_\Delta$ that causes the changes between the regimes regarding the volume of SCOEACU. Moreover, it can be interesting to consider the scenario where an increase in technological progress towards greener capital formation or higher $\beta$ may reduce the $PM_C$ and consequently a fall in P. Following similar money market arguments, that is, for a given M, such reduction in P enhances the real money balance (M/P). It creates an excess supply situation in the money market and, to clear it, a decrease in r becomes necessary. However, such a fall in r ($dr^* = [V_Y \underset{(-)}{F_\beta} / \left|J_{IS-EE}\right|]\, d\beta$) leads to an increase in Y ($dY^* = [-V_Y \underset{(+)}{F_\beta} / \left|J_{IS-EE}\right|]\, d\beta$), owing to a reduction in private investment to clear the commodity market. However, utilization arguments with $\alpha_Y > 0$ and $\gamma < 0$ resume the adverse effect on Y ($dY^* = [-V_U \underset{(-)}{V_Y} / \left|J_{IS-EE}\right|]\, dU$) and an upward pressure on P may be realized. Therefore, and surprisingly, we can experience SCOEACU even under a regime of positive technological progress if $\left|F_\beta\right| > \left|V_U\right|$.

Graphically we explain the same in terms of Fig. 3. Figure 3 explains the expansionary FP effects under the present approach. We first start with the initial state of the economy at point E, where there is full employment income (Y1) and the environmental sustainability is maintained. The full capacity level of output is given by YC. How much permit cost will respond to an increase in environmental degradation depends on the stringency of government's legal actions, which is captured by the value of 'Δ'. The more stringent the enactment of laws, the higher the increase in permit cost and, as a result, the higher the increase in commodity prices. Further, introducing technological progress (β factor) towards conservation capital, as in Lawn, will shift the LM in the opposite direction (to the right). Hence, the shifting of LM will depend on the magnitude of capacity utilization, β

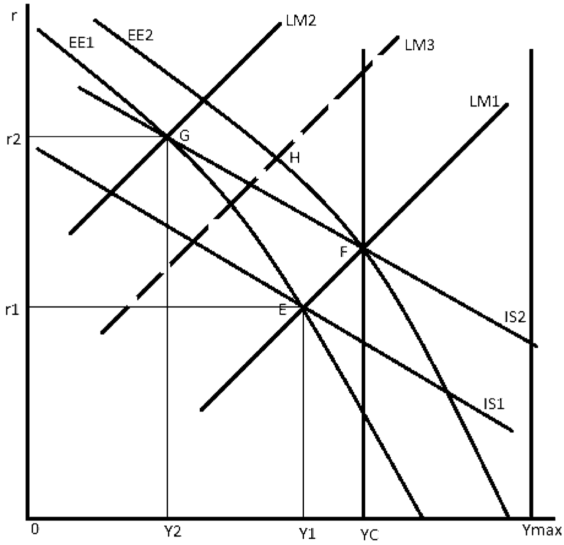


**Fig. 3** Expansionary fiscal policy under the present study's approach. Source: Drawn by the authors

and Δ. Thus, the effect of expansionary FP in this study can be explained under three different scenarios depending on the magnitude of increase in permit cost and $\beta$.

We start with the expansionary FP effects from E to F, where there is equilibrium on the demand side (IS–LM) and full capacity utilization of the economy, but there is environmental degradation as EE1 lies left of F.

**Scenario 1** Strong Δ: The gap between YC and EE1 (corresponding to Y1) leads the permit cost to increase to such a height that P will increase at full extent and, as a result, M/P will fall drastically. Consequently, there will be tight endogenous MP, causing a shift from LM to LM2. G will then be the new macro-environmental equilibrium, where IS2, LM2 and EE1 intersect. Y2 is the contracted output, where the economy will have long run sustainability. However, we observe that Y2 < < YC, which means that monetary contraction is too strong to outweigh fiscal expansion. The new equilibrium G may shift further leftward due to huge capacity under-utilization. Prices of the goods will increase, LM will shift leftward but IS will then shift further rightward due to an increase in public spending arising out of permit sales revenue. A new long run equilibrium will then be achieved to the left of G.

**Scenario 2** Weak Δ: Here permit cost will increase moderately leading to a moderate increase in P, and LM will shift to the left moderately. The new LM may be LM3 and the new IS–LM equilibrium at H, where there will be a reduction in pollution and also a moderate increase in excess capacity. This will again push up the price of permit as well as the price of goods, leading to further leftward shifting of LM to LM2. However, there is instability in capacity utilization as well. The aftermath effects will then be like those of case A.

**Scenario 3** Increase in β: From G, a low level of economic and sustainable output, an increase in technological progress towards greener capital formation will reduce the magnitude of pollution, permit cost and goods' prices, leading to a rightward shift of LM that will generate more output. Continuous upgradation in the technology will shift the LM

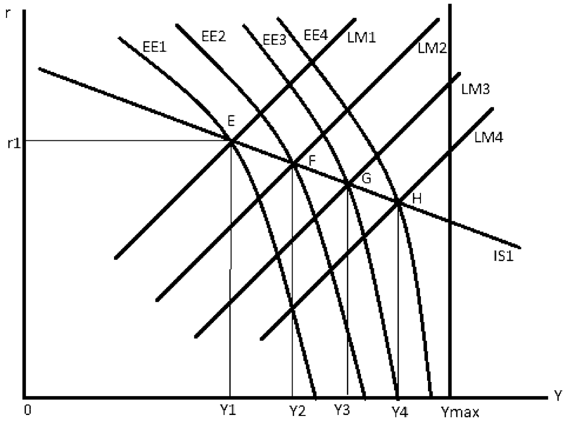


**Fig. 4** Expansionary monetary policy under Lawn's approach. Source: Drawn by the authors

rightward continuously until the full capacity equilibrium is attained at F, where the new EE curve will match IS, LM and YC. Any further progress in technology will shift LM rightward (as under Lawn), allowing an increase in output to finally reach Ymax. However, there is a difference of opinion between the present study and that of Lawn. As YC is reached at F, any upgradation in technology can be output- or growth-enhancing and sustainable from the nature's perspective, but unsustainable from the perspective of capacity utilization. Overuse of capacity is also inflationary as argued by Hamberg (1952), Dotsey and Stark (2005), among others. Hence, right of YC, the price of goods will increase, which will force LM to shift back to LM1. Hence, there is the critical value of technology upgradation (here EE2), where the system will have sustainability in both nature and capacity utilizations' perspectives. Lawn's approach has missed this aspect. If a new capacity is generated over YC, then further technological progress will expand output and the limit of expansion will again be decided by the new YC.

### 4.2.2 Expansionary monetary policy

Figure 4 explains Lawn's approach to the effect of an exogenous monetary expansion through an increase in money supply with an unchanged fiscal policy. Initial equilibrium of the goods sector, monetary sector and environmental sustainability is attained at E with the combination of IS1-LM1-EE1. (Y1 and r1) is the combination of income and rate of interest.

An expansionary MP creates a new demand side equilibrium at F, where there is more output and less rate of interest. But F is outside EE1, thus there is environmental pollution. There will be an increase in permit cost and prices of the goods leading LM2 to shift back to LM1. Hence, monetary policy is not effective. Heyes argued for contractionary FP to increase output. With technological progress in favour of the environment, Lawn suggested that prices will go down and LM will shift rightward along new EE curves (EE2, EE3, EE4…). The output will increase continuously with technological progress until Ymax is reached, which Lawn recommended. Hence, LM will freely move along the initial IS with technological progress.

To check the effectiveness of expansionary monetary policy in the presence of the EE framework, we use comparative steady-state analysis following a change in $M$. Using

Eqs. (4), (9) and (13), we get following expressions. It is to be noted that interactions between IS and LM, and LM and EE give us the overall effect of change in *M* on Y and r. Following the interaction between IS and LM and by using Eqs. (4) and (13) we can obtain

$$\frac{dY^*}{dM} = -\frac{\underset{-}{H_M}\underset{-}{V_r}}{\underset{+}{|J_{IS-LM}|}} > 0 \tag{19}$$

$$\frac{dr^*}{dM} = -\frac{\underset{-}{H_M}\underset{-}{V_Y}}{\underset{+}{|J_{IS-LM}|}} < 0 \tag{20}$$

Similarly, from the interaction between LM and EE in case of a change in M, and by considering Eqs. (9) and (13) we get

$$\frac{dY^*}{dM} = \frac{\underset{-}{F_r}\underset{-}{H_M}}{\underset{+}{|J_{LM-EE}|}} > 0 \tag{21}$$

$$\frac{dr^*}{dM} = -\frac{\underset{-}{H_M}\underset{-}{F_Y}}{\underset{+}{|J_{LM-EE}|}} < 0 \tag{22}$$

***Remarks 2***

(1) A rise in *M* augmenting with capacity utilization arguments leads to an increase in the stationary equilibrium value of Y and a decrease in the stationary equilibrium value of r under the IS–LM framework.

(2) An improvement in *M* with under-utilization of capacity under the LM–EE structure leads to an increase in the stationary equilibrium value of Y iff $\left|\frac{V_Y}{V_r}\right| > \left|\frac{F_Y}{F_r}\right|$.

Economic interpretations are given below. Intuitively we can explain the outcomes of expansionary monetary policy on stationary equilibrium values of Y and r in terms of Eqs. (19) to (22). Here again we start with the IS–LM structure and hence expressions (19) and (20) tell us the rest of the story. An increase in M in the form of expansionary monetary policy leads to a fall in r to clear the money market. Such a fall in r leads to an increase in private investment, and to clear the goods market Y must increase. We call this the First Round Positive output effect (FRPOE), owing to Expansionary monetary policy. Considering the LM–EE structure and Eqs. (21) and (22) we get the other side of the expansionary monetary policy response in the presence of environmental capital market. A rise in M leads to a fall in r via money market equilibrium. Following a reduction in r from EE specification, we get an increase in Y owing to a fall in e. We call this the Second Round Positive Output Effect (SRPOE) owing to an increase in M. However, the volume of SRPOE varies under three different scenarios. First, we start with a high value of Δ or strong environmental regulations scenario. High Δ under expansionary monetary policy creates enough space to increase Y at a higher volume compared to the usual scenario. As high Δ implies low e, Y must increase ($dY^* = [-F_\Delta H_r / \underset{(+)}{|J_{LM-EE}|}]\, d\Delta$)

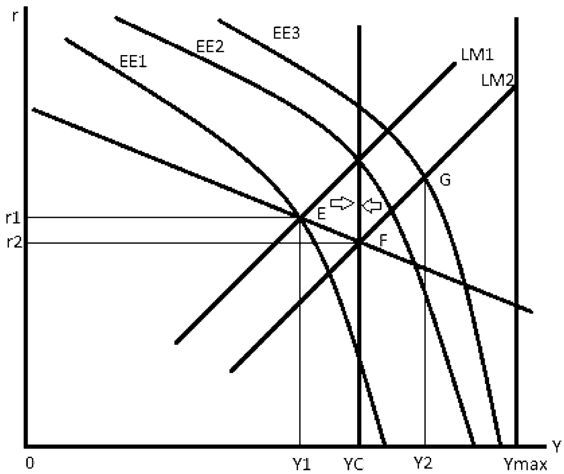


**Fig. 5** Expansionary monetary policy under the present study approach. Source: Drawn by the authors

of a higher volume to clear environmental capital market equilibrium, and we may experience high SRPOE. Again, for a given $\beta$, an increase in $\Delta$ leads to a rise in $PM_C$, and consequently Eqs. (7.1) and (7.2) reveal an increase in P following an under-utilization of capacity or $\alpha_Y > 0$ and $\gamma < 0$. Hence, a fall in Y ($dY^* = [-V_U V_Y / \underset{(-)}{|J_{IS-LM}|}]\, dU$) to a certain extent is quite obvious. Such increase in P either reduces the volume of SRPOE or eliminates the existence of SRPOE, that is, we find either low $H_r$ or $H_r \to 0$ and $|F_\Delta H_r| > |V_U V_Y|$. The second scenario illustrates expansionary monetary policy with low $\Delta$. Under the present scenario, by using a similar logic we experience a moderate level of SRPOE as $H_r \neq 0$ and ($|F_\Delta H_r| > |V_U V_Y|$) in the presence of utilization arguments. Apart from $H_r$, here $F_\Delta$ again makes the differences between the two scenarios, as we get in the case of expansionary fiscal policy. The third scenario involves an increase in technological progress or higher $\beta$. Higher $\beta$ may reduce the $PM_C$ and consequently lead to a fall in P. A reduction in P further enhances the scope of increase in Y ($dY^* = [-F_\beta H_r / \underset{(+)}{|J_{LM-EE}|}]\, d\beta$) due to a rise in M. However, similarly to the fiscal policy regime, here in the monetary policy context we get the following utilization arguments with $\alpha_Y > 0$ and $\gamma < 0$ that resume the adverse effect on Y ($dY^* = [-V_U V_Y / \underset{(-)}{|J_{IS-LM}|}]\, dU$), and an upward pressure on P may be realized. Therefore, we can experience SRPOE even under a regime of positive technological progress if $|F_\beta H_r| > |V_U V_Y|$. In short, we get the highest possible SRPOE owing to expansionary monetary policy under the regime with high $\beta$, or expansionary monetary policy is most effective under the regime with high $\beta$ iff $|F_\beta| > |F_\Delta|$ and $|F_\beta H_r| > |F_\Delta H_r| > |V_U V_Y|$.

Graphically we can illustrate the same in terms of Fig. 5. Figure 5 explains the effect of expansionary MP under the present study approach. E is the initial equilibrium, where sustainable full employment output is obtained in Y1 quantity, and r1 is the rate of interest. YC is similarly marked as the full capacity output. (YC–Y1) is the magnitude of excess capacity.

Now, as expansionary MP is undertaken, LM shifts rightward to LM2 and F becomes the new demand side equilibrium that absorbs the full capacity of the system. However, there is environmental degradation, as the expanded economic output produces high entropy of energy use. As a result, demand for permit will arise and the cost of permit will push up the cost of production of goods. Real money balance will then fall, causing LM to shift back to LM1. If we allow technological progress in line with Lawn, P will go down and LM will again shift rightward leading to an increase in output. According to Lawn, there will be continuous rightward shifting of LM due to technological progress until Ymax is reached. The present study differs here from Lawn's approach. Although continuous technological progress causes less and less pollution, output should not increase beyond YC, or there will be inflationary pressure which will shift back the LM to F (shown by leftward arrow mark). Hence, the critical position of the LM will be along YC, not free as claimed by Lawn. Therefore, capacity utilization is a crucial factor to the present study, which makes our analysis of policy effects different from Lawn's.

## 5 Empirical validation

To examine the validity of our theoretical enquiry, we consider the following empirical exercise. We incorporate a pooled data set consisting of the selected major 28 countries (comprising 14 developing and 14 developed) across the world for the 2010–2019 period, for a total of 280 pooled dataset. Further to check the robustness of our empirical study, we performed the same exercise for two separate pools, the first one exploring the cases of the developed countries, and the second one illustrating the cases of the selected developing countries. The concerned variables are GDP (gross domestic product at current USD) as the dependent variable, government expenditure (G) as the indicator for fiscal policy, broad money supply as the indicator for monetary policy (M), the institutional factors (I) consisting of pollution and technological progress captured by the interaction term between pollution (=$CO_2$/GDP) and technological progress (=R&D/GDP), and the dummy is used for capacity utilization (Di). The countries in the having more than average capacity utilization (CU) are given the dummy value of 1, while zero is given to the others. All the above indicators except the GDP (Y) are the independent variables in the empirical model. Again, in the case of the pool of developed countries, the same dummy of value 1 is put for those who have more than average value of CU in the group. The same procedures are followed for the pool of the developing countries. The study goes for estimating three multiple regression models, first for the pool of 28 (denoted as pool 28), then for the pool of developed 14 (denoted as pool developed) and finally the pool of developing 14 countries (denoted as pool developing). The models to be estimated are as follows-

$$\text{Model I}: Y_{i,Pool\,28} = \alpha_i + \beta_{1i} * G_i + \beta_{2i} * M_i + \beta_{3i} * I_i + \beta_{4i} * D_i + U_i$$

$$\text{Model II}: Y_{i,Pool\,14\,Developed} = \alpha_i + \beta_{1i} * G_i + \beta_{2i} * M_i + \beta_{3i} * I_i + \beta_{4i} * D_i + U_i$$

$$\text{Model III}: Y_{i,Pool\,14\,Developing} = \alpha_i + \beta_{1i} * G_i + \beta_{2i} * M_i + \beta_{3i} * I_i + \beta_{4i} * D_i + U_i$$

where I=($CO_2$/GDP)*(R&D/GDP) and U is the disturbance term with N (0, $\sigma^2$).

Table 3 illustrates the outcomes of the pool estimations. The second column represents the results for the overall pool, and it shows that GDP is positively influenced by government stimulus (for given exogenous monetary policy) in the form of expansionary fiscal policy. Moreover, simultaneous technological progress in terms of R&D expenditure augmenting with $CO_2$ emission and capacity utilization play a crucial role in promoting GDP.

**Table 3** Impact of fiscal and monetary policies on GDP. Source: Authors' own estimations

| Dependent variable: GDP | | | |
|---|---|---|---|
| Independent variables | Estimates of pool of 28 countries | Estimates of pool of developed countries | Estimates of pool of developing countries |
| Govt. expenditure (G) | 0.0374 (0.00) | 0.037 (0.00) | 0.021 (0.00) |
| Broad money supply (M) | −0.0005 (0.05) | 0.00043 (0.17) | 0.0012 (0.00) |
| Interaction term ($CO_2$/GDP)*(R&D/GDP) | 1.35E+12 (0.36) | 1.18E+13 (0.00) | 3.35E+12 (0.00) |
| Capacity utilization dummy | −4E+11 (0.00) | −9.4E+11 (0.00) | −1.1E +1 (0.07) |
| Adjusted $R^2$ | 0.92 | 0.94 | 0.98 |

The values of 1.35E+12 means 13,500,000,000,000.00

In this context Table 3 suggests that R&D augmenting with $CO_2$ affects GDP positively for underutilized economies. Therefore, for the overall pool a policy instrument like fiscal policy accompanied by better technology and less utilization of capacity may result in a higher increase in GDP compared to economies with higher utilization of capacity. This result remains valid for the individual pools of developed and developing economies, and it also confirms Remarks 1 of Sect.4. Again, the outcomes for the overall pool show that GDP is adversely affected by expansionary monetary policy (for a given exogenous fiscal policy). However, if we analyse the pools of developed and developing economies separately, we find a positive impact of expansionary monetary policy on GDP. Moreover, the simultaneous presence of technological progress in terms of R&D expenditure augmenting with $CO_2$ emission, strict environmental regulations and capacity utilization may play a crucial role in promoting GDP. In this context Table 3 suggests that R&D augmenting with $CO_2$ and strong institution affect GDP positively for underutilized economies. Therefore, for the overall pool, policy instruments like expansionary monetary policy accompanied by better technology, more environmental restrictions and less utilization of capacity may result in a higher increase in GDP compared to economies with higher utilization of capital. This result remains valid for the pools of developed and developing economies with different intensity, and it also confirms Remarks 2 of Sect. 4.

## 6 Discussion

So far the study goes, Sects. 4 and 5 show and validate the effectiveness of both the fiscal and monetary policies to promote green growth under different set ups in the presence of capacity utilization argument. For instance, the dynamic analysis of steady states reveals that expansionary fiscal policy with capacity utilization may lead to an increase in both Y. However, such increase may be curtailed following the presence of two distinct crowding out effects, namely FCOE and SCOEACU. This issue is also raised by Cottarelli (2020) and Gramkow (2020) in case of fiscal policy adaptation to promote green growth. Such fiscal policy sustainability risk can be managed if green public investment is increased at a higher rate and volume (Cottarelli 2020; IKI 2022). Our findings also suggest the same, and as reason, we argue that capacity utilization augmented with expansionary green public investment plays the major role. Moreover, in this article we claim that the nations using relatively less available capacity are the relatively more beneficiaries following expansionary green public investment compared to those nations which have already used more of its capacity. Further the present study signifies the role of institution and technological progress as the backbone to frame fiscal policy as an effective instrument to get green growth. Now coming to the monetary policy instrument, our study, both at the theoretical and empirical levels, suggests that expansionary monetary policy is also effective to achieve high green growth. In fact, under the expansionary monetary policy the economy may not experience any kind of crowding out effect like that of the fiscal policy. However, an adverse effect on Y via $PM_c$ may occur. Although such effect in the presence of less utilization of capacity and better innovation can eliminate the possibility to cut Y. Indirectly our outcomes re-establishes the arguments proposed by Soubeyran (2020) to achieve environmental sustainability. In that study the author suggests opting green monetary policy to enjoy the benefits of green growth. Similarly, in our study we argue to adopt monetary policy in presence of green innovation for under-capacity utilized economies to find green growth paths. It is to be noted that Akbari et al. (2022) and Chen and Chang (2013) recognize green innovation as the major element to achieve sustainable development. Although the path of achievement of sustainable development is slightly different in case of the present study as it passes through capacity utilization argument. In fact, the effectiveness of monetary policy may be greater compared to the overall fiscal policy under reasonable conditions. These findings are very much in line of Boneva et al. (2021, 2022).

## 7 Concluding observations

The attainment of sustainable growth and development should be the ultimate goal of an economy as proposed by the United Nations through its SDG missions. Introducing the concept of environmental sustainability in the macroeconomic system was thus an important research agenda. Daly (1991a, b), Heyes (2000), Lawn (2003a, b) realized studies that attempted to make the macroeconomic analysis green. While Heyes proposed one expansionary and one contractionary fiscal/monetary policy combination to maintain environmental sustainability, Lawn suggested that technological progress substitutes the contraction of the other policy effects. No studies introduced the factor 'Capacity Utilization' to justify the limitation of the technological progress as well as the shifting of the LM curve. The present study attempts to fill the gap by introducing the concept of full capacity utilization and concludes that expansionary fiscal policy, monetary policy and technological progress will centre on the critical value of full capacity utilization. Movements of LM will not be free as proposed by Lawn, rather they will stick to the level of full capacity utilization.

In this context, we have used the IS–LM–EE framework to explore the efficacy of both fiscal and monetary policies in the case of developed and developing economies. To do this, we have used a dynamic equilibrium analysis where all three schedules are satisfied simultaneously. To explore policy effectiveness, we considered comparative steady-state analysis for the relevant markets. Our theory suggests that expansionary monetary policy accompanied by better technology, strict environmental regulation and less utilization of capacity may result in a higher increase in output compared to economies with higher utilization of capacity. Similarly, the same applies to fiscal policy parameters, that is, expansionary fiscal policy augmenting with better technology, strict standards and less utilization of capacity may result in a higher increase in GDP compared to economies with higher utilization of capacity. Further, to check the robustness of our theoretical model we have used pooled data sets for both developed and developing economies, which basically validates our theoretical understanding.

### 7.1 Limitations of the study and future research agenda

Though the study has obtained satisfactory policy results on the IS–LM–EE framework using both theoretical and empirical models, we recognize its limitations. The study could have considered the complementary relationships between the physical and natural capitals instead of the substitute relations. On the other hand, the study could also have considered the empirical model using long time series data and attempted an analysis at the level of individual countries in a VAR structure. By including these issues, the results could have been more robust, if controlled properly. The study keeps them on the agenda for its future research.

## Appendix 1: Stability of IS–LM–EE model

### Case 1- dynamic stability and IS–LM model

Considering (5) and (11) and representing the same in matrix form we get

$$\begin{bmatrix} \dot{Y} \\ \dot{r} \end{bmatrix} = \begin{bmatrix} V_Y & V_r \\ H_Y & H_r \end{bmatrix} \begin{bmatrix} Y - Y^e \\ r - r^e \end{bmatrix} \tag{23}$$

The corresponding Jacobian of (23) can be written as

$$J_{IS-LM} = \begin{bmatrix} V_Y & V_r \\ H_Y & H_r \end{bmatrix} \tag{24}$$

Trace of the Jacobian

$$TrJ_{IS-LM} = \underset{-}{V_Y} + \underset{-}{H_r} < 0 \tag{25}$$

The determinant of the above Jacobian is

$$\left| \det J_{IS-LM} \right| = \underset{-}{V_Y}\,\underset{-}{H_r} - \underset{-}{V_r}\,\underset{+}{H_Y} > 0 \tag{26}$$

Expressions (25) and (26) ensure the stability of the dynamic equilibrium in IS–LM model.

### Case 2-dynamic stability and IS–EE model

Considering (5) and (13) and representing the same in matrix form we get

$$\begin{bmatrix} \dot{Y} \\ \dot{r} \end{bmatrix} = \begin{bmatrix} V_Y & V_r \\ F_Y & F_r \end{bmatrix} \begin{bmatrix} Y - Y^e \\ r - r^e \end{bmatrix} \tag{27}$$

The corresponding Jacobian of (27) can be written as

$$J_{IS-EE} = \begin{bmatrix} V_Y & V_r \\ F_Y & F_r \end{bmatrix} \tag{28}$$

Trace of the Jacobian

$$TrJ_{IS-EE} = \underset{-}{V_Y} + \underset{-}{F_r} < 0 \tag{29}$$

The determinant of the above Jacobian is

$$\left|\det J_{IS-EE}\right| = \underset{-}{V_Y}\,\underset{-}{F_r} - \underset{-}{V_r}\,\underset{-}{F_Y} > 0 \tag{30}$$

Expression (29) must be negative to ensure the stability of IS–EE model and it is possible only if absolute value of the slope of IS schedule is greater than the absolute value of the slope of EE schedule, that is, $\left|\frac{V_Y}{V_r}\right|_{slope-IS} > \left|\frac{F_Y}{F_r}\right|_{slope-EE}$.

Expressions (29) and (30) under shade of $\left|\frac{V_Y}{V_r}\right| > \left|\frac{F_Y}{F_r}\right|$ ensure the stability of the dynamic equilibrium in IS–EE model.

### Case 3-dynamic stability and LM–EE model

Considering (11) and (13) and representing the same in matrix form we get

$$\begin{bmatrix} \dot{Y} \\ \dot{r} \end{bmatrix} = \begin{bmatrix} F_Y & F_r \\ H_Y & H_r \end{bmatrix} \begin{bmatrix} Y - Y^e \\ r - r^e \end{bmatrix} \tag{31}$$

The corresponding Jacobian of (31) can be written as

$$J_{LM-EE} = \begin{bmatrix} F_Y & F_r \\ H_Y & H_r \end{bmatrix} \tag{32}$$

Trace of the Jacobian

$$TrJ_{LM-EE} = \underset{-}{F_Y} + \underset{-}{H_r} < 0 \tag{33}$$

The determinant of the above Jacobian is

$$\left|\det J_{LM-EE}\right| = \underset{-}{F_Y}\,\underset{-}{H_r} - \underset{-}{F_r}\,\underset{+}{H_Y} > 0 \tag{34}$$

Expressions (33) and (34) ensure the stability of the dynamic equilibrium in LM–EE model.

To get the overall stability of our said IS–LM–EE model we follow the work of Zhang and Lee (2017). Hence, by combining cases (1) to (3) we find that the IS–LM–EE model will be a stable one if and only if absolute value of the slope of IS schedule is greater than the absolute value of the slope of EE schedule.

## Appendix 2: Comparative steady-state analysis and major mathematical derivations

### Comparative steady-state and U

#### Interaction between IS and LM

Equations (4) and (9) can be expressed in the following form

$$\begin{bmatrix} V_Y & V_r \\ H_Y & H_r \end{bmatrix}_{(Y^*,r^*)} \begin{bmatrix} dY^* \\ dr^* \end{bmatrix} = \begin{bmatrix} V_U dU \\ 0 \end{bmatrix} \tag{35}$$

From (35) we obtain $(dY^*/dU)$ and $(dr^*/dU)$

$$\frac{dY^*}{dU} = \frac{\underset{+}{V_U}\,\underset{-}{V_Y}}{\underset{+}{|J_{IS-LM}|}} < 0 \tag{36}$$

$$\frac{dr^*}{dU} = -\frac{\underset{+}{V_U}\,\underset{+}{H_Y}}{\underset{+}{|J_{IS-LM}|}} < 0 \tag{37}$$

#### Interaction between IS and EE

Equations (4) and (13) can be expressed in the following form

$$\begin{bmatrix} V_Y & V_r \\ F_Y & F_r \end{bmatrix}_{(Y^*,r^*)} \begin{bmatrix} dY^* \\ dr^* \end{bmatrix} = \begin{bmatrix} V_U dU \\ 0 \end{bmatrix} \tag{38}$$

From (38) we obtain $(dY^*/dU)$ and $(dr^*/dU)$

$$\frac{dY^*}{dU} = \frac{\underset{+}{V_U}\,\underset{-}{V_Y}}{\underset{+}{|J_{IS-EE}|}} < 0 \tag{39}$$

$$\frac{dr^*}{dU} = -\frac{\underset{+}{V_U}\,\underset{+}{F_Y}}{\underset{+}{|J_{IS-EE}|}} < 0 \tag{40}$$

## Comparative steady-state and Δ

### Interaction between IS and EE

Equations (4) and (13) can be expressed in the following form

$$\begin{bmatrix} V_Y & V_r \\ F_Y & F_r \end{bmatrix}_{(Y^*,r^*)} \begin{bmatrix} dY^* \\ dr^* \end{bmatrix} = \begin{bmatrix} -V_\Delta d\Delta \\ -F_\Delta d\Delta \end{bmatrix} \tag{41}$$

From (41) we obtain $(dY^*/d\Delta)$ and $(dr^*/d\Delta)$

$$\frac{dY^*}{d\Delta} = \frac{\underset{-}{V_r}\,\underset{+}{F_\Delta}}{\underset{+}{\left|J_{IS-EE}\right|}} < 0 \tag{42}$$

$$\frac{dr^*}{d\Delta} = -\frac{\underset{-}{V_Y}\,\underset{+}{F_\Delta}}{\underset{+}{\left|J_{IS-EE}\right|}} > 0 \tag{43}$$

### Interaction between LM and EE

Equations (9) and (13) can be expressed in the following form

$$\begin{bmatrix} F_Y & F_r \\ H_Y & H_r \end{bmatrix}_{(Y^*,r^*)} \begin{bmatrix} dY^* \\ dr^* \end{bmatrix} = \begin{bmatrix} -F_\Delta d\Delta \\ -H_\Delta d\Delta \end{bmatrix} \tag{44}$$

From (44) we obtain $(dY^*/d\Delta)$ and $(dr^*/d\Delta)$

$$\frac{dY^*}{d\Delta} = -\frac{\underset{+}{F_\Delta}\,\underset{-}{H_r}}{\underset{+}{\left|J_{LM-EE}\right|}} > 0 \tag{45}$$

$$\frac{dr^*}{d\Delta} = \frac{\underset{+}{H_Y}\,\underset{+}{F_\Delta}}{\underset{+}{\left|J_{LM-EE}\right|}} > 0 \tag{46}$$

## Comparative steady-state and $\beta$.

### Interaction between IS and EE

Equations (4) and (13) can be expressed in the following form

$$\begin{bmatrix} V_Y & V_r \\ F_Y & F_r \end{bmatrix}_{(Y^*,r^*)} \begin{bmatrix} dY^* \\ dr^* \end{bmatrix} = \begin{bmatrix} -V_\beta d\beta \\ -F_\beta d\beta \end{bmatrix} \tag{47}$$

From (47) we obtain $(dY^*/d\beta)$ and $(dr^*/d\beta)$

$$\frac{dY^*}{d\beta} = -\frac{\underset{-}{V_r}\underset{+}{F_\beta}}{\underset{+}{|J_{IS-EE}|}} > 0 \tag{48}$$

$$\frac{dr^*}{d\beta} = \frac{\underset{-}{V_Y}\underset{+}{F_\beta}}{\underset{+}{|J_{IS-EE}|}} < 0 \tag{49}$$

### Interaction between LM and EE

Equations (9) and (13) can be expressed in the following form

$$\begin{bmatrix} F_Y & F_r \\ H_Y & H_r \end{bmatrix}_{(Y^*,r^*)} \begin{bmatrix} dY^* \\ dr^* \end{bmatrix} = \begin{bmatrix} -F_\beta d\beta \\ -H_\beta d\beta \end{bmatrix} \tag{50}$$

From (50) we obtain $(dY^*/d\beta)$ and $(dr^*/d\beta)$

$$\frac{dY^*}{d\beta} = -\frac{\underset{+}{F_\beta}\underset{-}{H_r}}{\underset{+}{|J_{LM-EE}|}} > 0 \tag{51}$$

$$\frac{dr^*}{d\beta} = \frac{\underset{+}{H_Y}\underset{+}{F_\beta}}{\underset{+}{|J_{LM-EE}|}} > 0 \tag{52}$$

## Comparative steady-state and monetary policy

### Interaction between IS and LM

Equations (4) and (9) can be expressed in the following form

$$\begin{bmatrix} V_Y & V_r \\ H_Y & H_r \end{bmatrix}_{(Y^*,r^*)} \begin{bmatrix} dY^* \\ dr^* \end{bmatrix} = \begin{bmatrix} 0 \\ H_M dM \end{bmatrix} \tag{53}$$

From (53) we obtain $(dY^*/dM)$ and $(dr^*/dM)$

$$\frac{dY^*}{dM} = -\frac{\underset{-}{H_M}\underset{-}{V_r}}{\underset{+}{|J_{IS-LM}|}} > 0 \tag{54}$$

$$\frac{dr^*}{dM} = -\frac{\underset{-}{H_M}\underset{-}{V_Y}}{\underset{+}{|J_{IS-LM}|}} < 0 \tag{55}$$

### Interaction between LM and EE

Equations (9) and (13) can be expressed in the following form

$$\begin{bmatrix} F_Y & F_r \\ H_Y & H_r \end{bmatrix}_{(Y^*,r^*)} \begin{bmatrix} dY^* \\ dr^* \end{bmatrix} = \begin{bmatrix} -F_M dM \\ -H_M dM \end{bmatrix} \tag{56}$$

From (56) we obtain $(dY^*/dM)$ and $(dr^*/dM)$

$$\frac{dY^*}{dM} = \frac{\underset{-}{F_r}\underset{-}{H_M}}{\underset{+}{|J_{LM-EE}|}} > 0 \tag{57}$$

$$\frac{dr^*}{dM} = -\frac{\underset{-}{H_M}\underset{-}{F_Y}}{\underset{+}{|J_{LM-EE}|}} < 0 \tag{58}$$

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## Declarations

**Conflict of interest** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.



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