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Monetary policy, neutrality and the environment

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Abstract

We study the interaction between monetary and fiscal policies in a Ramsey-Sidrauski model augmented with environmental capital. Equilibrium solutions are studied through the "Green Golden Rule". Despite the non-separability of money in utility and intertemporally non-separable preferences, money is environmentally neutral. Policy impacts the environment via the marginal rate of transformation rather than the marginal rate of substitution between consumption and environment. Fiscal policies, lump sum and distortionary, under a balanced budget, are also environmentally non-neutral. Only under a non-balanced budget, when deficits are monetized, is money environmentally non-neutral. In alternative approaches (Cash-in-Advance, Transactions Costs), money is environmentally non-neutral.

JEL classification: E52, E62, H23.

Keywords Ramsey-Sidrauski; Green Golden Rule; Environmental Capital; Chichilnisky et al. Conjecture; Cash in Advance; Transactions Costs; Friedman rule.

Non Technical Summary

Climate change is recognized as an urgent economic issue. Monetary policy makers, long silent on the subject, have now vigorously joined the debate. Much of their interest, though, lies with practical matters of financial-stability, 'stress tests' and macro-prudential regulations. What has somewhat gone under the radar is the integration of environmental interactions into the canonical set of theoretical monetary models: e.g., the Money-in-the-Utility function (MUIF), Cash in Advance (CA), and Transaction Cost (TC) approaches.

Our model adapts the Ramsey growth and Sidrauski MIUF frameworks to include a proxy for environmental capital. The environmental capital is a renewable environmental good, which, alongside consumption yields utility. The environmental framework used is the "Green Golden Rule" . This is a generalization of the Golden Rule of neoclassical growth theory and is defined as the highest indefinitely maintainable level of instantaneous utility in which environmental goods are valued.

Notably, consistent with the GGR concept, we eschew the traditional discounted utilitarian approach. This is because that approach downplays the welfare of future generations: generations who are more likely to be impacted by environmental degradation than their contemporaries. Accordingly, we adopt an alternative formulation of intertemporal welfare criteria in which society is only concerned with the very long run values of consumption and the environment. The combination of the GGR framework with the Sidrauski model allows us to examine whether or not money and inflation ultimately affect the environment in the long run.

Our conclusions are: (i) In the Sidrauski setup, money is environmentally neutral even when non separable from consumption and environmental capital. This is perforce an interesting conclusion since we tend to assume that Sidrauski MIUF leads to general non neutrality; (ii) Money in that framework is environmentally neutral even when time non separabilities in preferences over consumption streams are taken into account; (iii) In our policy set up, it is fiscal policy in a balanced budget which is environmentally non neutral (irrespective of whether it is financed by lump sum or distortionary taxes); (iv) However, in an unbalanced budget, when budget deficits are monetized, money becomes environmentally non-neutral. In short, real money balances and the inflation rate affect the environment; (v) Policy non-neutrality acts on the environment via the marginal rate of transformation rather than through the marginal rate of substitution between consumption and environment across steady states; and (vi) These set of results though are confined to MIUF models, in alternative monetary approaches such as CIA and TC Approach, money is non-neutral with respect to the environment in the long run.

"Climate change is an emerging risk to [..] the economy, and we are, as so many others are, in the very early stages of understanding what that means, what needs to be done about it and by whom." **Powell (2020)**.

"...[on the basis of the utilitarian approach] it is clearly irrational to be concerned about global warming, nuclear waste, species extinction, and other long-run phenomena. Yet we are worried about these issues, and are actively considering devoting very substantial resources to them. There appears to be a part of our concern about the future that is not captured by discounted utilitarianism.", **Beltratti, Chichilnisky and Heal (1993)**

1 Introduction

Climate change is recognized to be an urgent economic issue. Monetary policy makers, long silent on the subject, have now vigorously joined the debate.[1] Much of their interest, though, lies with practical matters of financial stability, 'stress tests' and macro-prudential regulations. What has somewhat gone under the radar is the integration of environmental interactions into the well-established set of theoretical monetary models: e.g., the Money-in-the-Utility function (MUIF), Cash in Advance (CIA), and Transaction Cost (TC) approaches (for discussions of these canonical approaches see e.g., Galí, 2015; Walsh, 2017). How would the presence of environmental assets fit into such frameworks? Can we say that monetary or indeed fiscal policy is neutral with respect to the environment? Moreover, given the interdependence between monetary and fiscal policy, and that the green transition may expand central-bank balance sheets through green asset purchases, thus potentially strengthening that dependence, does the fiscal-monetary policy mix matter for the environment? As far as we are aware, these links have yet to be made in the literature.

Our model adapts the Ramsey (1928) and Sidrauski (1967) MIUF frameworks to include a proxy for environmental capital (Dasgupta and Heal, 1974). The environmental capital is a renewable environmental asset, A, which, alongside consumption C, yields utility.[2] The environmental framework used is the "Green Golden Rule" (or GGR, as in the seminal papers of Beltratti, Chichilnisky and Heal, 1994; Chichilnisky, Heal and Beltratti, 1995). The environmental capital variable also enters as an argument in production. The GGR is a generalization of the familiar Golden Rule of neoclassical growth theory. It is defined as the highest indefinitely maintainable level of instantaneous utility in which environmental assets are valued.

Furthermore, and fully consistent with the GGR concept, our treatment eschews the traditional discounted utilitarian approach. As is well known, such an approach downplays the welfare of

[1] For example, Cœuré (2018), Mersch (2018), Olovsson (2018), NGFS (2019), Rudebusch (2019, 2021). See also Gillingham and Stock (2018), Auffhammer (2018) for more general and recent analyzes of the economic impact of climate change.

[2] Nordhaus and Boyer (2000) and Rezai, Foley and Taylor (2009) consider the stock of greenhouse gases as an additional state variable.

future generations, generations who are more likely to be impacted by environmental degradation than their contemporaries. Accordingly, we adopt an alternative formulation of intertemporal welfare criteria that focuses on the very long run values of consumption and the environment. The maximization of utility $u(C_t, A_t)$ over the feasible steady state paths yields the Green Golden Rule. The synthesis of the GGR framework with the Sidrauski model allows us to examine whether or not money and inflation ultimately affect the environment in the long run.[3] Moreover, although MUIF is probably the most famous of the theoretical approaches to incorporating money into optimizing models, it is not the only one. Accordingly, we also consider two other popular monetary approaches: *Cash in Advance* and *Transaction Cost* approaches.

Organization

Section 2 considers a general model of growth with physical capital and a stock of an environmental resource. We derive the GGR from the maximization of long-run utility and demonstrate that money, m, is environmentally neutral. Notice, moreover, that our concept of neutrality relates to super neutrality: namely, that changes in monetary quantities do not affect the real equilibrium.[4] Further, we demonstrate that money is environmentally neutral even when time non separabilities in preferences over consumption streams, such as with habit formation and future anticipation mechanisms, are incorporated (see Section 3). Thereafter, we allow for distortionary and non-distortionary fiscal policy with a balanced budget. For the distortionary case, the tax can be levied on the environmental asset or consumption or capital. Section 5 brings both arms of policy together and analyzes a monetized unbalanced budget. Section 6 examines Cash-in-Advance and Transactions Costs models and shows that, in these frameworks, money is (by contrast) environmentally non-neutral. Section 7 concludes. Additional material is in online appendices.

[3] Thus it should be clear that our monetary focus is not on business cycle, high-frequency stabilization issues but rather structural issues of long run impact and policy mix. This is in itself in harmony with the GGR focus on long-run utility.

[4] One consequence of neutrality is that if $A \perp\!\!\!\perp m$, then changes in the central banks' inflation target, which would be expected to be related to m, do not affect A. Thus, within the context of this model, environmental considerations would not be relevant for debates over the optimal inflation target. Otherwise the choice of inflation target may matter for the environment. Indeed, issues such as whether central banks target core inflation or overall inflation (the former excluding the typically volatile food and energy components) would gain heightened importance. However this is tangential to our current treatment.

2 The Green Golden Rule and the Ramsey-Sidrauski Model with Environmental Capital

In order to derive the green golden rule (GGR), the basic model adapts the Ramsey framework to include a proxy for environmental capital. It is derived from Dasgupta and Heal (1974) and Chichilnisky, Heal and Beltratti (1995). The environmental capital is a renewable environmental asset, A which, alongside consumption, yields utility.[5]

Per-capita output is defined according to the (per capita) production function, $f(k, A)$. Capital accumulation evolves as,

$$\dot{k}_t = f(k_t, A_t) - c_t \tag{1}$$

where $\dot{k}_t = dk_t/dt$ and c_t is per capita consumption.

The dynamics of the renewable environmental capital A is described by the difference between the rate of renewal, $R(A_t)$ (modeled as a logistic function satisfying $R(0) = 0$) and consumption:

$$\dot{A}_t \;=\; R(A_t) - c_t \;=\; rA_t\left(1 - \frac{A_t}{A^S}\right) - c_t \tag{2}$$

where parameter $r > 0$ is the reproduction rate of the environmental capital, and where A^S is the 'carrying capacity' of the environment. Equation (2) makes clear that environmental capital, though partly renewable through $R(A_t)$, is depleted by consumption.[6] The use of logistic functions, moreover, is a cornerstone of population and resource dynamic modeling, (Clark, 1979).[7]

Function $R(A)$ is bounded above, exhibits a threshold effect and is negative when $A > A^S$. Note that solving the derivative $R'(A) = 0$ implies, $A = A^S/2$ which is the stock corresponding to the maximum sustainable yield (MSY). Moreover, $R'(A) < 0$ for $A > A^S/2$. The MSY is the largest flow of consumption that can deducted from the environment in each period in the steady state.

Beltratti, Chichilnisky and Heal (1994) and Chichilnisky, Heal and Beltratti (1995) consider a general criterion function that depends both on the sum of utilities over time and on the long-run

[5] See also Ayong Le Kama (2001) who replaces Ramsey's bliss point by the GGR in an optimal growth model with an environmental resource.

[6] Kant and Shahi (2013) consider the case of multiple environmental assets and multiple users of those assets.

[7] The dynamic of this function is rapid initial growth, followed by linear growth, followed by zero growth.

behavior of utility values:

$$\varphi \int_{0}^{\infty} u\left(c_{t}, A_{t}\right) e^{-\vartheta t} dt+(1-\varphi) \liminf_{t \rightarrow \infty}\ u(c_{t}, A_{t}) \tag{3}$$

where $\vartheta > 0$ is the rate of time preference. The general problem is to maximize this criterion function taking into account capital accumulation and the dynamics of environmental capital. Setting $\varphi = 1$ yields the utilitarian solution. By contrast, if $\varphi = 0$, society is only concerned with the very long run values of consumption and the environment.[8] Whilst the former is a standard control problem, the latter is a somewhat less conventional one.

In their papers, moreover, the authors claim that $\max \liminf_{t\to\infty}\ u(c_t, A_t)$ over feasible paths satisfying (1) and (2) for given initial conditions, A_0, k_0, reduces to

$$\begin{gathered} \max u\left(c, A\right) \quad \text{s.t} \\ R(A)=c \end{gathered} \tag{4}$$

which yields,

$$\frac{u_A(c, A)}{u_c(c, A)}=-R'(A) \tag{5}$$

Equation (5) establishes the long run equilibrium in which the marginal rate of transformation equals the marginal rate of substitution between consumption and the environmental capital $-u_A/u_c$.[9] It defines the Green Golden Rule.

To proceed, assume the isoelastic utility function,

$$u\left(c, A\right)=\frac{\left[c^{\alpha} A^{\beta}\right]^{1-\sigma}}{1-\sigma} \tag{6}$$

where $\sigma > 0$ is the coefficient of relative risk aversion, and α and β capture the weights attached to real consumption and the environmental capital in utility. Substitute (6) and (2) into (5) and using the steady state condition $\dot{A}_t = 0 \Rightarrow R\left(A_t\right) = c_t$, yields the long-run equilibrium stock of environmental capital:

$$A=\frac{\alpha\ +\beta}{2\alpha+\beta} A^{S} \tag{7}$$

[8] See our opening citation of Beltratti, Chichilnisky and Heal (1993). This echoes the famous quote of Ramsey (1928): " ... *it is assumed that we do not discount later enjoyments in comparison with earlier ones, a practice which is ethically indefensible and arises merely from the weakness of the imagination ..* ", p. 543. See also Chichilnisky (2009), Perman et al. (2011) and La Grandville (2016) for discussions of the discounted utility assumption in economics.

[9] In fact, the reduction of the long run utility problem to (4) omits the information of equation (1) relating to capital accumulation. Therefore equation (5) characterizes the long run equilibrium up to the capital component of it, see Viscolani (2021) and Appendix A.

This, to recall, shows the level of the environmental capital that is consistent with the maximization of consumption. If, for simplicity, we assume homogeneity $\beta = 1 - \alpha$ we then end up with the simpler,

$$A = \frac{1}{1+\alpha} A^S \tag{8}$$

2.1 Introducing Money

We now extend the basic model by including money. Specifically, we demonstrate that money à la Sidrauski is environmentally neutral in spite of being non separable in the utility function. To incorporate both money and the environmental capital (or asset) into utility we rewrite (6) as,

$$u\left(c, A, m\right) = \frac{\left[(cA^{\beta})^{\alpha} m^{1-\alpha}\right]^{1-\sigma}}{1-\sigma}. \tag{9}$$

where $m = M/PN$ is real per-capita money balances (P is the price level, M is the quantity of money, and N is population).[10] Thus money enters multiplicatively (non-separably). Using the substitution of (9) and (2) into (5) yields, after some simplification,

$$A = \frac{1+\beta}{2+\beta} A^S \tag{10}$$

Thus, according to (10) there is no long run relation between money and the environment. In short, money is environmentally neutral.

2.1.1 An Equivalence in Money Demand

Another way to show this result is by adapting Reis (2007) in which the first order conditions of the Sidrauski model yield a money demand function. Real money balances are a function of consumption and nominal interest rates: $m = m(c, i)$, where the nominal interest rate is given by $i = f_k\left(k, A\right) + \pi$ (where $\pi = \dot{P}/P$ is the inflation rate). Using utility function (9), the money demand function implicitly defined by $u_m = i \times u_c$, yields:

$$m = \frac{1-\alpha}{\alpha} \cdot \frac{c}{i} \tag{11}$$

[10] For simplicity, we consider population growth n to be zero, so $N = 1$ without loss of generality.

Substituting this money demand back into (9), we have from the GGR:[11]

$$A = \frac{1 + \alpha\beta}{2 + \alpha\beta} A^S \tag{12}$$

Again, there is no long run relationship between money and the environment.

2.2 Robustness of Main Result

As an alternative way to check the robustness of the above results, consider a slightly different specification of utility as,

$$u(c, A, m) = \frac{\left[(cm^\beta)^\alpha A^{1-\alpha}\right]^{1-\sigma}}{1 - \sigma} \tag{13}$$

Then we can show,

$$\frac{1-\alpha}{\alpha} \frac{c}{A} = r\left(\frac{2A}{A^S} - 1\right) \tag{14}$$

which simplifies to

$$A = \frac{A^S}{1 + \alpha} \tag{15}$$

This is identical to expression (8). Thus, the result that there is no equilibrium relation between the environment and money still stands.

2.3 Some Remarks

Remark 1: Ignoring the term $1 - \sigma$, utility is homogeneous of degree one in c and A in the base model, equation (6), which yields the expression (8). In the utility functions of this section, utility is linearly homogeneous in c and m in (9), and in c and A in (13). The derivation of expressions (12) and (15) shows that it does not matter whether the utility function is homogeneous or not with regards to real money balances, m, since the variable and/or its utility parameters will not impact the long-run equilibrium stock of environmental capital. However, if the utility function is homogeneous of degree one in c and A, the long-run equilibrium stock of environmental capital depends only on one parameter, in our case α.

Remark 2: In Appendix A, we present the non-linear programming (NLP) problem of maximizing the steady-state utility, under information on the joint contribution of capital accumulation, the environmental asset and money. The NLP analysis in the appendix makes clear that the model is capable of supporting multiple equilibria. An economically sensible solution, however, is available

[11] The equivalence between (12) and (10) is clear in the correspondence of the respective powers of A: namely, $A^{\beta\alpha}$ and A^β.

and is one in which we impose the Friedman rule, namely the satiation of money balances, $u_m = 0$. With that solution introduced, we see that the *Chichilnisky et al. Conjecture* can be declared not a conjecture but a theorem: the conjecture is that the GGR is the optimal condition independent of the accumulation of assets (capital as well as, in our case, money); their accumulation can effectively be ignored for the long run outcome.

3 Intertemporally Non Separable Preferences

An additional and important robustness check involves *intertemporally* non separable preferences. The evident intuition is that they should matter for the GGR (Faria and McAdam, 2018). In addition, it is well-known that standard representative agent models with intertemporally separable preferences have failed to explain several empirical stylized facts, including the effects of monetary policy on the aggregate economy (see Fuhrer (2000), Levine, McAdam and Pearlman (2008)).

The habit formation hypothesis fills such a gap by providing intertemporally non separable preferences that relate present consumption to the stock of past consumption (e.g., Ryder and Heal, 1973; Abel, 2012; Gómez, 2015; Havranek, Rusnak and Sokolova, 2017). Accordingly, we examine whether or not money has any long run relationship with the environment when time non separabilities in preferences over consumption streams are considered. For completeness and balance, besides habit formation, we also study the anticipation of future consumption (AFC) hypothesis in which utility is a function of both current consumption and a reference consumption level based on expected future consumption (e.g. Kuznitz, Kandel and Fos, 2008; Faria and McAdam, 2013).

Specifically, the habit formation model introduces a new state variable in the Sidrauski model (Faria (2001), namely, the stock of habits H, which is a weighted average of past consumption levels, (Ryder and Heal, 1973):

$$H = \rho A^{-\rho t} \int_{-\infty}^{t} A^{\rho t} c(\tau)\ d\tau \tag{16}$$

Likewise, the anticipation of future consumption model introduces the stock of future consumption F, which is a weighted average of future consumption (Faria and McAdam (2013):

$$F = \rho A^{\rho t} \int_{t}^{\infty} A^{-\rho t} c(\tau)\ d\tau \tag{17}$$

Taking the differential with respect to time, they respectively evolve as,

$$\dot{H} = \rho(c - H) \tag{18}$$

$$\dot{F} = \rho(F - c) \tag{19}$$

Parameter $\rho > 0$ determines the relative weights of consumption at different times (which, for simplicity, we can assume to be common to both formulations). Given utility function (9) and substituting c by c/H^{γ} as in Abel (2012)[12] and then substituting c by cF^{δ}, respectively, and evaluating at the steady state yields the GGR:

$$A^H = \frac{1 + \beta - \gamma}{2 + \beta - 2\gamma} A^S \tag{20}$$

$$A^F = \frac{1 + \beta + \delta}{2 + \beta + 2\delta} A^S \tag{21}$$

From (20) it is clear that whilst the parameters of the habit formation mechanism enter the level of the GGR environmental capital (A^H is increasing in γ), there is no long run relationship with money; money remains environmentally neutral when habit formation is taken into consideration. Equation (21) shows the same when anticipation of future consumption is considered (A^F is decreasing in δ).[13]

All these results are interesting. Since Brock (1974)'s monetary model with consumption c, money m, and leisure l as arguments in utility, it has been well-known that monetary non-neutrality is associated with its non separability from other arguments in the utility function. Wang and Yip (1992) show that the Sidrauskian super-neutrality only holds when money is separated from consumption and labor in the utility function in such a way that $u_{cm} = u_{lm} = 0$. However, when money is non separable from consumption and leisure, one can have either Tobin effects, i.e., a positive effect of money growth on capital and consumption, or a negative effect, i.e., anti-Tobin effect. In our case, however, our new result stands because our welfare criterion places weight on the very long run. This, to restate, is distinct from the usual utilitarian approach, which emphasizes the immediate future at the expense of the long run.

[12] If $\gamma = 1 (= 0)$ consumption relative to habit stocks is very important (unimportant).

[13] Note that for $\gamma > 0, \delta > 0, A^H > A^F$. Thus, the steady state stock of environmental capital will be highest under standard habit formation.

4 Fiscal Policy

In the literature on environment and growth (e.g. Bovenberg and Smulders, 1995; Brown, 2000; Harrington, Khanna and Zilberman, 2005), public intervention mainly takes the form of regulation and taxation (e.g., Silva and Caplan (1997); Cremer, Gahvari and Ladoux (1998)). For Nordhaus (1994, 2007) optimal regulations should be limited and gradual, reducing long-run growth only modestly. For Stern (2009) they must be immediate, extensive and permanent despite the high economic cost. The Greenpeace view is bleaker still, arguing that growth needs to cease to save the planet.[14] Acemoglu et al. suggest that immediate intervention is necessary in the case where two sectors (clean and dirty inputs) are highly substitutable (see also Papageorgiou, Saam and Schulte (2017)).

Accordingly, we assume that a government uses its fiscal instruments to protect the environment.[15] Fiscal expenditures can be thought of as the provision of public environmental capital or enforcing environmental regulations, and taxes can be lump sum or distortionary and applied to the environmental capital, consumption or capital.[16] In what follows we consider the impact of fiscal policy on the environment with a balanced budget. We also show that, irrespective of whether taxes are distortionary or not, fiscal policy is always effective in the sense that it has an impact on the environment; fiscal policy is environmentally non-neutral. This is because expenditures and taxes directly enter the economy's resource constraint and thus affect how society chooses between consumption goods and environmental quality.

Let us define G as environmental expenditures, and T as taxes (or negative subsidies). We assume two types of taxes, respectively, lump sum and distortionary:

$$\dot{A} = R(A) - c - T \tag{22}$$

$$\dot{A} = R(A) - c - \tau_A A \tag{23}$$

[14] See www.greenpeace.org/international

[15] Notice we bypass issues related to Ricardian Equivalence. This reflects the following:

1. Ricardian equivalence holds true in regards to u_A/u_c, for the representative agent it does not matter whether the government issue a debt or print money.
2. What really matters is that T impacts $R(A)$, and, therefore as T is monetized, $T = G - \pi m$, then money impacts environmental capital via the rate of transformation.

[16] Van Long, Tidball and Zaccour (2020) assume the GGR approach (i.e., that the central planner should aim to maximize steady-state welfare) and demonstrate that the government can reach the same social optimum using either a constant tax or an inversely proportional tax to the stock of the renewable resource.

and further assume budget equilibrium:

$$G = T = \tau_{_A} A \tag{24}$$

where $\tau_{_A} > 0$ represents a tax on environmental capital. Accordingly, we can rewrite utility as

$$u\left(c, A, G\right) = \frac{\left[(cG^{\beta})^{\alpha} A^{1-\alpha}\right]^{1-\sigma}}{1-\sigma} \tag{25}$$

which yields the first order condition,

$$\frac{1-\alpha}{\alpha} \frac{c}{A} = r\left(\frac{2A}{A^S} - 1\right) \tag{26}$$

4.1 Non-Distortionary Taxation

Considering the non-distortionary taxation as in (22), we have the steady-state condition: $c = R(A) - T$, inserting (2) and then substituting it into (26) yields, after some simplification,

$$\frac{r\left(1+\alpha\right)}{A^S} A^2 - rA + (1-\alpha)T = 0 \tag{27}$$

and the roots

$$A_{1,2} = \frac{r \pm \sqrt{\Delta}}{2r(1+\alpha)/A^S} \tag{28}$$

For a non-zero discriminant, $\Delta = r^2 - \frac{4r(1-\alpha^2)T}{A^S} \neq 0$, this yields two distinct solutions in the very long run for the stock of the environmental capital A. A sufficiently high A^S will ensure that both roots are real. This multiplicity of solutions might be considered troubling since a conservationist would necessarily prefer the outcome with a higher A value but note that there is no choice criteria being employed here; both roots are optimal long run solutions. Further, the environmental impact of lump-sum taxes can be shown to be,

$$\frac{dA_{1,2}}{dT} = \mp \frac{1-\alpha}{\sqrt{\Delta}} \lesseqgtr 0 \tag{29}$$

Thus, non-distortionary taxation is non-neutral: the derivative of the highest stock of environmental capital being negative and the second, positive.

4.2 The Distortionary Case

Consider now the distortionary case. From (23), inserting the steady-state condition $c = R(A) - \tau_A A$ into (26), we have, after simplification,

$$A = \frac{A^S}{1+\alpha}\left[1 - (1-\alpha)\frac{\tau_A}{r}\right] \tag{30}$$

Accordingly,

$$\frac{dA}{d\tau_A} = -\frac{A^S}{r}\frac{1-\alpha}{1+\alpha} < 0 \tag{31}$$

Equation (31) shows that distortionary taxes are also non-neutral with regards to the environment that, and, in comparison to the non-distortionary case, however, they unambiguously deteriorate environmental capital; equivalently environmental protection can be enhanced through subsidies. Note also that the absolute strength of the tax multiplier is a function of the carrying capacity of the environment, and is in absolute terms larger the smaller is α. As regards other tax incidences, we have the following remark:

Remark 3: Distortionary taxation may also apply to consumption or to capital. Whichever is the case, the tax remains environmentally non-neutral. Indeed, we demonstrate that consumption and capital taxes both lead to an increase in environmental capital.
Proof: See Appendix B.

5 Fiscal, Monetary Policies and Debt Financing

When we move into the realm of a non-balanced budget, we can analyze the joint environmental effects of fiscal and monetary policies. Consider the case in which the government deficit is financed by monetary growth: $G - T = \dot{M}/P$. Note that from the real money balances

$$m = \frac{M}{P} \Rightarrow \dot{m} = \frac{\dot{M}}{P} - \pi\frac{M}{P}$$

Then,

$$G - T = \dot{m} + \pi m \tag{32}$$

where, in the steady-state, and assuming $T = \tau_A A$:

$$T = \tau_A A = G - \pi m \tag{33}$$

Inserting into (28) we have the solutions:

$$A_{1,2} = \frac{r \pm \sqrt{\Delta}}{2r(1+\alpha)/A^S} \tag{34}$$

Thus, inflation, real money balances and government expenditures do affect the environment since,

$$\frac{dA_{1,2}}{d\pi} = \pm \; m\frac{1-\alpha}{\sqrt{\Delta}} \gtrless 0$$

$$\frac{dA_{1,2}}{dm} = \pm \; \pi\frac{1-\alpha}{\sqrt{\Delta}} \gtrless 0$$

$$\frac{dA_{1,2}}{dG} = \pm \; \frac{1-\alpha}{\sqrt{\Delta}} \gtrless 0$$

where in this case $\Delta = r^2 - \dfrac{4r(1-\alpha^2)(G-\pi m)}{A^S}$ [17], as long as $G \neq \pi m$, money matters for the environment.

So far, all our results suggest an intriguing general result, namely, that for a class of Sidrauskian models with MIUF, environmental monetary and fiscal policy non-neutrality stems only from the dynamics of the environmental capital and is independent of the form of the utility function. In sum, policy non-neutrality acts on the environment via the marginal rate of transformation rather than through the marginal rate of substitution between consumption and environment across steady states.

There is arguably an echo of this non-neutrality result in some countries' historical experiences. In nations such as Brazil, governments have often de facto used inflation to manage their fiscal burdens (e.g., Issler and Lima, 2000). The resulting inflation and real money balances may have impacted the incentives to preserve the environment (e.g., Faria, 1998; Mendonça, Sachsida and Loureiro, 2003). This is troubling since Brazil's interior contains some of the world's highest biodiversity and houses most of the Amazonian rain forest. Thus – given that results depend on the form of the dynamics of the renewable environmental capital A, and budgetary characteristics, rather than the form and composition of the utility function – the non-neutrality of monetary policy upon the environment can, considering the joint fiscal-monetary mix, be mapped potentially to countries' institutional characteristics.

[17] An alternative way to reach the same result is by substituting (33) into (26): $c = R(A) - \tau_A A = R(A) - G + \pi m$. This implies,

$$\frac{1-\alpha}{\alpha}\left[r\left(1-\frac{A}{A^S}\right) - \frac{G}{A} + \frac{\pi m}{A}\right] = r\left(\frac{2A}{A^S} - 1\right)$$

This yields the same roots as in (34).

6 Cash in Advance and Transactions-Costs Approaches

How general is our result regarding money and environmental neutrality? In this section we show that other common approaches of money in growth models *do not* support our earlier conclusions concerning Sidrauskian MIUF models and the environment. As we have seen MIUF, in itself, leads to the result that money is neutral with respect to the environment (even if money enters utility in a non-separable manner). Now we show that in competing models, such as Cash-in-Advance (CIA) and Transactions-Costs Approach (TCA), money is non-neutral with respect to the environment.

6.1 Cash in Advance

The CIA model differs from the Sidrauski model by removing money from the utility function and introducing one additional dynamic constraint such that consumption and a fraction, $\eta \in [0, 1]$ of investment $\dot{k}$ have to be purchased out of existing real money balances:

$$m \geq c + \eta \dot{k} \tag{35}$$

where $\eta = 0$ and $\eta > 0$ respectively capture the Lucas (1980) and Stockman (1981) formulations.

In the steady-state, from (35) we have $c = m$, and using (6) and the GGR yields:

$$A = \frac{A^S + \sqrt{(A^S)^2 + 8A^S \frac{\beta m}{r\alpha}}}{4} \tag{36}$$

This expression demonstrates that an increase in real money balances m, increases environmental capital. That this formulation of money in the economy is environmentally non neutral makes sense since consumption expenditures (which deplete the environmental capital) are constrained directly by the availability of money.

6.2 Transactions Costs

Considering the TCA (e.g., Saving, 1971), we introduce a new term in the utility function to capture transactions costs T which is a function of consumption and real money balances characterized by:

$$\begin{aligned} T_c(c, m), T_{cc}(c, m) &> 0 \\ T_m(c, m) < 0, T_{mm}(c, m) &> 0 \\ T_{cm}(c, m) &\leq 0 \end{aligned} \tag{37}$$

Feenstra (1986) has shown the equivalence between MIUF and money as a medium of exchange that minimizes transactions costs. In what follows, though, we assume $T(c,m)$ and utility functions that do not fulfill the conditions for equivalence with MIUF:

$$T(c,m) = \frac{c^2}{m} \tag{38}$$

$$u(c, A, 1 - T(c,m)) = \frac{\left[c^{\alpha} A^{\beta}(1 - \frac{c^2}{m})\right]^{1-\sigma}}{1-\sigma} \tag{39}$$

Solving this model, the GGR yields:

$$A = \frac{m(\alpha+\beta)c^{-2} - 2 - \alpha - \beta}{m(2\alpha+\beta)c^{-2} - 4 - 2\alpha - \beta} A^S \tag{40}$$

Note that, in this case, there is a long run relationship between environmental capital A, and consumption c and real money balances m.

In these two models (CIA and TCA), money is non-neutral with respect to the environment in the long run. Therefore, they clarify that monetary neutrality is confined to the limited class of monetary models, namely the Sidrauskian MIUF case.

7 Conclusions

In this paper we sought to open a new area of analysis: namely integrating environmental capital into optimizing monetary models, taking into account the Green Golden Rule. The GGR is an important development in the literature since it emphasizes the preservation of environmental quality by maximizing long run utility rather than following the standard discounted utilitarian approach.

We demonstrate the following:

(i) In the Sidrauski setup, money is environmentally neutral even when non separable from consumption and environmental capital, as well as when time non separabilities in preferences over consumption streams are taken into account. This is perforce an interesting conclusion since we tend to assume that Sidrauski MIUF with non-separable preferences leads to general non neutrality;

(ii) In our policy set up, it is fiscal policy under a balanced budget which is environmentally non neutral (irrespective of whether it is financed by lump sum or distortionary taxes);

(iii) However, with an unbalanced budget, in which deficits are monetized, money becomes environmentally non-neutral. In short, real money balances and the inflation rate affect the environment;

(iv) Policy non-neutrality acts on the environment via the marginal rate of transformation rather than through the marginal rate of substitution between consumption and environment across steady states. In other words, what matters with regard to non-neutrality relates to the dynamics of the environment rather than with preferences;

(v) If we impose the Friedman rule on the optimality conditions of the model, the Chichilnisky et al. Conjecture can be declared not a conjecture but a theorem.

(vi) These (above) set of results, though, are confined to MIUF models. In alternative monetary approaches such as Cash-in-Advance and Transactions-Costs Approach, money is non-neutral with respect to the environment in the long run. The key aspect of these two latter models is that money directly enters as a static per-period constraint in the economy, rather than as a dynamic one.

Finally, our analysis also establishes the importance of the fiscal-monetary policy mix in determining environmental neutrality. To illustrate, if higher public expenditures and lower growth rates in the transition to a greener economy imply budget deficits, this raises the specter of monetization, increased fiscal-monetary dependence and of direct environmental impacts. In passing, it also gives credence to the idea that countries endowed with environmental riches, but otherwise burdened with weak institutions, may require greater fiscal discipline.

Future work could extend the model with endogenous labor supply and a richer analysis of the nature of the multiple equilibria in the model conditions.

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Appendix:

Monetary Policy, Neutrality and the Environment

Faria, McAdam, & Viscolani

A Steady-state utility problem: Necessary conditions

A.1 Introducing Money

In the Sidrauski model, the representative agent holds her real wealth (assets) a_t in the form of either real money balances m_t or capital k_t:

$$a_t \equiv k_t + m_t \,. \tag{A.1}$$

where $m = M/PN$ is real per-capita money balances (P is the price level, M is the quantity of money, N is population). Assume that $\pi_t = \dot{P}/P$ is the inflation rate, $\phi \geq 0$ is an optional depreciation rate[1], and n is the rate of population growth (the variables are in per-capita terms). The budget constraint is given by

$$\dot{a}_t = f(k_t, A_t) - (\phi + n)k_t - (\pi_t + n)m_t - c_t \tag{A.2}$$

Substituting for capital, and for simplicity and without loss of generality assuming zero population growth, this can be re-expressed as,

$$\dot{a}_t = f(a_t - m_t, A) - \phi a_t - (\pi_t - \phi)m_t - c_t \tag{A.3}$$

To incorporate both money m and the environmental capital A into utility, we then assume a utility function $u(c, A, m)$, a C^2 function, strictly increasing in each of its arguments, concave, and we admit $u_m \geq 0$. The latter condition is compatible with the Friedman rule wherein it is optimal for the government to satiate individuals with money, driving its marginal utility to zero.

A.2 Long-run and Steady-State Utility Problems

The long-run utility problem is

$$\max \liminf_{t \to \infty} u(c_t, A_t, m_t) \tag{A.4}$$

subject to the equations of motion (A.3), and (2), along with boundary conditions

$$k(0) = k_0, \qquad A(0) = A_0 \tag{A.5}$$

[1] "Optional" in the sense that the presence or otherwise of a non-zero capital depreciation rate does not affect the solutions.

$$\liminf_{t\to\infty} k_t \ \geq \ 0, \qquad \liminf_{t\to\infty} A_t \ \geq \ 0 \tag{A.6}$$

the assets definition (A.1), and control sign condition

$$c_t \ \geq \ 0\,. \tag{A.7}$$

Now, let us assume that the functions π_t, ... are constant. By analogy with (Chichilnisky, Heal and Beltratti, 1995), we associate with the long-run utility problem the following steady-state utility problem

$$\max u(c, A, m) \tag{A.8}$$

subject to

$$f(a-m, A) - \phi a - (\pi - \phi)m - c \ = \ 0 \tag{A.9}$$

$$R(A) - c \ = \ 0 \tag{A.10}$$

$$c \ \geq \ 0, \quad a - m \ \geq \ 0, \quad A \ \in \ [0, A^S] \tag{A.11}$$

The steady-state utility problem (A.8)–(A.10) can be stated as the problem of minimizing $-u(c, A, m)$ subject to the constraints (A.9), (A.10):

$$\mathcal{L} = -u(c, A, m) + \mu_1 \left(f(a-m, A) - \phi a - (\pi - \phi)m - c\right) + \mu_2 \left(R(A) - c\right)$$

Note, we are neglecting the constraints in equation (A.11), under the implicit assumption that they should not be active at an optimal solution.

We can observe that a feasible solution (c, a, m, A) is also a regular point (Luenberger and Ye (2008) (p. 325)). Hence, we can use the Lagrange conditions to characterize the candidate optimal solutions. The Lagrange necessary conditions are:

$$-\frac{\partial u}{\partial c}(c, A, m) - \mu_1 - \mu_2 \ = \ 0 \tag{A.12}$$

$$\mu_1 \left(\frac{\partial f}{\partial k}(a-m, A) - \phi\right) \ = \ 0 \tag{A.13}$$

$$-\frac{\partial u}{\partial m}(c, A, m) - \mu_1 \left(\frac{\partial f}{\partial k}(a-m, A) - \phi + \pi\right) \ = \ 0 \tag{A.14}$$

$$-\frac{\partial u}{\partial A}(c, A, m) + \mu_1 \frac{\partial f}{\partial A}(a-m, A) + \mu_2 R'(A) \ = \ 0 \tag{A.15}$$

together with equations (A.9), (A.10). The Lagrange multipliers $\mu_1, \mu_2 \in \mathbb{R}$ are associated with constraints (A.9) and (A.10), respectively.

Let $\mu_1 = 0$, and substituting this condition into equation (A.14) yields $-\partial u/\partial m = 0$. Hence, setting $\mu_1 = 0$ makes economic sense in the context of the Friedman rule of monetary satiation. By contrast, $\mu_1 \neq 0$ implies from (A.13) that the marginal productivity of capital is determined by the depreciation rate, $\phi \geq 0$, which runs counter to standard neoclassical production conditions.[2]

From equation (A.12) and $\partial u/\partial c > 0$ we have that

$$-\mu_2 = \frac{\partial u}{\partial c}$$

Thus $\mu_2 < 0$. Then, substituting for $-\mu_2$ in equation (A.15) implies the GGR:

$$\frac{\dfrac{\partial u}{\partial A}}{\dfrac{\partial u}{\partial c}} = -R'(A) \tag{A.16}$$

and hence that $-u_A/u_c < 0$ and $R'(A) < 0$.

Therefore $A = A(c) \in (A^S/2, A^S)$ is the greater root of the quadratic equation (A.10) in the unknown A.

Accordingly, we see that the *Chichilnisky et al. Conjecture* can be declared not a conjecture but a theorem: the GGR is the optimal condition independent of the accumulation of assets: capital as well as, in our case, money. Their accumulation can effectively be ignored for the long run outcome. Notice, this outcome is consistent with the Friedman rule of optimal monetary satiation.

[2] Moreover, the specific case of zero depreciation would imply an infinite capital stock and indeterminacy for the stock of the environmental capital.

B Consumption and Capital Tax Variants

Distortionary taxation of course may also apply to consumption and / or to capital. Whichever is the case, the tax remains environmentally non-neutral.

B.1 Distortionary Consumption Taxes

To see this, consider first taxes on consumption so as that government expenditures $G = T = \tau_c c$, are allocated for environmental protection and, as such, G enters positively upon the dynamics of environmental capital:

$$\dot{A} = rA\left(1 - \frac{A}{A^S}\right) - c + G \tag{B.1}$$

In the same vein, assuming people value environmental assets, G enters the utility function:

$$u(c, A, m, G) = \frac{\left[c^{\alpha} A^{\beta} G^{\delta} m^{1-\alpha-\beta-\delta}\right]^{1-\sigma}}{1-\sigma} \tag{B.2}$$

Solving the model yields:

$$A^* = \frac{\beta + \alpha(1-\tau_c)}{\beta + 2\alpha(1-\tau_c)} A^S \tag{B.3}$$

Raising taxes on consumption leads to an increase in the environmental capital in the long run:

$$\frac{dA^*}{d\tau_c} = \frac{\alpha\beta}{(\beta + 2\alpha(1-\tau_c))^2} A^S > 0 \tag{B.4}$$

B.2 Distortionary Capital Taxes

As regards distortionary taxes on capital, $\tau_k k$, considering $G = T = \tau_k k$, we make the same assumptions as in the case of distortionary taxes on consumption, as such we use equations (B.1) and (B.2). We then obtain a quadratic equation for A. Since the smaller root is negative, we only consider the positive one:

$$A^* = \frac{\left(\frac{\alpha+\beta}{\beta}\right) r + \sqrt{\left(\frac{\alpha+\beta}{\beta}\right)^2 r^2 + \frac{4r\tau_k k}{A^S}\left(\frac{2\alpha+\beta}{\beta}\right)}}{\frac{2r}{A^S}\left(\frac{2\alpha+\beta}{\beta}\right)} \tag{B.5}$$

It is straightforward to see that distortionary taxes on capital, τ_k, have a positive impact on the environmental capital, A^*.

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