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Commentary

Substitutability or complementarity? Re-visiting Heyes' IS-LM-EE model

Christopher S. Decker*, Mark E. Wohar

Department of Economics, College of Business Administration, University of Nebraska at Omaha, Omaha, NE 68182, United States

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1. Introduction

Traditionally, the environmental economics discipline has stressed microeconomic applications.[1] However, the broader economic impacts of climate change, sustainable growth, large-scale environmental accidents, and national energy policies that concern academics and policy-makers today have a decidedly macroeconomic focus. Daly (1991) observes that the models developed and presented in environmental economics courses tend not to align with macroeconomic models and thus do not effectively address macroeconomic policy implications.[2] To address this, Heyes (2000) developed a novel approach that incorporates into the basic fixed price IS-LM framework an environmental constraint, offering insights into the potential environmental consequences of fiscal and monetary policy.[3]

Since its publication, a number of studies have extended Heyes' basic IS-LM-EE model in a number of ways (see, e.g. Sim, 2006; Lawn, 2003). That said, there is within the model an assumption (acknowledged by Heyes) that has not yet been explored and that, if reconsidered, can have substantial policy implications. The model assumes that resources drawn from the natural environment (called environmental capital) and man-made, or physical, capital are *substitutes* in production; a condition referred to as "weak sustainability".[4] As an example of such substitutability, consider recent developments in the US construction industry. In order to comply with new EPA regulations, called "Tier 4 rules", that require the industry to reduce the amount of particulate matter (soot) and NO*x* its off-road heavy construction equipment emits into the air, engine manufacturers are developing new technologies to reduce harmful exhaust and improve diesel fuel economy.[5] This is indicative of substitutability as improvements in engine technology (man-made capital) are creating an opportunity for these firms to substitute away from environmental capital (the use of diesel and the reduced use of the atmosphere as a repository for waste).

However, the empirical literature on the substitutability of environmental capital (typically proxied by energy use) and physical capital has generated mixed results. Hudson and Jorgenson (1974) and Pindyck (1979) find evidence that energy and capital are indeed substitutes.[6] However, Berndt and Wood (1975) and Prywes (1986) find that that energy and capital are *complements* in production.[7] In fact, more recent work by Arnberg and Bjorner (2007) corroborates the complementarity finding.[8]

As an example of complementarity, consider the summer 2011 announcement by United Postal Service's (UPS's) plan to replace 100 of its diesel-powered trucks with 100 all-electric delivery vehicles in its California fleet. While this might initially seem to suggest

* Corresponding author.
E-mail address: christopherdecker@unomaha.edu (C.S. Decker).

[1] This is reasonable given that many of the main concerns of the discipline involve the correction of market failures and an analysis of economic efficiency characteristics of different policy instruments. Such analysis usually involves the application of microeconomic concepts.

[2] This is not to say that environmental economic textbooks do not address economy-wide issues. However, many authors group environmental economics together with natural resource economics where much of the economy-wide issues are addressed via renewable vs. exhaustible resources (see e.g. Perman et al., 2003; Tietenberg, 2003).

[3] Heyes (2000) argued that using the IS-LM framework as a foundation to build off of does make sense from a pedagogical perspective. First, the model, while subject to criticism, is still the primary model presented in intermediate-level macroeconomic texts. Second, it is widely used in policy circles as well. It should be mentioned, however, that modification of the standard IS-LM model is not the only means of introducing environmental constraints into macroeconomics. Seeley (2008), for instance, builds environmental resource constraints directly into the economy's potential output function.

[4] "Weak sustainability" is a condition whereby the aggregate stock of capital (natural, physical, and human) remains unchanged from generation to generation. Under this condition, each generation essentially utilizes only the "interest earned" on the existing stock leaving the "principal" constant. This contrasts with the "strong sustainability" concept whereby the aggregate stock of environmental capital remains constant from one generation to the next. If one were to accept "weak sustainability" then one therefore accepts that it is possible to draw down environmental capital resources and still generate a "sustainable" outcome so long as the reduction in environmental capital is offset with increases in physical or human capital. The implication is that as the cost of physical and/or human capital increases, the economy can substitute away from such productive inputs in favor of environmental capital inputs.

[5] For details, see Mike Larson, "The Diesel Dilemma," *Engineering News Record*, April 19, 2010, 22-25.

[6] For context, suppose a firm invests in new, vintage capital equipment that is more energy efficient. The increase in physical capital, therefore, can then allow the firm to substitute away from some energy use.

[7] In this context, a firm's investment in capital equipment requires additional energy for power. The result in this case, then, is that energy increases with physical capital.

[8] See Neumayer (2000) for an exhaustive survey of the current literature on this subject.

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substitutability (cleaner-operating trucks replacing diesel-fueled vehicles), a broader view recognizes the fact that the electric batteries used in these new vehicles require re-charging, the electricity for which is likely generated by the burning of coal and natural gas, both of which are drawn from the environmental stock. Moreover, the burning of coal returns pollution to the atmosphere (another source of environmental capital). UPS's move to electric vehicles actually highlights a continued complementarity between physical capital inputs (i.e. the fleet of delivery trucks) and energy inputs ultimately derived from environmental capital (i.e. the use of coal to generate electricity). Given that the empirical evidence has not settled the "substitutes versus complements" debate, it is reasonable then to reconsider Heyes' model under the assumption of complementarity.[9]

The remainder of this paper is organized follows. In Section 2, we review Heyes' (2000) model, illustrating its monetary and fiscal policy implications. In Section 3, we alter the structure of the model to allow for complementarity between environmental and physical capital inputs and illustrate the resulting policy implications. Section 4 re-casts the model in light of Sim's (2006) critique of Heyes' model. Section 5 concludes.

2. A Review of Heyes' Model

2.1. The IS-LM Model

Heyes (2000) builds on the simple fixed price IS-LM model, defined by the following variables:

- E = aggregate expenditures
- Y = aggregate income (production)
- C = consumption expenditures
- I = investment expenditures
- G = government expenditures (assumed to be exogenous)
- T = taxes on income Y (assumed to be exogenous)
- NX = net exports (assumed to be exogenous)
- P = price level (assumed to be constant)
- r = interest rate
- M_s = nominal supply of money
- M_d = (nominal) money demand

Identity and equilibrium equations are:

$$\begin{aligned} &E = C + I + G + NX \\ &E = Y \\ &\frac{M_d}{P} = \frac{M_s}{p}. \end{aligned} \tag{1}$$

Consumption is assumed to follow the form: $C = C_o + c(Y - T)$, where C_o is an autonomous consumption parameter and c is the marginal propensity to consume out of after-tax income.[10] Investment spending is given by: $I = I_o - kr$, where I_o is autonomous investment spending and k measures the sensitivity of investment to the cost of borrowing, r.[11] Money demand is given by: $M_d/P = gY - hr$, where g measures the sensitivity of money demand to income and h measures the sensitivity of money demand to changes in the interest rate.

[9] Additionally, because the IS-LM analysis is typically viewed as more akin to short-run conditions in the economy, the benefits of considering input complementarity are further exemplified. That is, it is perhaps easier to envision substituting man-made capital for environmental capital as taking place over a longer period of time, allowing for technological innovation and diffusion to take place. In the short run, substation opportunities may be more limited.

[10] Linearity is assumed for pedagogical ease of presentation.

[11] Normally, the nominal interest rate, i, would equate real money supply and real money demand, while the real interest rate is the equilibrating variable in the goods market. In the fixed price IS-LM model the real interest rate, r, is equal to the nominal interest rate, i, thus, there is no inconsistency.

Equilibrium in the goods market (i.e. $E = Y$) defines the IS schedule:

$$Y = \frac{1}{1-c}(C_o + cT + I_o - kr + G + NX). \tag{2}$$

Note that the slope of the IS curve is $\frac{dY}{dr} = -\frac{k}{1-c} < 0$, which is standard. Equilibrium in the money market defines the LM schedule:

$$r = \frac{g}{h}Y - \frac{M}{hP}. \tag{3}$$

Note that the slope of the LM curve $\frac{dr}{dy} = \frac{g}{h} > 0$, which is also standard.

2.2. The Environmental Equilibrium Schedule

The environmental equilibrium (EE) curve is derived as follows. Define E as the total stock of environmental capital available to an economy that can be tapped as an energy input in production. This stock is a composite stock of both non-renewable resources (oil, natural gas, coal, etc.) and renewable resources (lumber, grains for ethanol production, river flow for hydropower, etc.). Given that at least part of this stock is renewable, E has a natural replication (or regeneration) growth rate.[12] Following Heyes (2000), this rate is sE per unit time. Note that this implies that s is the (natural) percent growth in the environmental stock.[13]

Define e as the amount of E converted to energy that it then uses to produce one dollar's worth of output, Y. Heyes' (2000) model considers e as a function of r such that $\frac{de}{dr} > 0$, the condition that implicitly assumes substitutability between environmental and physical capital. If the cost of borrowing to finance capital purchases decreases, firms alter their production mix of inputs, inducing the use of more physical capital and fewer amounts of other inputs, such as environmental inputs.

A simple functional form that embodies this behavior is: $e(r) = e_o + \delta r$, where e_o is the minimal amount of e necessary in production and δ is the sensitivity of e to changes in r. The total stock of environmental capital used then is $e(r)Y$.

The net rate of environmental resource stock growth (dE/dt) relates the rate of stock usage in production to the rate of resource regeneration:

$$\frac{dE}{dt} = sE - (e_o + \delta r)Y. \tag{4}$$

Thus, the stock increases with s and declines with higher production levels (Y), higher minimal energy requirements, e_o, and higher capital costs, r. An environmental equilibrium, EE, is obtained when the rate of usage equals the environment's natural regeneration rate (i.e. $dE/dt = 0$). This steady-state condition yields the EE schedule:

$$sE = (e_o + \delta r)Y. \tag{5}$$

There are implications for the environment when condition (5) is not met. When Y is too high for a given r, then $sE < (e_o + \delta r)Y$. The economic use of environmental resources exceeds the natural rate of regeneration. Thus, E falls. When Y is too low for a given r, then $sE > (e_o + \delta r)Y$. The economic use of environmental resources falls short of the natural rate of regeneration, resulting in environmental stock growth.

Moreover, implicit differentiation of Eq. (5) implies $\frac{dr}{dY} = -\frac{sE}{\delta Y^2} < 0$, indicating that, under the steady-state condition, an increase in r is

[12] Alternatively, as Heyes (2000) also points out, consider the burning of fossil fuels as a cost that draws down the stock of "clean air." The variable s, then, can be thought of as the ability of the environment to absorb and ultimately dissipate this pollutant.

[13] To see this, note that absent production, since $dE/dt = sE$, then $(dE/dt)/E = s$.

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