The Development of the IS-LM-EE model and its Implications for Economic Policy

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Abstract. The macroeconomic activity must consider the effects of the ecological environment as ecological sustainability increasingly constrains humans' economic behaviour. Therefore, how to use fiscal and monetary policy tools to achieve harmonious economic and environmental development has become a hot topic of research among scholars. As a result, this study begins by distinguishing between the IS-LM-EE family of models and the various impacts of the same combination of monetary and fiscal policies on economic growth. It is discovered that the link between environment and capital is not clearly described in the models, which results in a variety of policy consequences. For example, tight fiscal and expansionary monetary policy would boost the economy in the Heyes and Sim IS-LM-EE models, whereas the Decker and Wohar model would experience an economic downturn as a result of the same policy combination. Meanwhile, the models of Heyes, Lawn, Decker and Warhar lack further automatic adjustment methods, and although the Sim model features an adjustment mechanism, its lag can significantly affect its effectiveness. Secondly, the study employs Heyes' model as a theoretical basis to simulate the economic impact of government policies including carbon emission quotas and concludes by summarising the limitations of the existing models.

Keywords: Ecological economics; IS-LM-EE models; Policy implications; Carbon emissions issues.

1. Introduction

Economic growth has long been reliant on an ecological base that has taken natural resources from the environment and released massive volumes of waste into the ecosystem [1]. The long-term consequences of the current economic model, such as soil and water pollution, natural disasters, greenhouse gases, and climate extremes, eventually proved to be a major impediment to economic progress [2]. Environmental elements have been introduced into the theoretical advances of traditional macroeconomics to solve the limitations of traditional macroeconomics, which are becoming more visible in explaining contemporary global economic occurrences. In reality, since Daly developed a theoretical framework for environmental macroeconomics in the 1990s [3], the field has achieved considerable theoretical advancements. Heyes initially created the IS-LM-EE model to examine how economic policy could be allocated for sustainable development [4]. Lawn, Sim, Decker and Wohar then extended the basic IS-LM-EE model [5, 6, 8]. Among them, Heyes and Sim assumed that physical and environmental capital are substitutable and come to the conclusion that the EE curve's slope is negative and is steeper than the IS curve [4, 6]. According to Lawn and Decker and Wohar, environmental and physical capital are complementary rather than substituting for one another, which results in an EE slope that is positive and steeper than the LM curve [5, 8]. The relationship between environment and capital has not been explicitly declared as a substitute or complementary, and there is a lack of empirical study in the context of policy, therefore the IS-LM-EE model still has limits. Governments can employ fiscal and monetary policy tools to ensure that the economy and the environment grow in harmony. This paper uses the current models to offer a theoretical foundation for this idea and to provide practical case studies. The paper firstly reviews the research and expansion of the IS-LM-EE series of models by different scholars, and gives suggestions for policy combinations, followed by a comparative analysis and summary of the IS-LM-EE series of models, then takes the carbon emission issue as an example, simulates and analyses the impact of setting a cap on carbon emissions on total output and how the government uses the IS-LM-EE model to make decisions, and finally sums up the limitations of the research so far and the future direction.

2. The original form of Heyes' model and its policy implications

Daly's concept of environmental macroeconomics remained in the conceptual realm of analysis for a long time and lacked sufficient theoretical support for policy formulation until Heyes presented the concept of environmental equilibrium curves, which shifted the theory's development to a new starting point. The environmental limits of economic growth are reflected in a curve known as the environmental macro-equilibrium curve. Heyes extended the conventional macroeconomic framework of IS-LM analysis with the environmental equilibrium curve EE [4], which has significant theoretical and policy ramifications.

Heyes based his definition of the EE curve on the crucial supposition that capital and the environment are substitutes, meaning that the level of pollution caused by economic activity increases as capital costs increase and decreases as environmental costs increase [4]. Higher capital expenditures and lower environmental costs will propel technological innovation. By derivation, the slope of the EE curve in this model is negative and it is steeper than the IS curve because the EE curve responds more slowly to the cost of capital than the product market. Add the EE curve into the IS-LM model, the system reaches equilibrium when the rate at which the economy consumes the environment equals the rate at which it can produce resources. When new resources are extracted, this rate is equal to the rate at which the new resources are replenished. In the presence of pollution emissions, the total rate of emissions is equal to the rate of environmental absorption without reducing the capacity of the environment. And when the rate of pollution exceeds the range of environmental absorption and renewable capacity, environmental degradation occurs. Among the elements affecting the EE curve, increased environmental regulation shifts the EE curve to the left, as does the self-purifying function of the environment (i.e. Environmental overuse that exceeds the EE curve in each period), which implies that short-term overload development reduces the potential for long-term economic sustainability.

According to Heyes' analysis of the mechanism of policy action, when the government adopts an expansionary fiscal policy, it must be accompanied by a tight monetary policy to keep the economy on the original environmental equilibrium curve [4]. As a result of this combined effect, the aggregate output will be lower than the initial level. This suggests that to maintain environmental equilibrium, any high-interest rate policy must be followed by lower output under the constraints of the macro-environmental policy. By a similar mechanism, the government's expansionary monetary policy must be counterbalanced by a tight fiscal policy to keep the economy operating on the original environmental equilibrium curve. The aggregate output will be higher than the initial level under the combined effect.

It can be seen that Heyes blended Daly's ideas on environmental macroeconomics into the Keynesian analytical framework and provided a new perspective on the analysis of environmental issues, which is an important breakthrough in environmental macroeconomics. Hayes' model is an important theoretical innovation and contributes to policy analysis since it can demonstrate transmission mechanisms of environmental and other policy instruments to enhance the abstract analysis of the real world, thus laying the foundation for the development of subsequent environmental macroeconomic models. Harris was very positive about Heyes' work, arguing that the IS-LM-EE model implies that economic growth must be accompanied by the advance of clean technology and stronger environmental regulation policies and that the model can provide a strong explanation for sustainable development [9]. Venkatachalam also argued that Heyes' model incorporates environmental issues into the theoretical neoclassical IS-LM model at the theoretical level, proving that neoclassical economics can adequately respond to emerging issues by accommodating reasonable realistic factors [10]. Heyes' model also contributed to integrating environmental and ecological macroeconomics in his study. Furthermore, Halkos and Paizanos also referred to the interaction mechanism between government expenditure and the environment embodied in Heyes' model in their study of the impact of government expenditure on the environment. However, they also pointed out the limitation that this relationship had not been extensively studied in the literature [11].

3. Extension of the Heyes model and their policy implications

3.1 Lawn's model

Lawn extended the Heyes model by adding the factors of technological progress and net sustainable development account. First, Lawn refuted Heyes' claim that natural and man-made capital can be substituted for each other since in this case the rapid growth in production and the subsequent decline in natural capital might be unrealistically offset by a considerable amount of human capital [5]. Second, The EE curve has a negative slope that is not constant. The technical efficiency of production is less responsive to the cost of capital, the curve is steeper, and it is harder to expand output using energy-efficient and environmentally friendly technologies as production gets closer to the maximum. The EE curve shifts as the technical and institutional parameters change because the institutional parameters internalise the externalities and the technical parameters help to increase the efficiency of resource use. As a result, as the technical and institutional parameters rise, the EE curve moves to the right to reach higher output levels. The EE curve will also move to the left when the production level surpasses the environmental carrying capacity. Third, policy instruments are required to reduce the EE curve. Lawn argues that macroeconomic adjustments in the EE curve are not driven by natural forces [5, 6]. Policy interventions are necessary, and these interventions should be able to allocate resources efficiently and at an environmentally sustainable rate. To achieve this, two alternatives are proposed: the deployment of tradable resource permits and the introduction of insurance vouchers, both promoting rapid investment in pollution-reducing human capital and mitigating the environmental impacts of pollution. Fourth, is the role of technology in economic policy. The environment's capacity increases as a result of technological development, and the EE curve moves to the right. Then, while retaining maximum sustainable growth, an expansionary fiscal or monetary policy can raise output and income levels. In other words, changes in the level of output cannot simply be observed in policy analysis, as such increases in output may be temporary and unstable. To understand the long-term patterns in economic performance, environmental and technological advancement aspects must be taken into consideration.

3.2 Sim model

Sim, in contrast to Lawn, concurred with Heyes' assumptions on the substitutability of capital and the environment, and he extended his model by emphasizing the influence of the output gap and the significance of environmental regulation [7]. Sim's LM and EE curves are essentially the same as those in Heyes, but Sim contended that the Heyes model lacked the natural adjustment mechanism that maintains macro-environmental equilibrium, that is, policymakers must provide sufficiently explicit information on environmental regulations to allow fiscal and monetary policies to adjust exactly to equilibrium, where the IS, LM, and EE curves intersect, and he avoided this overly strong assumption in his model. In summary, the Sim model shows that if a country neglects the environment during economic growth, it would have higher output in the short term, but lower income in the long term in equilibrium [7]. To compensate, costly control mechanisms need to be implemented. On the other hand, stronger environmental controls may lead to a short-term decline in relative output, but a long-term increase in living standards. Thus, government environmental controls are critical to macroeconomic growth. However, the benefits of pollution reduction do not materialize immediately, and the advantages of environmental change only become apparent over time. Thus, economic growth and employment growth cannot be the only indicators of government success and improving management standards should also be included in the measurement.

3.3 Decker & Wohar model

Decker and Wohar modified the assumption of substitutability made by Heyes, embraced the notion of complementarity between the physical capital and the environment, and set the environmental intensity of production to be associated linearly with the cost of capital R [8]. The rest of the model follows Heyes' model setup essentially perfectly, producing an environmental

equilibrium curve with a positive slope that is the exact reverse of Heyes' conclusions. According to the EE curve, which slopes to the upper right, when the government implements an expansionary monetary policy, real interest rates fall, borrowing costs become more affordable, and producers decide to invest more in physical capital. Since physical and environmental capital is complementary, the use of natural capital also increases, exceeding the regenerative capacity of the ecosystem. Therefore, governments must combine this with a tight fiscal policy to keep the economy on the original environmental equilibrium curve and thus keep interest rates and production levels low. Similarly, when the government implements an expansionary fiscal policy, it must simultaneously implement a tight monetary policy to maintain the economy on the initial environmental equilibrium curve. This leads to an integrated policy outcome that keeps the economy stable at higher interest rates and higher levels of output. This diverges from the policy advice of the Heyes model: in the Heyes model, expansionary monetary policy and tight fiscal policy can stimulate economic growth when the environmental equilibrium curve is constant, whereas Decker and Wohar demonstrate, in the context of complementary, that tight monetary policy with expansionary fiscal policy can stimulate economic growth in the absence of automatic adjustment, yielding policy advice that is the opposite policy recommendation [8].

4. Comparative analysis of the IS-LM-EE family of models

The IS-LM-EE model proposed by Heyes has been widely recognised by the academic community, and researchers have conducted more in-depth research and expanded around this model. Based on the results of the previous studies, it is evident that there is a consensus that environmental factors need to be taken into account in macroeconomic analysis, and one of the main areas of academic research is the use of fiscal and monetary policy tools to achieve economic and environmental coherence. Based on a comparative study of the IS-LM-EE family of models, previous research has shown cognitive differences on two topics: whether the link between environment and capital is complementary or substitution, and the different policy mixes that result. Heyes and Sim argued for a substitutable relationship between environmental and physical capital, deriving a negative and steeper slope of the EE than the IS [4][7]. They contended that tight fiscal policy and expansionary monetary policy can support economic growth while preserving the environment. In addition to this Sim also emphasized the importance of the output gap and environmental regulatory policies [7]. However, Lawn, and Decker and Wohar refuted the substitution by arguing that environmental and physical capital is complementary and come to a different conclusion about the slope of the EE curve [5][6][8]. In Decker and Wohar's model, the slope of the EE curve is positive and tight monetary policy and expansionary fiscal policy can stimulate higher aggregate output when the environmental equilibrium curve is constant [8]. While in Lawn's model the EE curve shifts due to technological advances and adjustments in environmental rules, changes in aggregate output can also become uncertain due to policy interventions [6].

5. Scenario analysis of ecological and macroeconomics (with the example of carbon emission issues)

According to Sim and Lawn, governments need to adopt active macroeconomic policy instruments to decrease finite resource consumption and greenhouse gas emissions, which can promote sustainable economic growth and maintain the quality of the environment [5-7]. With the above theoretical model as its foundation, governments can use the model to predict the effects of regulatory interventions on the economy when implementing policies.

Take the issue of carbon emissions as an example. To control global warming, human society must seek to reduce the emission of greenhouse gases, also known as carbon emissions. In 2016 over 55 countries with at least 55% of total emissions signed the Paris Agreement, committing to work together to reduce carbon emissions by approximately 12 to 14 billion tonnes by 2030 [12]. This

means that governments will take measures to limit carbon emission caps, but carbon reduction may have an impact on both consumption and investment demand [13].

To verify the impact of setting a ceiling on carbon emissions on the impact on aggregate output, Zhang et al. Conducted an analysis based on Heyes' hypothetical model (i.e. Substitutability between natural and physical capital, with a steeper EE curve than the IS curve with a negative slope) [14]. Assuming that government measures to limit carbon emissions are to invest in clean energy equipment or develop carbon capture and storage technologies, in such a specific scenario, total carbon emissions are used to represent the volume of natural capital in the EE curve and carbon reduction investments are imported into the EE curve. As the behaviour of carbon abatement investment affects aggregate demand, carbon abatement investment is added to correct the IS curve.

The study's findings demonstrate that a carbon tax system generates a higher equilibrium production than a cap-and-trade system for carbon pollution. Whereas, when the instruments of environmental macroeconomic policy change, it will be highly challenging to achieve the new equilibrium in the IS-LM-EE model with a dioxide tax system using the fixed carbon taxation; however, the IS-LM-EE model with a carbon cap-and-trade system will automatically achieve the new balance under the same circumstances. As a result, in actuality, the carbon cap-and-trade system is more rational and workable than the carbon tax approach. When any macroeconomic environmental policy instrument changes, the new models will effectively reach a new equilibrium by altering the investment size of carbon abatement. The investment in carbon reduction in the new IS-LM-EE model has crowding-out implications. When the set emission limit and the investment in emission reduction stay constant, an expansionary fiscal policy must be combined with a tight monetary policy. The equilibrium output will drop as a result of this policy portfolio, and vice versa.

6. Limitations of the research

Although ecological macroeconomic models are making progress in explaining basic policy implications, there are still many problems with their theoretical innovations. Firstly, the IS-LM-EE model, as a theoretical model of environmental macroeconomic realities, simplifies many real problems. When it comes to analysing real-world issues, it frequently has to be expanded upon with new specialised models since the parameters it takes into account and the area it covers are not broad enough. The model also suffers from overly absolute assumptions, such as the assumption that the policy sector is perfectly informed and that the IS and LM curves intersect exactly on the EE curve. Most crucially, the relationship between environment and capital is not clearly explained as to whether it is a substitution or complementarity. Furthermore, most of the existing empirical studies emphasise the importance of environmental issues, but less frequently do empirical research combine environmental policies with fiscal and monetary policies. In conclusion, ecological macroeconomics is still a relatively new field of research, and although it can predict policy formulation with some revelation, there are still shortcomings in the theoretical system and the refinement of the model needs to be improved.

7. Conclusion

The context for environmental macroeconomics is that the resource environment is gradually constraining human economic behaviour and macroeconomic activities must take into account the ecological consequences. The issue at hand now is how to sustain improved environmental quality while fostering economic expansion. In this paper, based on the analysis of Heyes' original IS-LM-EE model and combing through the extensions of the model by different scholars, the IS-LM-EE family of models is used to study the matching and coordination of financial and monetary policy instruments to achieve sustainable development of limited environmental resources. In Heyes' model, with a constant environmental equilibrium curve, both a tight fiscal policy and an expansionary monetary policy can spur economic growth. In the Lawn model, the environmental equilibrium curve

is variable and the effect of policy becomes unpredictable. Tighter monetary policy and expansionary fiscal policy can both increase and decrease output, depending on variables like the slope of the three curves, the degree to which monetary and fiscal policy has moved, the pace of technological advancement, and the level of environmental regulation. The Lawn model's environmental equilibrium curve varies, making the impact of policy unpredictable. Tighter monetary policy and expansionary fiscal policy can both increase and decrease output, depending on variables like the slope of the three curves, the degree to which monetary and fiscal policy has moved, the pace of technological advancement, and the level of environmental regulation. In the Sim model, strict fiscal and monetary controls can result in greater equilibrium output, but if these controls are separated from the environmental equilibrium curve, this rise will be short-lived and will eventually collapse to a lower level. Therefore, it is crucial to offer incumbents incentives to increase environmental control to encourage. Finally, when the environmental equilibrium curve remains constant in the Decker and Wohar model, restrictive monetary policy and expansionary fiscal policy can lead to increased aggregate output. The model demonstrates that, in the absence of government action, there is an environmental market failure and that the macro economy is unable to naturally shift towards the environmental equilibrium curve. To guarantee that the best possible level of resource and environmental usage is realised, government interventions in environmental policy are therefore required to rectify environmental market failures. Ecological macroeconomists have recently begun to simulate the economic effects of policies by using scenario modelling techniques to explore the link between the economy and the environment. In this study, we take the issue of carbon emissions as an example and simulate the impact of setting a cap on carbon emissions on aggregate output and how governments use the IS-LM-EE model to make decisions. Although ecological macroeconomics can explain policy effects, most current studies emphasise the importance of environmental issues, with few empirical analyses considering fiscal and monetary policies, and without the support of specific cases and data, it is difficult to make convincing policy recommendations. In conclusion, environmental macroeconomics is still a young topic of study, there are still issues with the theoretical framework and unfinished model improvements. Environmental macroeconomics is anticipated to become increasingly incorporated into the area of mainstream economics study soon and play a significant role in it.

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