



WP/09/76

IMF Working Paper

Simple, Implementable Fiscal Policy Rules

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IMF Working Paper

Research Department

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Authorized for distribution by Charles Collins

April 2009

Abstract

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This paper analyzes the scope for systematic rules-based fiscal activism in open economies. Relative to a balanced budget rule, automatic stabilizers significantly improve welfare. But they minimize fiscal instrument volatility rather than business cycle volatility. A more aggressively countercyclical tax revenue gap rule increases welfare gains by around 50 percent, with only modest increases in fiscal instrument volatility. For raw materials revenue gaps the government should let automatic stabilizers work. The best fiscal instruments are targeted transfers, consumption taxes and labor taxes, or, if it enters private utility, government spending. The welfare gains are significantly lower for more open economies.

JEL Classification Numbers: F 41, H21, H30, H62

Keywords: Fiscal policy rules; balanced budget rules; automatic stabilizers; countercyclical fiscal policy; welfare analysis.

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I. Introduction

This paper analyzes the scope for systematic rules-based fiscal activism in open economies. In doing so it follows in the tradition of the monetary policy literature, which starting with Taylor (1993) has developed a conceptual framework that has proved invaluable for policymakers. It is partly due to this success that fiscal activism has long been deemed unnecessary. But that is now changing rapidly, with massive countercyclical fiscal measures having been announced by, among others, the US, the EU, the UK, and China. As we discuss in more detail in the literature review in the following section, these recent developments represent only the latest twist in a long history that has seen fiscal activism come into, fall out of, and now come back into favor in the post-war period.

The current state of the theoretical literature is of most interest to this paper. It can be summarized as follows. First, models with non-Ricardian features in which fiscal policy can have a significant business cycle stabilizing role have only recently become more common. We will use one such model. Second, there is almost no analysis of systematic rules-based fiscal policy that could eventually become the equivalent in practical usefulness to interest rate rules in monetary policy. This is where this paper attempts to make a contribution.

The paper proposes a class of rules that, similar to Taylor rules, should be implementable by policymakers. In general terms this means that a policy instrument, or an aggregate policy variable that depends on a policy instrument, ensures debt sustainability in the long run, but also stabilizes the business cycle in the short run by reacting to a real activity gap measure. In our proposal, the aggregate policy variable is the budget surplus to GDP ratio, the available policy instruments are six tax rates and spending categories, and the gaps are the tax revenue gap, the raw materials revenue gap, and the debt gap. We will explain why output or absorption gaps are not desirable alternatives. We attempt to make the analysis applicable to a broad group of countries by choosing an open economy setup. For concreteness we calibrate our model economy to Chile. We perform a full second-order approximation of the model and utility function, and we numerically optimize the coefficients of the policy reaction function according to a welfare criterion. Results are presented by way of grid searches over those coefficients.

Our paper focuses on the following questions. First, how should fiscal policy respond to the different gap variables to maximize welfare without causing excessive volatility in fiscal instruments? Second, which of the many feasible fiscal instruments should be chosen to obtain the maximum welfare gain? And third, what is the contribution of different types of shocks to the welfare and macroeconomic volatility results?

We find that tax revenue gap rules can be used to represent a continuum of rules that includes the balanced budget rule, the structural surplus rule, and highly countercyclical rules. We use the balanced budget rule as the reference point for our welfare analysis, and find that relative to this rule the structural surplus rule improves welfare very significantly. A structural surplus rule targets a desired long-run government surplus to GDP ratio and responds to cyclically low (high) government surpluses by increasing (reducing) government debt rather than instantaneously changing fiscal instruments. This turns out to be a very natural representation of the concept of automatic stabilizers, which is discussed in more detail in Section II. Automatic stabilizers, which are still

avored by most commentators, *are* therefore a fiscal rule, but one that minimizes fiscal instrument volatility. A key insight of our paper is that, if minimizing business cycle volatility should instead be the main objective, we can gain very significantly by reparameterizing a structural surplus rule as a much more strongly countercyclical tax revenue gap rule. We find that this increases the welfare gains by around 50%, with only modest increases in fiscal instrument volatility.

Raw materials revenue is a critical and highly volatile component of fiscal revenue in many developing countries, including Chile. We find that a countercyclical response to a raw materials revenue gap is not desirable, instead here the government should rely on automatic stabilizers. In other words, net excess revenue from such gaps should be saved by the government and passed on to households over time through lower taxes or higher spending. This is because the government has a comparative advantage over liquidity constrained households in smoothing wealth shocks.

The recent literature, with few exceptions, considers only one gap variable in fiscal rules, namely the debt gap.¹ We find that such a version of our rule does produce non-negligible welfare gains over a balanced budget rule - it performs about as well as automatic stabilizers. But it is far inferior to the best countercyclical rules. In such rules the coefficient on the debt gap plays a comparatively small role.

We are also able to report on the relative benefits of six different fiscal instruments, and find that the best choices are targeted transfers, consumption taxes and labor taxes. But government spending becomes the preferred instrument if it enters private utility with a unitary marginal rate of substitution with consumption. Finally, we find that the welfare gains are significantly lower for more open economies.

It is critical to embed the analysis of fiscal rules in an appropriate overall modeling framework. An obvious candidate is the new generation of open economy monetary business cycle models with both nominal and real rigidities that is being deployed rapidly in central banks and policymaking institutions to replace the previous generation of models, which were not completely based on microfoundations.² However, while such models are well suited to address many monetary business cycle issues, several important papers argue that they face difficulties in adequately replicating the dynamic *short-run* effects of fiscal policy.³ They also have serious shortcomings when applied to the analysis of *medium- and long-run* fiscal issues such as the crowding-out effects of a permanent increase in public debt.⁴ The key factor that accounts for these difficulties is the absence of non-Ricardian household savings behavior that would make the timing of fiscal interventions non-neutral. A model that adds non-Ricardian behavior while maintaining the nominal and real rigidities of existing models can also account for the critical interactions between monetary and fiscal policies.

¹For a well-known recent example see Schmitt-Grohe and Uribe (2007).

²The related literature is very large. For early surveys of open and closed economy applications see Clarida, Gali and Gertler (1999) and Lane (2001). For current applications in policymaking institutions see the Federal Reserve Board's SIGMA model and the IMF's Global Economy Model (GEM).

³See Fatas and Mihov (2001), Blanchard and Perotti (2002), Ganelli and Lane (2002) and Gali, López-Salido and Vallés (2007).

⁴See for example Kumhof and Laxton (2007).

The candidate non-Ricardian features known from the literature are overlapping generations models following Blanchard (1985) and Weil (1989) and infinite horizon models with a subset of liquidity constrained agents following Gali, López-Salido and Vallés (2007). In this paper we use the latter model class, mainly because the consumption optimality condition of an overlapping generations model can only be derived under certainty equivalence, which rules out welfare analysis. However, this modeling choice also has significant costs, in that liquidity constrained agents imply a much more extreme short-run behavior of consumption in response to fiscal interventions, especially in an open economy.

The rest of the model features endogenous labor supply, endogenous capital accumulation, productive government investment in infrastructure, habit persistence, investment and import adjustment costs, sticky nominal goods prices, and an endowment sector for raw materials, which are used as a manufacturing input.

We assume that there is no coordination problem between monetary and fiscal policies, and that monetary policy follows the familiar type of interest rate reaction function, calibrated to reflect the historical conduct of monetary policy in Chile.⁵ A key result is that if a large share of agents are liquidity constrained, as has long been the case in most developing countries, and as may soon be the case in many developed countries, the ability of monetary policy to stabilize the economy is much reduced because it relies on intertemporal substitution effects. Fiscal policy on the other hand becomes more powerful because it relies on income effects. The consequences can be illustrated by comparing the welfare gains of an optimized fiscal rule over a balanced budget rule with the welfare gains from inflation targeting over exchange rate targeting. The former are four to five times larger.

The remainder of the paper is organized as follows. Section II contains a literature review, Section III describes the model, Section IV discusses calibration, and Section V presents our results. Section VI concludes.

II. Literature Survey

Keynesian demand management through fiscal policy became popular in the 1950s. Philips (1954) stressed the role of automatic stabilizers in the Keynesian framework, while Musgrave (1959) advocated the systematic use of discretionary fiscal policy, specifically a system whereby changes in taxes or spending would be legislated in advance to respond to changes in income. Tobin (1972) contains a similar argument.⁶

Keynesian fiscal activism first started to be challenged in the 1960s, for both theoretical and empirical reasons. The first theoretical challenge came with the extension of the Keynesian IS-LM model to the open economy by Mundell (1963) and Fleming (1962), who showed that under a flexible exchange rate regime fiscal policy would lose its effectiveness in stimulating demand. New and stronger challenges arose from the emerging neoclassical school. Eisner (1969), based on Friedman (1957), first realized that in a permanent

⁵We are separately pursuing the joint optimization of monetary and fiscal policy rules, but for for computational tractability this requires a simpler closed economy setup.

⁶Very similar ideas have been proposed more recently by Seidman (2003).

income model temporary changes in taxation would have only minor effects on lifetime income and therefore on consumption demand. Barro (1974) went further by showing that the timing of tax changes (as long as they are non-distortionary) has no real effects within the paradigm of the infinitely lived representative agent because they are offset by private savings behavior. This is known as the Ricardian Equivalence hypothesis. These challenges to fiscal activism were reinforced by a similar skepticism towards the effectiveness of discretionary monetary policy, such as Lucas (1972). The early empirical challenges came from papers which found that the 1968 tax surcharge and the 1975 tax rebate had limited effects, such as Okun (1971), Springer (1975), Modigliani and Steindel (1977) and Blinder (1981).⁷

It was for monetary policy that the pendulum first started to swing back in favor of activism. This resurgence was based on both much improved theoretical foundations and on empirical arguments. As for theory, the time-dependent price adjustment formulations of Taylor (1980), Rotemberg (1982) and Calvo (1983) made it possible to incorporate nominal rigidities into rational expectations models with forward-looking optimizing agents. Empirical support came from evidence showing that monetary policy has significant short-run real effects, such as Christiano, Eichenbaum and Evans (1996, 1998) and Leeper, Sims and Zha (1996). Finally, the work on monetary policy rules of Taylor (1993), and on constrained discretion, e.g. Bernanke and Mishkin (1997), made it possible to think about discretionary monetary policy as a theoretically coherent and empirically testable strategy.

But the presumption was still that policy activism should be left to monetary policy. It was argued (Gramlich (1999)) that it is critical that fiscal policy deliver its stimulus in a “timely, targeted and temporary” (TTT) manner, but that experience showed this to be hard to achieve. Legislatures are generally much slower at changing taxation and spending than central banks at changing the policy rate, they may not deliver stimulus where it is most needed but instead where it is politically advantageous, and they may be reluctant to withdraw it sufficiently quickly in good times to preserve fiscal sustainability.

Furthermore, empirical work has still not fully settled the theoretical debates about the effectiveness of fiscal activism, mainly because isolating the discretionary component of fiscal policy poses serious methodological problems. But at least the key studies show significantly positive fiscal multipliers of between 0.5 as in Mountford and Uhlig (2002) and around 1 as in Blanchard and Perotti (2002).^{8,9} The evidence certainly does not strongly support the Ricardian Equivalence hypothesis.

To settle these issues in a convincing manner, the most promising approach is the Bayesian estimation of structural DSGE models, which has been used very successfully in the monetary policy literature. But progress with models that have a meaningful role for fiscal policy has been slow until recently. Theoretical work on fiscal policy in the 1990s¹⁰ and in the current decade has focused almost exclusively on the study of optimal taxation that

⁷Studies of the 2001 tax rebates have generated similar results, see Shapiro and Slemrod (2002).

⁸However, Perotti (2007) has outliers as high as 4 and Krogstrup (2002) as low as -2.

⁹In emerging markets there is the additional problem that countercyclical policy may simply not be possible due to external or political constraints. Evidence and theoretical explanations are offered by Gavin and Perrotti (1997), Kaminsky, Reinhart and Vegh (2004), and Talvi and Vegh (2005). We do not think that these arguments apply to Chile in the recent period.

¹⁰This is surveyed in Chari and Kehoe (1999).

minimizes tax wedges. Because the models used have few rigidities, and because typically state-contingent taxes are assumed to be available, this analysis finds little benefit from time variation in taxes and spending. This has started to change more recently with the introduction of New Keynesian models that not only contain significant nominal and real rigidities, but that also have a non-Ricardian element, liquidity constrained households. A key contribution in this literature is Gali, Lopez-Salido and Valles (2007).

But there has been almost no progress on fiscal rules. Taylor (2000) considers a rule in which the budget surplus depends on the output gap, but he argues that such a rule is unnecessary, and in fact undesirable, because the Fed has been very successful at stabilizing the business cycle and would only suffer from having to forecast the fiscal stance. He therefore argues, along with many other commentators at that time, that the role of fiscal policy should be limited to minimizing distortions and to “letting automatic stabilizers work”. Automatic stabilizers describes channels through which policy can be mildly countercyclical even if fiscal instruments are not varied at all in response to the business cycle. Holding spending, the transfer system and tax rates constant in an upturn reduces the spending to GDP ratio and the transfers to GDP ratio, and it increases the tax revenues to GDP ratio. This latter effect becomes even stronger if the tax system is progressive.

Crucially however, Taylor (2000) makes two exceptions to his assessment. The first is fixed exchange rate regimes, where monetary policy deliberately gives up its stabilizing role. The second is a situation where nominal interest rates approach their zero lower bound, so that discretionary monetary policy becomes much more difficult. A fixed exchange rate regime such as EMU is indeed the only case for which countercyclical fiscal policy has so far been analyzed by the theoretical literature. The zero lower bound problem is what the world’s economies face today, and is a major reason for the renewed interest in fiscal policy even under flexible exchange rates. There is however a critical third exception that is overlooked by Taylor, namely the much greater power of fiscal policy in an economy with many liquidity constrained agents. In such an environment fiscal activism may be desirable even under flexible exchange rates and away from the zero lower bound.

The contributions on fiscal policy under fixed exchange rates include Beetsma and Jensen (2005) and Gali and Monacelli (2008). The latter focus exclusively on the theoretically fully optimal policy. The former does discuss fiscal rules, albeit of a highly abstract nature. By contrast this paper systematically studies fiscal rules that are much closer in spirit to those of Taylor (2000).

This is of course subject to all the justified concerns about TTT. But two well-known authors, Solow (2005) and Wyplosz (2005), argue strongly that this can be overcome. Both try to develop the outlines of institutions and procedures that would allow fiscal policy to adopt the core principles of monetary policy. These include either automatically triggered countercyclical rules or a technocrat-run Fiscal Policy Board that decides on the overall budget balance, but that leaves decisions on the composition of the budget to parliament to reduce concerns about a lack of democratic accountability.

Wyplosz (2005) also provides a list of countries that actually use specific fiscal rules. Apart from the Maastricht criteria of the EU, which include a 60% of GDP maximum debt and a 3% of GDP maximum deficit, a small number of other countries pursues either

a debt rule or a golden rule that limits the deficit to financing public investment over the cycle. More interestingly, four countries pursue structural surplus rules fairly similar to the one analyzed in this paper, including Brazil (4.5% primary surplus), Chile (0.5% overall surplus), Sweden (2% overall surplus) and Switzerland (0% overall surplus).

III. The Model

The world consists of 2 countries, Chile and the rest of the world (RW), whose shares in world output equal $\omega/(\omega + \omega^*)$ and $\omega^*/(\omega + \omega^*)$. When the interaction between two countries is discussed we identify RW by an asterisk. Time units represent quarters.

Each country is populated by two types of households, both of which consume final output and supply labor. Infinitely lived households, identified by the superscript *INF*, have full access to domestic and international financial markets, while liquidity constrained households, identified by *LIQ*, are limited to consuming their after tax income in every period. The share of *LIQ* agents in the population equals ψ . Households of both types are subject to uniform taxes on labor income, capital income and consumption, as well as to a lump-sum tax. *LIQ* agents also receive targeted transfers.

Chile's most important export by far has been copper. We will therefore from now on refer to the raw materials sector as the copper sector. Copper output is modeled as an endowment, with flexible copper prices that are arbitrated worldwide. The two major sources of volatility in copper prices are endowment shocks and technology driven demand shocks.

Manufacturers buy investment goods from distributors, labor from households, and copper from the world copper market. They sell to domestic and foreign distributors, with exports priced in producer currency. Distributors produce final output by assembling domestic and foreign manufactured goods, and then combining them with a publicly provided, tax-financed capital stock (infrastructure). Final output is sold to domestic consumers, investors and the government, subject to nominal rigidities in price setting.

Asset markets are incomplete. There is complete home bias in ownership of domestic firms and in government debt, which takes the form of nominally non-contingent one-period bonds denominated in domestic currency. There are two international financial claims, first claims on the dividend income of foreign copper firms, and second nominally non-contingent one-period bonds denominated in the currency of RW.

Technology in the world economy grows at the constant rate $g = T_t/T_{t-1}$, where T_t is the level of labor augmenting world technology. The model's real variables, say x_t , therefore have to be rescaled by T_t , where we will use the notation $\tilde{x}_t = x_t/T_t$. The steady state of \tilde{x}_t is denoted by \bar{x} .

A. Households

1. Infinitely Lived Households

The utility of a representative *INF* household at time t depends on consumption c_t^{INF} , labor supply ℓ_t^{INF} , and real money balances (M_t/P_t) (where P_t is the consumer price index). Lifetime expected utility has the form

$$E_t \sum_{s=0}^{\infty} \beta^s \left[\frac{1 - \frac{v}{g}}{1 - \beta \frac{v}{g}} S_{t+s}^c \ln (c_{t+s}^{INF} - v c_{t+s-1}^{INF}) - \frac{\kappa}{1 + \frac{1}{\gamma}} (\ell_{t+s}^{INF})^{1+\frac{1}{\gamma}} + \frac{\vartheta}{1 - \epsilon} \left(\frac{M_{t+s}}{P_{t+s}} \right)^{1-\epsilon} \right], \quad (1)$$

where β is the discount factor, v determines the degree of habit persistence, γ is the labor supply elasticity, and ϵ is the interest elasticity of money demand. For the money demand coefficient ϑ we will only consider the case of the cashless limit advocated by Woodford (2003), where $\vartheta \rightarrow 0$. S_t^c is a consumption shock. We will also consider an alternative where government consumption g_t^{cons} enters private utility, in which case we add $+\chi \ln(g_t^{cons} (1 - \psi) \bar{c}^{INF}/\bar{c})$ to period utility, where the term following g_t^{cons} is the steady state share of *INF* consumption in aggregate consumption. Consumption c_t^{INF} , which is taxed at the rate $\tau_{c,t}$, is given by a CES aggregate over consumption goods varieties $c_t^{INF}(i)$, with elasticity of substitution σ :

$$c_t^{INF} = \left(\int_0^1 (c_t^{INF}(i))^{\frac{\sigma-1}{\sigma}} di \right)^{\frac{\sigma}{\sigma-1}}. \quad (2)$$

A household can hold nominal domestic government bonds B_t denominated in domestic currency, and nominal foreign bonds F_t denominated in the currency of RW.¹¹ In each case the time subscript t denotes financial claims held from period t to period $t+1$. Gross nominal interest rates on Chilean and RW currency denominated assets held from t to $t+1$ are i_t and i_t^* . We denote the nominal exchange rate vis-a-vis RW by \mathcal{E}_t , and gross nominal exchange rate depreciation by $\varepsilon_t = \mathcal{E}_t/\mathcal{E}_{t-1}$. The real exchange rate vis-a-vis RW is $e_t = (\mathcal{E}_t P_t^*)/P_t$.

To calibrate an empirically reasonable process for Chilean sovereign interest rate spreads, we assume that the country faces an external interest rate risk premium ξ_t^f that depends on expectations of the current account (ca_t) to GDP (gdp_t) ratio and on exogenous shocks S_t^{fx} :

$$\xi_t^f = -\xi \left(\sum_{s=0}^{\bar{s}} \frac{ca_{t+s}}{gdp_{t+s}} \right) / (1 + \bar{s}) + S_t^{fx}. \quad (3)$$

We assume that the premium ξ_t^f is paid to an intermediary who distributes it in a lump-sum fashion to residents of RW.

In addition to interest income households receive after tax labor income, lump-sum dividend distributions and net transfers from the government. Real labor income equals

¹¹We adopt the convention throughout the paper that all nominal/real variables are written in upper/lower case letters. For real asset stocks, each nominal asset is deflated by the consumer price index of the currency of its denomination, so that real domestic bonds are $b_t = B_t/P_t$ and real internationally traded bonds are $f_t = F_t/P_t^*$.

$w_t \ell_t^{INF} (1 - \tau_{L,t})$, where $w_t = W_t/P_t$ is the real wage rate and $\tau_{L,t}$ is the labor tax rate. Dividends are received from the manufacturing and distribution sectors $d_t^M + d_t^D$, the domestic copper sector d_t^X , and the foreign copper sector d_t^F . *INF* households pay lump-sum transfers $\tau_{T_t}^{INF}$ to the government, which in turn redistributes them to the relatively less well off *LIQ* agents, with $\tau_{T_t}^{LIQ} = \frac{1-\psi}{\psi} \tau_{T_t}^{INF}$. This is a technical assumption that allows us to allocate at least a part of the economy's dividend income to *LIQ* agents even though they do not own firms. Both groups of households also pay lump-sum taxes $\tau_{ls,t}$ to the government in proportion to their consumption shares. The *INF* household's budget constraint in nominal terms is

$$P_t c_t^{INF} (1 + \tau_{c,t}) + B_t + \mathcal{E}_t F_t = i_{t-1} B_{t-1} + i_{t-1}^* \mathcal{E}_t F_{t-1} \left(1 + \xi_{t-1}^f\right) \quad (4)$$

$$+ W_t \ell_t^{INF} (1 - \tau_{L,t}) + \sum_{j=M,D,X,F} D_t^j - P_t \frac{c_t^{INF}}{C_t} \tau_{ls,t} - P_t \tau_{T_t}^{INF}.$$

We denote the multiplier of this budget constraint by Λ_t , and let $\lambda_t = \Lambda_t P_t$. The *INF* household maximizes (1) subject to (2) and (4). The first-order conditions are shown in Appendix 1.

2. Liquidity Constrained Households

The objective function of *LIQ* households is assumed to be identical to that of *INF* households except that they do not hold money and are not subject to autonomous consumption demand shocks S_t^c . But their budget constraint is different in that they can consume at most their current income, which consists of their after tax wage income plus three types of net government transfers, first lump-sum transfers from *INF* to *LIQ* agents $\tau_{T,t}^{LIQ}$, second their share of lump-sum taxes, and third lump-sum transfers Υ_t that are targeted specifically to *LIQ* agents:¹²

$$c_t^{LIQ} (1 + \tau_{c,t}) = w_t \ell_t^{LIQ} (1 - \tau_{L,t}) + \Upsilon_t + \tau_{T,t}^{LIQ} - \frac{c_t^{LIQ}}{c_t} \tau_{ls,t}. \quad (5)$$

The condition for the optimal consumption-leisure choice of *LIQ* households is identical to that of *INF* households. Aggregate consumption and labor supply are given by $\check{c}_t = (1 - \psi) \check{c}_t^{INF} + \psi \check{c}_t^{LIQ}$ and $\ell_t = (1 - \psi) \ell_t^{INF} + \psi \ell_t^{LIQ}$.

¹²We therefore keep the two lump-sum items separate. This also allows a better calibration of the baseline fiscal accounts.

B. Manufacturing

Manufacturers are perfectly competitive in their input and output markets. They pay out each period's net cash flow as dividends to *INF* households and maximize the present discounted value of these dividends. The technology of a representative manufacturer is given by a CES production function in capital k_{t-1} , labor ℓ_t , and copper x_t :

$$\begin{aligned} z_t^H &= f(k_{t-1}, \ell_t, x_t) \\ &= \mathfrak{T} \left((1 - \alpha_t^X)^{\frac{1}{\xi_X}} (o_t)^{\frac{\xi_X - 1}{\xi_X}} + (\alpha_t^X)^{\frac{1}{\xi_X}} (x_t)^{\frac{\xi_X - 1}{\xi_X}} \right)^{\frac{\xi_X}{\xi_X - 1}}, \\ o_t &= \left((1 - \alpha^U)^{\frac{1}{\xi_Z}} (k_{t-1})^{\frac{\xi_Z - 1}{\xi_Z}} + (\alpha^U)^{\frac{1}{\xi_Z}} (T_t S_t^a \ell_t)^{\frac{\xi_Z - 1}{\xi_Z}} \right)^{\frac{\xi_Z}{\xi_Z - 1}}. \end{aligned} \quad (6)$$

The technology scale factor \mathfrak{T} is used to calibrate relative levels of per capita GDP in Chile and RW. The elasticities of substitution between copper and capital/labor and between labor and capital are ξ_X and ξ_Z , respectively. Labor augmenting technology consists of the level of world technology T_t and of a stationary country specific productivity shock S_t^a . The relative copper demand coefficient α_t^X is subject to shocks. Capital is accumulated within firms, and is subject to quadratic adjustment costs $G_{I,t}$ in gross investment I_t

$$G_{I,t} = \frac{\phi_I}{2} I_t \left(\frac{(I_t(i)/g) - I_{t-1}(i)}{I_{t-1}(i)} \right)^2, \quad (7)$$

where firm specific indices i indicate choice variables of the firm. The law of motion of capital is described by

$$k_t = (1 - \delta_k) k_{t-1} + I_t S_t^{inv}, \quad (8)$$

where δ_k represents the depreciation rate of privately held physical capital and S_t^{inv} is a shock to investment.

Real dividends d_t^M equal revenue $p_t^H z_t^H$ minus cash outflows.¹³ The latter include the wage bill $w_t \ell_t$, investment I_t , copper purchases $p_t^X x_t$, investment adjustment costs $G_{I,t}$, and taxes on post-depreciation capital income $\tau_t^k (r_t^k - \delta_k q_t) k_{t-1}$, where τ_t^k is the capital income tax rate, r_t^k is the return to capital, and q_t is the shadow price of installed capital (Tobin's q). The optimization problem of each manufacturing firm is given by

$$\underset{\{\ell_{t+s}, I_{t+s}, k_{t+s}, x_{t+s}\}_{s=0}^{\infty}}{Max} E_t \sum_{s=0}^{\infty} \beta^s \lambda_{t+s} d_{t+s}^M, \quad (9)$$

subject to (6)-(8), where the multiplier of (8) is q_t . The optimality conditions are shown in Appendix 1.

¹³Our notation for relative prices p uses the same superscripts as the respective quantities.

C. Copper Production

In each period Chile and RW receive a stochastic endowment flow of copper x_t^{sup} . This endowment is sold to manufacturers in Chile and RW, with total demand for each country given by x_t^{dem} . Copper exports are therefore given by

$$x_t^x = p_t^X (x_t^{sup} - x_t^{dem}). \quad (10)$$

The world market for copper is perfectly competitive, with flexible prices that are arbitrated worldwide, $p_t^X = p_t^{X*} e_t$. A constant share of steady state copper revenue is paid out to domestic factors of production as dividends \bar{d}^X . The rest is divided in fixed shares $(1 - s_f^x)$ and s_f^x between payments to the government g_t^X , for the case of publicly owned producers, and dividends to foreign owners f_t^X . This means that all benefits of favorable copper price shocks accrue exclusively to the government and foreigners, and vice versa for unfavorable shocks. This corresponds more closely to the situation of the Chilean copper sector than the polar opposite assumption of assuming equal shares between the three recipients at all times. We have

$$f_t^X = s_f^x (p_t^X x_t^{sup} - \bar{d}^X T_t) , \quad (11)$$

$$g_t^X = p_t^X x_t^{sup} - \bar{d}^X T_t - f_t^X .$$

The dividends received by Chilean households from ownership of RW copper producers are then given by

$$d_t^F = \frac{\omega^*}{\omega} e_t f_t^{X*} . \quad (12)$$

D. Distribution

Firms in this sector are indexed by i . They produce final output $z_t^D(i)$ by combining domestic manufacturing output $y_t^H(i)$ with foreign manufacturing output $y_t^F(i)$ subject to an adjustment cost $G_{F,t}^T(i)$ that makes rapid changes in the share of foreign tradables costly¹⁴, and then combining the resulting private output composite $y_t^T(i)$ with government infrastructure capital k_{t-1}^G . Final output is sold subject to nominal rigidities in price setting.

The profit maximization problem of distributors consists of maximizing the present discounted value of dividends $d_t^D(i)$, where the latter equal real revenue $P_t(i) z_t^D(i) / P_t$ minus real costs of domestic and foreign manufactured goods inputs $p_t^H y_t^H(i) + p_t^F y_t^F(i)$, inflation adjustment costs $G_{P,t}(i)$, and a fixed cost $T_t \theta^D$. The latter arises as long as the firm chooses to produce positive output, and grows at the constant growth rate of world technological progress. Net output is therefore equal to $\max(0, z_t^D(i) - T_t \theta^D)$. This cost term will be useful for calibrating the model's steady state. The optimization problem is

$$\text{Max}_{\{y_{t+s}^H(i), y_{t+s}^F(i), P_{t+s}(i)\}_{s=0}^{\infty}} E_t \sum_{s=0}^{\infty} \beta^s \lambda_{t+s} d_{t+s}^D(i) . \quad (13)$$

¹⁴This assumption has become widely used. It prevents excessive short-term responsiveness of international trade to real exchange rate movements.

The technology for private output is given by

$$y_t^T(i) = \left((\alpha_H)^{\frac{1}{\xi_T}} (y_t^H(i))^{\frac{\xi_T-1}{\xi_T}} + (1 - \alpha_H)^{\frac{1}{\xi_T}} (y_t^F(i)(1 - G_{T,t}(i)))^{\frac{\xi_T-1}{\xi_T}} \right)^{\frac{\xi_T}{\xi_T-1}}, \quad (14)$$

$$G_{T,t}(i) = \frac{\phi_T}{2} \frac{(\mathcal{R}_t - 1)^2}{1 + (\mathcal{R}_t - 1)^2}, \quad \mathcal{R}_t = \frac{\frac{y_t^F(i)}{y_t^T(i)}}{\frac{y_{t-1}^F}{y_{t-1}^T}}, \quad (15)$$

where ξ_T is the elasticity of substitution between Chilean and RW goods and α_H is a share parameter determining long-run home bias. The technology for combining private output with the public capital stock is given by

$$z_t^D(i) = y_t^T(i) (k_{t-1}^G)^{\alpha_G} \mathcal{S}. \quad (16)$$

The stock of public infrastructure k_{t-1}^G is identical for all firms and provided free of charge to the end user (but not of course to the taxpayer). It enters in a similar fashion to the level of technology, but with decreasing returns to public capital as long as $\alpha_G < 0$. The advantage of this formulation is that it retains constant returns to scale at the level of each firm. The term \mathcal{S} is a technology scale factor that is set to ensure $(\bar{k}^G/g)^{\alpha_G} \mathcal{S} = 1$. The conditions for cost-minimizing input choice are shown in Appendix 1.

Each group of distributors' customers demands the same CES aggregate of distributed varieties as consumers, see equation (2). The aggregate demand for variety i is therefore

$$\mathcal{D}_t(i) = \left(\frac{P_t(i)}{P_t} \right)^{-\sigma} \mathcal{D}_t, \quad (17)$$

where $\mathcal{D}_t(i)$ and \mathcal{D}_t remain to be specified by way of market clearing conditions. Following Ireland (2001) and Laxton and Pesenti (2003), inflation adjustment costs are quadratic in changes in the rate of inflation rather than in price levels:

$$G_{P,t}(i) = \frac{\phi_P}{2} z_t^D \left(\frac{\pi_t(i)}{\pi_{t-1}} - 1 \right)^2 = \frac{\phi_P}{2} z_t^D \left(\frac{\frac{P_t(i)}{P_{t-1}(i)}}{\frac{P_{t-1}}{P_{t-2}}} - 1 \right)^2. \quad (18)$$

The first order condition for pricing is symmetric across firms, and given by

$$\left[\frac{\sigma}{\sigma-1} p_t^D - 1 \right] = \frac{\phi_P}{\sigma-1} \left(\frac{\pi_t}{\pi_{t-1}} \right) \left(\frac{\pi_t}{\pi_{t-1}} - 1 \right) - E_t \beta \frac{\phi_P}{\sigma-1} \frac{\lambda_{t+1}}{\lambda_t} \frac{z_{t+1}^D}{z_t^D} \left(\frac{\pi_{t+1}}{\pi_t} \right) \left(\frac{\pi_{t+1}}{\pi_t} - 1 \right), \quad (19)$$

where p_t^D is the marginal cost of final output. Furthermore, we assume that observed inflation is subject to autocorrelated measurement errors S_t^π that account for inflation variability not explained by the other shocks in the model. Observed final goods inflation π_t^{obs} is therefore

$$\pi_t^{obs} = \pi_t S_t^\pi. \quad (20)$$

E. Government

Monetary policy follows a conventional policy rule for the nominal interest rate that depends on an inflation gap. Fiscal policy takes the parameterization of this rule as given and optimizes the coefficients of a fiscal policy rule that depends on a tax revenue gap, a copper revenue gap, and in some versions of the rule on a debt gap.

1. Monetary Policy

The interest rate rule is

$$i_t = (i_{t-1})^{\delta_i} (\bar{r}\pi_{4,t+4})^{1-\delta_i} \left(\frac{\pi_{4,t+4}}{\bar{\pi}} \right)^{(1-\delta_i)\delta_\pi}, \quad (21)$$

$$\pi_{4,t} = (\pi_t \pi_{t-1} \pi_{t-2} \pi_{t-3})^{\frac{1}{4}}. \quad (22)$$

The long-run or target real interest rate is \bar{r} and the inflation target is $\bar{\pi}$. Both Chile and RW are assumed to follow rules of this type.

2. Fiscal Policy

The government's policy rule for transfers from *INF* agents to *LIQ* agents specifies that the redistributed share of dividends is $\iota \leq \psi$:

$$\tau_{T,t}^{LIQ} = \iota (d_t^M + d_t^D + \bar{d}^X T_t + d_t^F). \quad (23)$$

Government consumption spending g_t^{cons} is wasteful except when we allow for it to enter the utility function. Government investment spending g_t^{inv} on the other hand augments the stock of publicly provided infrastructure capital k_t^G , the evolution of which is given by

$$k_t^G = (1 - \delta_G) k_{t-1}^G + g_t^{inv}. \quad (24)$$

The government budget constraint, in nominal terms, therefore takes the form

$$B_t = i_{t-1} B_{t-1} - P_t s_t, \quad (25)$$

$$s_t = \tau_t + g_t^X - g_t - \Upsilon_t, \quad (26)$$

$$\tau_t = \tau_{L,t} w_t \ell_t + \tau_{c,t} c_t + \tau_{k,t} (r_t^k - \delta_K q_t) k_{t-1} + \tau_{ls,t}. \quad (27)$$

where s_t is the primary surplus and τ_t is total tax revenue. The final component of fiscal policy is the policy rule, which is presented separately in the following section.

F. Fiscal Policy Rules

1. Chile's Structural Surplus Rule

Fiscal policy in Chile currently follows the structural surplus rule (henceforth SSR) explained in Medina and Soto (2006). A suitable model representation is

$$\frac{\check{g}s_t}{g\check{d}p_t} = \frac{\overline{gs}^{rat}}{100} + \left(\frac{\check{\tau}_t - \check{\tau}_t^{pot}}{g\check{d}p_t} \right) + \left(\frac{\check{g}_t^X - \check{g}_{X_t}^{pot}}{g\check{d}p_t} \right), \quad (28)$$

where the exposition now uses variables in their growth-normalized form because this is more instructive. In this rule the government surplus is defined as

$$\check{g}s_t = -\check{b}_t + \frac{\check{b}_{t-1}}{\pi_t g}, \quad (29)$$

which equals the sum of the primary surplus and net interest payments on government debt. The structural surplus target \overline{gs}^{rat} is exogenous, and in the Chilean case has been fixed at +0.5 since May 2007.¹⁵ The remaining items represent cyclical adjustment terms whereby the government saves, in the form of reduced debt or increased assets, excess tax revenue and excess revenue from copper sales. Potential tax revenue $\check{\tau}_t^{pot}$ is given by the same formula as actual tax revenue τ_t in equation (27), at current tax rates, but with the actual tax bases replaced by potential tax bases that are estimated by a team of macroeconomic experts. For the purpose of this paper we assume that potential tax bases equal their steady state values:

$$\check{\tau}_t = \tau_{L,t} \bar{w} \bar{\ell} + \tau_{c,t} \bar{c} + \tau_{k,t} \left(\bar{r}^k - \delta_K \right) \left(\bar{k}/g \right) + \check{\tau}_{ls,t}. \quad (30)$$

The treatment for $\check{g}_{X_t}^{pot}$ by the Chilean authorities is slightly different. Here a team of experts estimates the potential or long-run international price of copper and the potential domestic output of copper for an estimate of potential dollar revenue, but changes in the real exchange rate are allowed to affect the estimate of potential revenue in terms of Chilean currency:

$$\check{g}_{X_t}^{pot} = \left(e_t \bar{p}^{X^*} \bar{x}^{sup} - \bar{d}^X \right) \left(1 - s_f^x \right). \quad (31)$$

Chile's fiscal rule has been in effect since late 2000, and during its initial operation excess revenues were saved in the form of cash and short-term instruments. In late 2006 the rule was embedded in a formal legal framework, the Fiscal Responsibility Law, which specifies that savings are to be accumulated in an Economic and Social Stabilization Fund. As of the end of 2008 this fund had accumulated over 20 billion U.S. dollars (about 14 percent of GDP), principally from excess copper revenues. Chile's January 2009 fiscal stimulus plan, which amounts to 4 billion U.S. dollars, is being funded from this source. This plan includes a significant component of increased transfers, the baseline policy instrument of our paper, as well as tax reductions. In terms of the rule it is being formalized as a temporary reduction of the structural surplus target \overline{gs}^{rat} from 0.5 to 0.

¹⁵The target had previously been held at +1 for several years.

It is worth discussing some important implications of this rule. We start with **dynamic stability**, specifically the ability of the rule to stabilize long-run debt. Equation (29) shows that a SSR anchors the long-run debt to GDP ratio at

$$\bar{b}^{rat} = - \left(\frac{\bar{g}^{s^{rat}}}{4} \right) \frac{\bar{\pi}g}{\bar{\pi}g - 1} . \quad (32)$$

Our calibrated economy features a 5% annual nominal growth rate $\bar{\pi}g$ and a surplus target of 0.5% of GDP, which implies a long-run government assets to GDP ratio of approximately 10%.¹⁶ More importantly however, it implies a quarterly autoregressive coefficient on debt in equation (29) of 0.988, which is very close to the unit root on debt which has been found optimal in some theoretical literature. Equation (28) is a targeting rule, and it leaves open which instrument is to be used to move the government surplus in the desired direction. We will look at six possible instruments, three tax rates ($\tau_{c,t}$, $\tau_{L,t}$, $\tau_{k,t}$) and three spending items (Υ_t , g_t^{cons} , g_t^{inv}). The default instrument for our baseline results reported in Sections V.A through V.H below is transfers targeted to *LIQ* agents, Υ_t .

A second critical aspect of rule (28) concerns its performance at **business cycle stabilization**. The rule states that when the economy is hit with a shock that produces additional tax or copper revenue at given tax rates, all of that excess revenue should go towards repaying debt, while only the interest savings on debt that accrue over time should be used to gradually lower tax rates or increase spending. This is a natural rules-based way to formalize the popular notion of automatic stabilizers. Such a rule however mainly minimizes the volatility of *fiscal instruments* rather than of the *business cycle*.

2. A Tax Revenue Gap Targeting Rule

The critical insight for developing a more general class of rules is that the coefficients multiplying the gap variables in (28) can be varied continuously rather than being limited to values of 1 as in the SSR. We denote these coefficients by d^{tax} and d^{cop} . We also add an additional debt gap variable with coefficient d^{debt} . The rule therefore becomes

$$\frac{\check{g}s_t}{g\check{d}p_t} = \frac{\bar{g}^{s^{rat}}}{100} + d^{tax} \left(\frac{\tau_t - \check{\tau}_t^{pot}}{g\check{d}p_t} \right) + d^{cop} \left(\frac{g_t^X - \check{g}_{X_t}^{pot}}{g\check{d}p_t} \right) + d^{debt} \left(\frac{\check{b}_t}{4g\check{d}p_t} - \frac{\bar{b}^{rat}}{100} \right) . \quad (33)$$

The case of $d^{tax} = d^{cop} = d^{debt} = 0$ corresponds to a strict balanced budget rule (henceforth BBR). This is highly procyclical because it calls for lower tax rates (or higher spending) in a boom. It also implies volatile fiscal instruments. A choice of $d^{tax} > 1$ is countercyclical by calling for a higher tax rate (or lower spending) in a boom.¹⁷ This does increase fiscal instrument volatility, but with tax rates moving in the opposite direction

¹⁶Incidentally, this target is a very good choice from the point of view of stabilizing the business cycle, because Chile's net assets to GDP ratio is currently around 10%. This coincidence of flow and implied stock targets makes it unnecessary to intertemporally vary fiscal instruments in order to allow debt to reach the stock target.

¹⁷Therefore, in this more general form of the rule, Chile's recent stimulus package could be reinterpreted in terms of the rule as a more aggressive countercyclical behavior $d^{tax} > 1$, rather than as a temporary reduction in the structural surplus target $\bar{g}^{s^{rat}}$.

from a BBR. In the context of our model $d^{tax} > 1$ represents systematic discretionary fiscal policy. But it can also be interpreted more broadly to represent automatic stabilizers in an economy where the tax system, unlike in our model, is progressive. But it is highly unlikely that such automatic stabilizers would be as countercyclical as the best rules selected by our welfare analysis.

We have considered variants of (33) where potential ($\tilde{\tau}_t^{pot}$ and $\tilde{g}_{X_t}^{pot}$) is a moving average of current and past actual values, as this may come closer to what policymakers actually do.¹⁸ The resulting welfare gains are quantitatively smaller but qualitatively very similar to the baseline case. We therefore do not present them here.¹⁹

We have mentioned that a key concern in fiscal policy concerns implementation lags. We have introduced such lags into the fiscal rule, but the results, not reported here, only reflect the extreme nature of *LIQ* consumption behavior. Specifically, their complete inability to smooth consumption even over short periods means that even a one period implementation lag is very costly. A more realistic answer to the question of implementation lags requires a more realistic model, such as a hybrid between the liquidity constrained agents and OLG models.

3. A Tax Revenue Gap Instrument Rule

Given the multiplicity of fiscal instruments there is a multiplicity of instrument rules that can be written as alternatives to the general targeting rule (33). Our baseline will use targeted transfers as the instrument, in which case we have

$$\left(\frac{\tilde{Y}_t}{g\check{d}p_t} - \frac{\tilde{Y}^{rat}}{100} \right) = -d^{tax} \left(\frac{\tilde{\tau}_t - \tilde{\tau}_t^{pot}}{g\check{d}p_t} \right) - d^{cop} \left(\frac{\tilde{g}_t^X - \tilde{g}_{X_t}^{pot}}{g\check{d}p_t} \right) - d^{debt} \left(\frac{\check{b}_t}{4g\check{d}p_t} - \frac{\bar{b}^{rat}}{100} \right), \quad (34)$$

where \tilde{Y}^{rat} has been set to satisfy the structural surplus target $\overline{gs}/\overline{gdp} = \overline{gs}^{rat}/100$.

G. Shocks

The seven shocks of the model are given by

$$z_t = (1 - \rho_z) \bar{z} + \rho_z z_{t-1} + \bar{z} u_t^z, \quad (35)$$

where $z_t \in \{S_t^c, S_t^{fx}, S_t^a, S_t^{inv}, S_t^\pi, \check{x}_t^{sup}, \alpha_t^{x^*}\}$.

¹⁸The evidence is however for less smoothing in fiscal policy than in monetary policy. See Gali and Perotti (2003).

¹⁹Such a variant of the rule would be essential in the case of permanent shocks that drive potential to a new level. In this paper all shocks are transitory.

H. Equilibrium and Balance of Payments

In equilibrium *INF* and *LIQ* households maximize utility, manufacturers and distributors maximize the present discounted value of their cash flows, and the following market clearing conditions hold for the world copper market, and for each country's intermediate and final goods markets:²⁰

$$\omega(\check{x}^{sup} - \check{x}_t^{dem}) + \omega^*(\check{x}^{sup*} - \check{x}_t^{dem*}) = 0, \quad (36)$$

$$\check{z}_t^H = \check{y}_t^H + \check{y}_t^{F*} \frac{\omega^*}{\omega}, \quad (37)$$

$$\check{z}_t^D = \check{c}_t + \check{I}_t + \check{g}_t + \check{G}_{P,t} + \check{G}_{I,t} + \theta^D. \quad (38)$$

Furthermore, the net foreign asset evolution for Chile is given by

$$e_t \check{f}_t = \frac{i_{t-1}^* \varepsilon_t (1 + \xi_{t-1}^f)}{\pi_t g} e_{t-1} \check{f}_{t-1} + p_t^H \check{y}_t^{F*} \frac{\omega^*}{\omega} - p_t^F \check{y}_t^F + \check{x}_t^X - \check{f}_t^X. \quad (39)$$

Notice that the last two terms represent the direct effects of the copper sector. Copper export earnings add to the trade surplus, but transfers of a share of copper revenue to other countries reduce the current account surplus. The current account equals the change in the level of net foreign assets, $c\check{a}_t = e_t \check{f}_t - (e_{t-1} \check{f}_{t-1}) / (\pi_t g)$. The market clearing condition for international bonds is

$$\omega \check{f}_t + \omega^* \check{f}_t^* = 0. \quad (40)$$

Finally, GDP at consumer prices is

$$g\check{d}p_t = \check{c}_t(1 + \tau_{c,t}) + \check{I}_t + \check{g}_t + p_t^H \check{y}_t^{F*} \frac{\omega^*}{\omega} - p_t^F \check{y}_t^F + \check{x}_t^X. \quad (41)$$

I. Computation of Welfare

Appendix 2 shows how we compute the Lucas (1987) compensating consumption variation (in percent) for each group of households, η^{INF} and η^{LIQ} . With one exception we will only focus on aggregate welfare, which we define as the population-weighted average of compensating variations:

$$\eta = (1 - \psi) \eta^{INF} + \psi \eta^{LIQ}. \quad (42)$$

IV. Calibration

A. Steady State

To fix steady state values we use sample averages of Chilean data for the period 1999Q3-2007Q4. Chile represents 0.3% of world GDP by setting $\omega = 1$ and $\omega^* = 332.333$. Its per capita GDP is roughly equal to world per capita GDP.

²⁰For the latter two only the market clearing conditions for Chile are listed. RW conditions are symmetric.

Chile's steady state net foreign liabilities to GDP ratio is 20%, which implies a current account deficit to GDP ratio of 1%. We estimate $\xi = 0.0006$ from Chilean current account and risk premium data (with $\bar{s} = 3$ in equation (3)), and use the (small) residuals from this regression to calibrate the shock process S_t^{fx} . We fix the steady state world real interest rate at 3% per annum, $\bar{r} = 1.0075$, and the world real growth rate at 2% per annum, $g = 1.005$, which implies $\beta = 0.9969$ and $\beta^* = 0.9975$. The steady state inflation rates for both countries are set at 3% per annum, $\bar{\pi} = \bar{\pi}^* = 1.0075$.

As for household preferences, the labor supply elasticities are $\gamma = \gamma^* = 0.5$, based on the evidence in Pencavel (1986), and habit persistence is $v = 0.7$ following Boldrin, Christiano and Fisher (2001). The shares of liquidity constrained agents in the population are $\psi = 0.5$ as in Gali, Lopez-Salido and Valles (2007), while their shares in dividends are $\iota = 0.25$. When government consumption enters utility, we set χ to a value consistent with a unitary marginal rate of substitution between consumption of private and government goods, as in Gali and Monacelli (2008).

The split of copper revenue into the incomes of domestic labor, domestic capital, domestic government and foreign investors is assumed to be 40%/20%/20%/20% in Chile and 40%/40%/20%/0% for RW. This reflects the low labor share of this sector, the high degree of state ownership in raw materials production worldwide, and the fact that the Chilean government, through the state owned copper company CODELCO, does receive roughly 50% of the profits of the copper sector, with the rest going to foreigners. The overall labor shares in both economies are 64%. The steady state investment to GDP ratios are 22% in Chile (and 20% in RW). For government spending the overall ratios equal 12% and 18%, respectively, reflecting the relatively small size of Chile's public sector. We set the trade share parameters α_H to produce a non-copper steady state imports to GDP ratio of 33%. For copper trade, we calibrate the supply and demand parameters \bar{x}^{sup} and $\bar{\alpha}^X$, first to reflect the ratio of the value of copper used in production to world GDP of 0.08%, and second to reflect the recent historic average Chilean copper exports to GDP ratio of 12.3%.²¹

We assume a conventional Cobb-Douglas technology between capital and labor, a trade elasticity of $\xi_T = 1.5$, and a low elasticity of substitution between copper and labor/capital $\xi_X = 0.5$. The elasticity of substitution between final goods varieties is assumed to equal $\sigma = 6$, for a markup of 20%, which is common in the monetary business cycle literature.

One of the more challenging aspects of the model calibration is the public capital stock. For the U.S. infrastructure investment represents one sixth of all government spending. This may however be too low as it assumes a zero productivity of public education and health spending. As a sensible middle ground we therefore raise that share to one third, or 4% of GDP in Chile. Kamps (2004) presents evidence for the depreciation rate of public capital of 4% per annum. We therefore set $\delta_G = 0.01$. The productivity of public capital is determined by the parameter α_G . Ligthart and Suárez (2005) present a meta analysis that finds an elasticity of aggregate output with respect to public capital of 0.14, which we can replicate by setting $\alpha_G = 0.1$.

Given the calibration of spending, steady state transfers are set to replicate aggregate tax revenue to GDP ratios. Based on recent Chilean averages we set the steady state shares of

²¹This ratio has declined since the early 1990s.

consumption, labor, capital and lump-sum taxes in overall tax revenue at 50%, 15%, 14% and 25%²², with the corresponding numbers for RW of 35%, 35%, 8% and 22%. Government debt to GDP ratios are 0% in Chile (this ratio turned positive in 2006) and 50% in RW.

B. Policy Rules, Adjustment Costs and Shocks

The autocorrelation coefficients and standard deviations of the model's seven shocks, together with the real and nominal adjustment cost parameters ϕ_I , ϕ_T and ϕ_P , are calibrated to reproduce the autocorrelations and standard deviations of detrended Chilean GDP, consumption, investment, inflation, physical copper output, and dollar copper prices for the period 1999Q3-2007Q4.²³ We calibrate monetary and fiscal policy according to the rules used in Chile during this time, either according to the authorities or available empirical estimates. This was a period of high macroeconomic stability and without major changes in trend growth. We therefore detrended the data by removing a log-linear trend. Table 1 reports the moments of the data. The model is able to reproduce these exactly, because of two critical features. First, the endowment nature of the copper sector can generate the observed extreme volatility of copper prices. Second, the presence of liquidity constrained households ensures that the associated wealth effects do not generate excessively persistent output and consumption.

Table 1. Key Moments of the Data

	Standard Deviation	Auto- Correlation
<i>GDP</i>	1.52	0.72
<i>Inflation</i>	2.31	0.60
<i>Consumption</i>	2.60	0.93
<i>Investment</i>	5.94	0.85
<i>Copper Output</i>	5.14	0.08
<i>Copper Price</i>	25.66	0.91

In this calibration 60% of the variation in the Fisher chain-weighted measure of GDP is accounted for by productivity shocks, with 25% coming from shocks to the copper sector and 15% from demand shocks. Risk premium and inflation shocks have only a modest or no effect on the real economy, and in our presentation below we will therefore for the most part ignore them. We will show that our main results on welfare and fiscal instrument volatility are not sensitive to changes in the relative sizes of the shock processes, by decomposing the results into the contributions of the major shocks.

²²Lump-sum taxes are all tax revenues that could not obviously be associated with the other three categories.

²³We set $\phi_P = 80$, which corresponds to an average duration of price contracts in a Calvo-type model of between 4 and 5 quarters.

V. Results

A. Monetary Rules

In order to obtain a benchmark for the benefits of fiscal policy, we begin by computing the more familiar benefit of moving from completely fixed to optimally flexible exchange rates or inflation targeting. We first conduct a grid search over dynamically stable combinations of the parameters δ_i and δ_π of the monetary rule, holding all other parameters at their baseline values.²⁴ As is familiar from the literature, welfare increases in δ_π , but with only small incremental benefits above $\delta_\pi = 2$. The maximum welfare gain however is very small at less than 0.03% of steady state consumption, for two reasons. First, we have chosen a fairly calm period for the Chilean economy. Second, monetary policy relies primarily on an intertemporal substitution channel, which in our economy is completely absent for 50% of the population. In our analysis of fiscal policy we will assume a specification of monetary policy that represents a compromise between the rule actually pursued in Chile according to its monetary authorities ($\delta_i = 0.7$ and $\delta_\pi = 0.5$) and the specification suggested by our grid search. We set $\delta_i = 0.7$ and $\delta_\pi = 2$, for a welfare gain of 0.025%.

B. Impulse Responses

Before analyzing the welfare implications of different rules, we illustrate their dynamic responses to shocks in Figures 1-3. The fiscal rule for RW is held constant at $d^{tax*} = d^{cop*} = 1$ and $d^{debt*} = 0$. In Figures 1 and 2 we contrast a BBR, a SSR and a CCR with coefficients $d^{tax} = 0/1/5$, in all cases holding $d^{cop} = 1$ and $d^{debt} = 0$.

Figure 1 shows a one standard deviation technology shock. Given sticky goods prices, on impact the real wage falls as firms require less labor. Given habit persistence in their consumption, *LIQ* households therefore increase their labor supply to maintain a steady income flow. But aggregate labor demand moves much less, with real wages doing much of the work to clear markets. This means that *INF* agents are indirectly affected, their labor supply moving in the opposite direction to *LIQ* agents.

The technology shock causes an endogenous decrease in tax revenue, mainly labor and capital income taxes. Under a BBR this calls for an offsetting reduction in transfers that reduces the income of *LIQ* agents even further, thereby causing an additional increase in their labor supply, but despite that also a drop in consumption. A SSR by contrast allows some endogenous fluctuations in the government deficit, with almost no change in transfers. This is the automatic stabilizer at work, but the main variable being stabilized is transfers. There is a reduction in the fluctuations of *LIQ* employment and consumption, and thereby also in the indirect effects on *INF* employment. But this effect is comparatively small. A CCR is far more countercyclical. It greatly reduces initial period differences in the labor supply behavior of *LIQ* and *INF* agents, by increasing rather than reducing transfers in the face of lower tax revenue and thereby eliminating most of the income effects of the technology shock on *LIQ* agents. These agents can

²⁴We also explored output gap and output growth terms, but these had only a small effect on welfare, with optimal coefficients near zero.

therefore better smooth their consumption, and in addition *INF* agents suffer from much smaller indirect employment effects. We note that fiscal policy clearly satisfies the TTT requirements under the CCR.

It is easy to see that a countercyclical rule must improve welfare because of its powerful stabilizing effects on consumption and labor. Note however that the effects on GDP volatility are much smaller, while investment becomes more volatile.

In Figure 2 we turn to a one standard deviation shock to investment. This shock causes a strong increase in the real wage as firms attempt to hire more workers to benefit from more productive investment. This allows *LIQ* agents to reduce their labor supply while increasing their consumption. Because equilibrium employment does not rise dramatically, the effect on *INF* agents is a strong increase in labor supply to make up for the reduction in *LIQ* labor supply.

Compared to its alternatives a BBR again increases the volatility caused by the shock, by raising transfers to *LIQ* agents in response to higher tax revenue and thereby further reducing their labor supply and increasing their consumption. The business cycle stabilizing effect of a SSR is again quite modest. A CCR strongly reduces transfers to *LIQ* agents when their wages rise, to such an extent that their labor supply initially increases and their consumption falls. Consequently the required increase in labor is, as for the technology shock, supplied in roughly equal measure by both groups of agents, thereby minimizing the volatility of each group's labor supply.

Figure 3 illustrates a one standard deviation copper demand shock, with $d^{tax} = 1$, $d^{debt} = 0$ and $d^{cop} = 0/1/5$. The shock has a strong and persistent effect on Chile's income and wealth that allows households, *ceteris paribus*, to increase consumption while reducing labor supply. Under a copper revenue BBR ($d^{cop} = 0$) the government responds to the additional copper revenue by distributing it in the form of increased transfers, causing *LIQ* agents to work less and consume more. The copper revenue SSR ($d^{cop} = 1$) in this case introduces significantly less volatility by keeping transfers roughly unchanged. Both groups of agents experience a small but sustained increase in consumption that reflects their increased wealth, accompanied by a very small reduction in labor supply. A copper revenue CCR ($d^{cop} = 5$) is highly undesirable. The government responds to the extra revenue by reducing transfers to *LIQ* agents, thereby reducing their consumption and increasing their labor effort. This has labor market spillover effects to *INF* agents, allowing them to work less.

Copper revenue shocks are exogenous shocks to wealth that *LIQ* agents are unable to smooth. It is therefore optimal for the government to do so for them, by saving excess revenue and then slowly releasing it over time, in other words through a copper revenue SSR.

C. Welfare

Figure 4 illustrates the welfare effects of rule (33) as a function of its two key parameters, d^{tax} and d^{cop} . Each subplot shows the compensating consumption variation η , in percent, along the vertical axis. The baseline against which all parameter combinations are

compared is the balanced budget rule, so that at $d^{tax} = d^{cop} = 0$ we have $\eta = 0$. We hold the debt coefficient at its baseline value of zero for now.

The top left subplot shows the overall welfare result. We find that welfare gains are increasing in the response coefficient to regular tax revenue d^{tax} , most steeply in the neighborhood of the balanced budget rule, and eventually becoming flat around $d^{tax} = 5$. Welfare gains are hump-shaped in relation to d^{cop} , with a maximum near 1 and very steep losses for large coefficients. The striking part of this figure is however the size of the gain, which at around 0.131% of balanced budget rule consumption is around four to five times larger than the gain of letting the exchange rate float. The remaining plots in Figure 4 show the contributions of the major shocks to this gain, leaving out inflation and risk premium shocks. We observe roughly equal contributions of technology, consumption demand, investment demand and copper demand shocks. For the domestic shocks the copper coefficient is nearly irrelevant. For the copper shocks it remains optimal to react counter-cyclically to the induced domestic tax revenue. In response to these shocks a coefficient choice for d^{cop} in the neighborhood of 1 is optimal.

D. Fiscal Instrument Volatility

To judge the attractiveness of fiscal rules to policymakers it is essential to evaluate not only welfare but also the implied fiscal instrument volatility.²⁵ Certainly in Chile's case a major reason behind the adoption of the SSR was a desire to minimize fiscal volatility rather than business cycle volatility, presumably because of costs of fiscal volatility not captured by the model. Figure 5 addresses this question, by looking at the implications of different rules for the standard deviation of the transfers to GDP ratio. One clear result is that $d^{cop} > 1$ is not only undesirable from a welfare perspective, it also leads to sharply higher fiscal volatility. Volatility is minimized, as expected, near the SSR combination of $d^{tax} = d^{cop} = 1$, at around 0.7. But setting $d^{tax} > 1$ leads to only a fairly modest increase in volatility, reaching around 1.1 near $d^{tax} = 5$.

E. Welfare - Fiscal Instrument Volatility Efficiency Frontiers

Figure 6 evaluates welfare and fiscal instrument volatility jointly, by way of efficiency frontiers that show the achievable combinations of both measures. The figure also compares targeting and instrument rules. The broken frontiers are not fully optimized, in that they set the copper coefficients at the a priori reasonable values of $d^{cop} = 1$ for the targeting rule and $d^{cop} = 0$ for the instrument rule. In this case we set the debt coefficients at the smallest possible values consistent with non-exploding debt. Also, for the instrument rule the BBR does not have a natural representation. The frontier shown therefore starts at $d^{tax} = 0$, which corresponds to the SSR. We find that under these assumptions the targeting rule achieves higher welfare with lower fiscal volatility. We use the BBR version of that rule ($d^{tax} = 0$) as our zero welfare gain baseline.²⁶

²⁵For a similar reason limits on nominal interest rate volatility are sometimes imposed in the optimal monetary policy literature.

²⁶Note that this is a different baseline from Figure 4, where $d^{cop} = d^{debt} = 0$. This accounts for the differences in maximum welfare gains.

The solid lines are the result of a grid search optimization over all three coefficients, and then holding d^{cop} and d^{debt} at their optimized values while varying d^{tax} . Now the frontiers, in their relevant portions, are identical. For the targeting rule the optimal coefficients are $d^{tax} = 5.0$, $d^{cop} = 0.87$ and $d^{debt} = 0.15$. These are interior solutions, meaning welfare does indeed decline when policy becomes too aggressively countercyclical or when debt is stabilized too aggressively. For the instrument rule the optimal coefficients are $d^{tax} = 4.5$, $d^{cop} = 0$ and $d^{debt} = 0.20$. In terms of improving welfare relative to a BBR the coefficient d^{tax} is far more important than d^{debt} .

The frontier is vertical, minimizing fiscal volatility, near the SSR, and it is horizontal, maximizing welfare, at the optimized CCR. The relevant portion of the frontier is of course the one between the SSR and CCR, as all other portions combine decreasing welfare with increasing fiscal volatility. What is most striking about this portion is its steepness, meaning a large increase in welfare is possible at a small cost in terms of fiscal volatility. Between the SSR and the CCR welfare increases by about 50% while fiscal volatility only increases by about 25%, or 0.25% of GDP.

F. Macroeconomic Volatility

Policymakers will also be interested in how welfare gains relate to volatilities of various macroeconomic aggregates. Figure 7 shows how the standard deviations of several key variables change as the targeting version of the rule is made more countercyclical by raising d^{tax} from 0 to 5.²⁷ In these plots we again hold d^{cop} at 1 and the debt coefficient at the smallest possible value consistent with non-exploding debt. For comparison, the first subplot shows the breakdown of overall weighted welfare into the welfare of *INF* and *LIQ* agents. The key observation is that nearly all the welfare improvement achieved by fiscal rules is due to their effect on *LIQ* agents.

The volatilities of consumption and employment are the determinants of welfare. A more countercyclical rule achieves a dramatic reduction in employment volatility, both for *LIQ* agents (from 2.2 to less than 1) and *INF* agents (from 1.5 to 0.7). This comes both through the direct effect of supplementing the income of *LIQ* agents who are thereby in less need of varying their labor supply to sustain their consumption levels, and through the reduced labor market spillovers to *INF* agents that this makes possible. The volatility of *LIQ* consumption is also considerably reduced (from 2 to 1.75). But note that the optimal rule does not minimize the variance of GDP, which in fact increases somewhat from 1.52 to 1.6, principally due to more variable *INF* consumption and investment.

G. Other Real Activity Gaps?

A natural question is whether an output gap (actual or flexible price) or an absorption gap might not perform better than the tax revenue gap. We have examined both alternatives, and the answer is that they perform much worse. The reason is that, as we have seen above, in an economy with liquidity constrained agents the most important task of policy is to stabilize *income* (of liquidity constrained agents) rather than output or

²⁷These are standard deviations of 100 times the log of the respective variable.

absorption. Labor and capital income are a very important part of the tax base, so that a countercyclical response to tax revenue will automatically stabilize income. This effect will be even stronger in economies that rely more heavily than Chile on income taxation. It might be possible to construct an even better theoretical measure of an income gap, but in practice the tax revenue gap is likely to represent the preferred combination of theoretical desirability and practical implementability.

H. Openness

Figure 8 shows sensitivity analysis with respect to the economy's trade openness. The first row reproduces the welfare and fiscal volatility outcomes for the baseline case of Figures 4 and 5. The second row considers the effects of reducing the steady state imports to GDP ratio from 33% to 22%. For parameterizations close to a BBR we were unable to compute the welfare results for this case. The plots therefore only show results for $d^{tax} \geq 1$ and $d^{cop} \geq 1$, with the SSR as the welfare benchmark. The welfare gains of going from the SSR to a CCR are now 0.13%, which is two and a half times larger than in the more open economy. In other words, fiscal policy is far more effective in a more closed economy. The reason is that there is less leakage of the demand stimulating effects of countercyclical policy to the rest of the world.

I. Alternative Fiscal Instruments

The results presented so far have all been based on using targeted transfers as the instrument of fiscal policy, by letting them adjust endogenously to satisfy rules (33) or (34). Figures 9a and 9b consider six alternative instruments, including taxes on labor, consumption and capital, government consumption spending, and overall government spending that maintains the existing proportions of consumption and investment spending.²⁸ The benchmark of zero welfare in this figure is for transfers as an instrument, $d^{tax} = 0$, $d^{cop} = 1$ and the debt coefficient at the smallest possible value consistent with non-exploding debt. We observe that consumption and labor income taxes perform very similarly to transfers, while capital income taxes are much less desirable because of their distortionary effects on capital accumulation. Government consumption on the other hand is unambiguously welfare reducing, with overall government spending performing in between transfers/taxes and government consumption. The reason is that relative to the other instruments counter-cyclical government spending provides an extra stimulus to private consumption in an expansion, first by making more resources available (crowding-in), and second by not reducing *LIQ* income. The result is greater volatility in both consumption and labor supply.

This however is based on the assumption that government consumption does not enter private utility. If it does, with a marginal rate of substitution of one, the previous results are reversed, with government spending performing much better than transfers. This is shown in Figure 9b. The intuition is that countercyclical government consumption now helps to smooth the flow of overall utility.

²⁸Using government investment spending alone as an instrument requires extreme variability in this variable. We were not able to obtain computational solutions for this case.

As the existing literature focuses almost exclusively on debt gap rules, Figure 9a also includes a comparison with such a rule, in this case an instrument rule with $d^{tax} = d^{cop} = 0$ and d^{debt} optimized. The best version of this rule, by setting a relatively low d^{debt} that allows some deviations from a balanced budget, performs about as well as a SSR using targeted transfers. But the welfare gain over a BBR is very much smaller than under the best CCR. This is because a debt gap rule is not designed to stabilize income.

Figure 10 shows the volatilities of different fiscal instruments corresponding to Figure 9a, but in this case considering two cases, $d^{cop} = 1$ and $d^{cop} = 0$. Here we see more clearly than in Figure 5 that a copper revenue SSR implies far less fiscal instrument volatility than a copper revenue BBR, because the government smooths copper revenue on behalf of *LIQ* agents. The capital income tax rate is an outlier in that it needs to be highly volatile to satisfy the fiscal rule. All other instruments, for the case of $d^{cop} = 1$, show only a modest increase in volatility of between 30% and 70% as fiscal policy moves from a SSR to a highly countercyclical CCR with $d^{tax} = 5$, with the smallest increase required for the consumption tax rate because it is levied on the largest tax base (50% of tax revenue).

VI. Conclusion

This paper has presented an analysis of systematic rules-based fiscal policy in an open economy DSGE model with non-Ricardian household behavior. The motivation behind this research is to start developing a framework that could eventually become the equivalent in practical usefulness to interest rate rules in monetary policy.

In terms of delivering on this agenda, the results presented in this paper are encouraging. We have developed a class of rules, tax revenue gap rules, that delivers sizeable welfare gains relative to a balanced budget rule, and also in comparison to monetary policy rules. These gains are achieved at a very modest cost in terms of fiscal instrument volatility, and the reductions in macroeconomic volatility corresponding to the welfare gains are substantial. We have shown how to represent such rules as either targeting rules or instrument rules, and we have presented a performance comparison of different fiscal instruments which suggests that targeted transfers, consumption and labor taxes are roughly equally effective, but inferior to government spending if the latter enters utility with a unitary marginal rate of substitution with consumption. Finally, we have shown that shocks to raw materials revenue should be treated differently from shocks to regular tax revenue. The government should respond to such shocks by performing consumption smoothing on behalf of liquidity constrained households. In other words, it should rely on automatic stabilizers.

Our work suggests a number of issues that should be investigated in more detail. First, the dependence of the performance of tax revenue gap rules on the composition of a country's tax base should be investigated in detail. Second, the joint optimization of monetary and fiscal policies deserves further study. Space constraints prevent us from undertaking either of these tasks here. We aim to do so in future research.

Figure 1. IRF for Technology Shock

Technology Shock

BBR=..., SSR=---, CCR=___

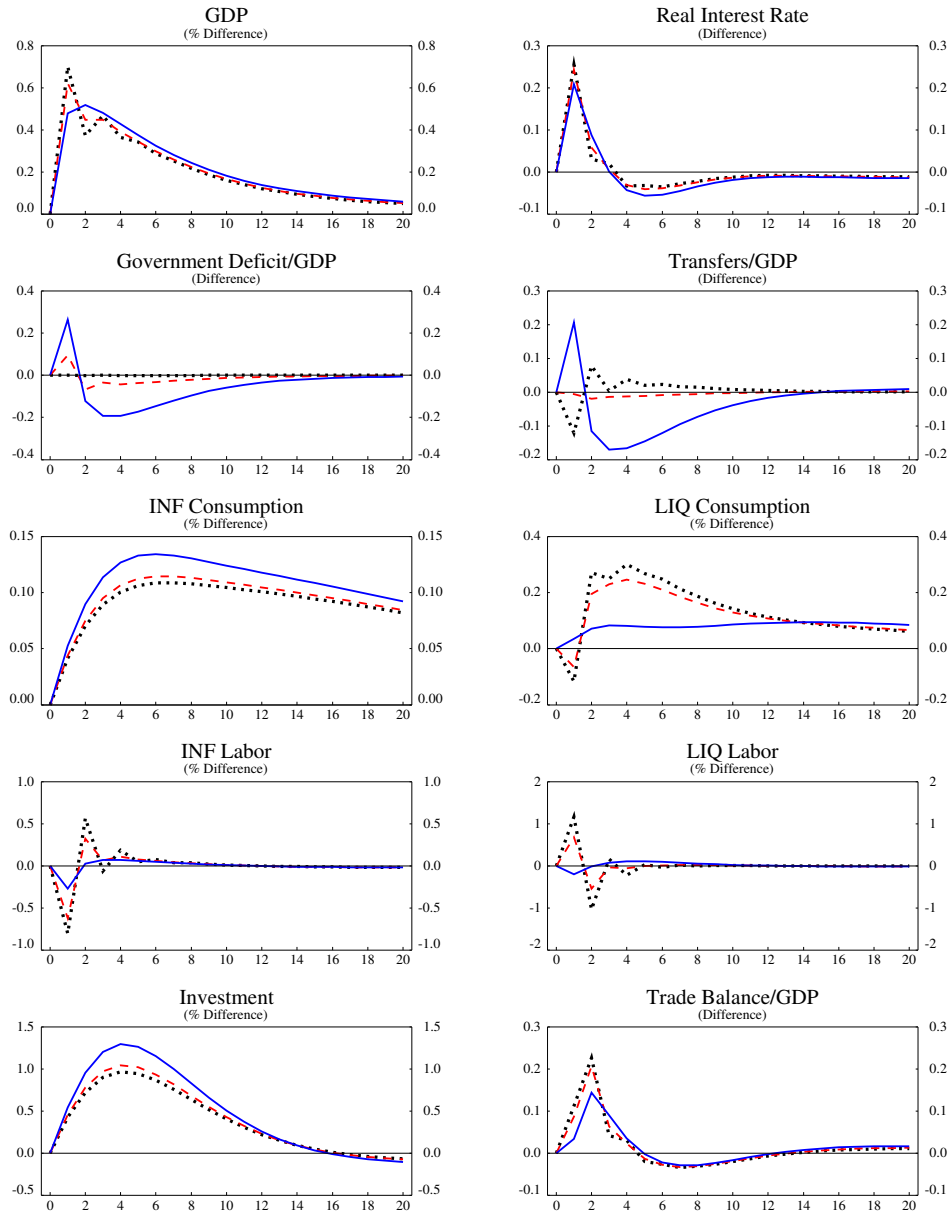


Figure 2. IRF for Investment Shock

Investment Shock

BBR=..., SSR=---, CCR=___

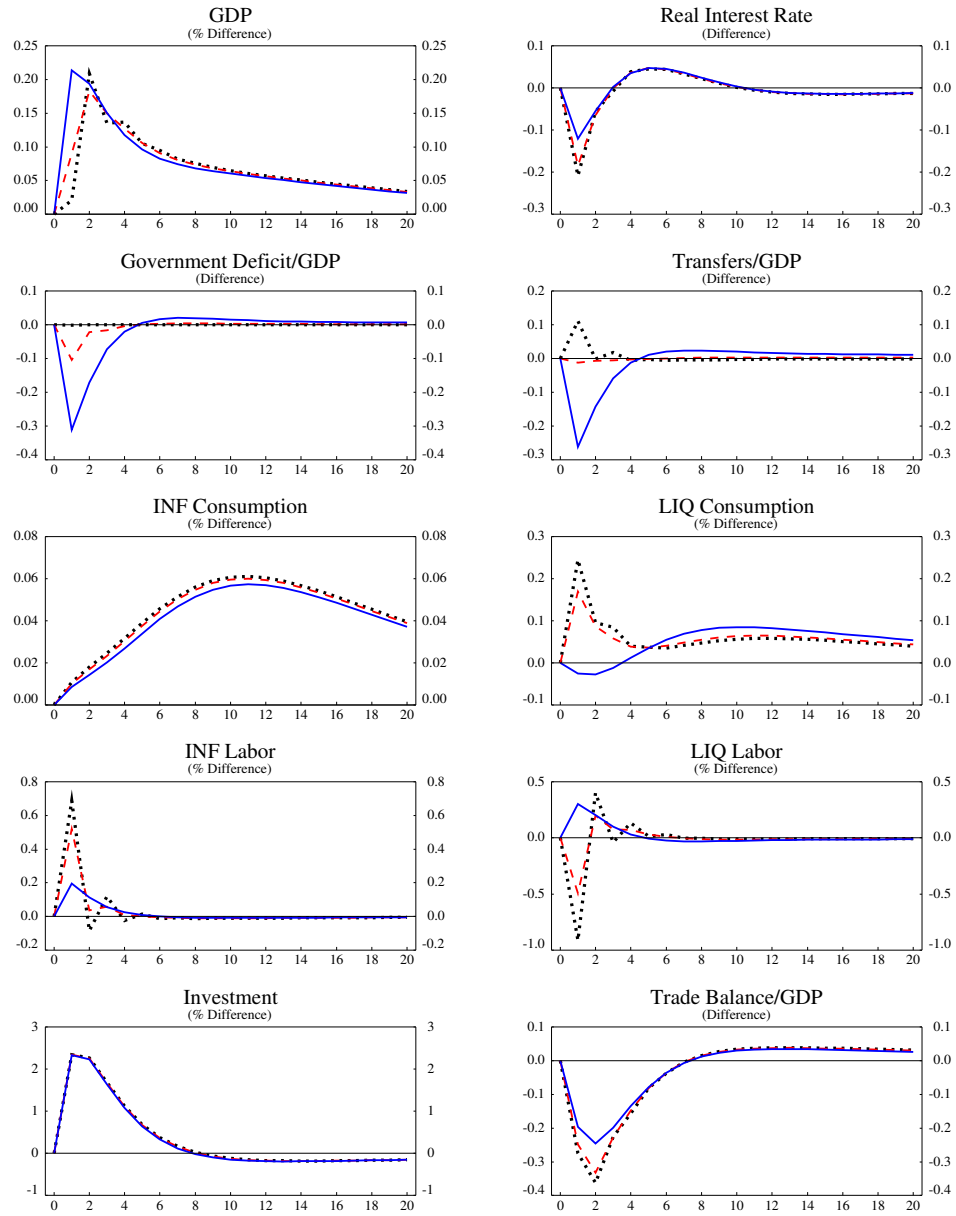


Figure 3. IRF for Copper Demand Shock

Copper Demand Shock

BBR=..., SSR=---, CCR=___

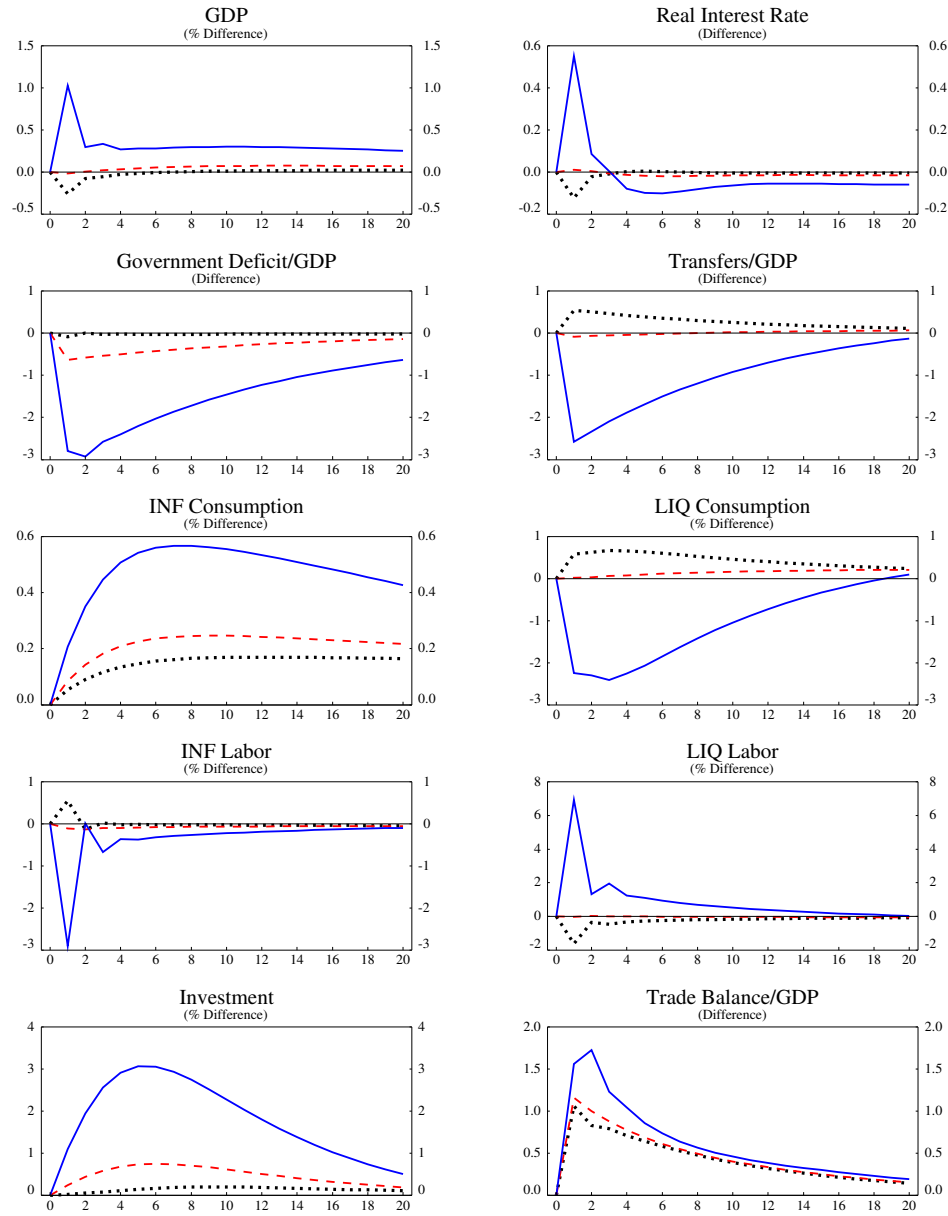


Figure 4. Welfare for Tax Revenue Gap Rule

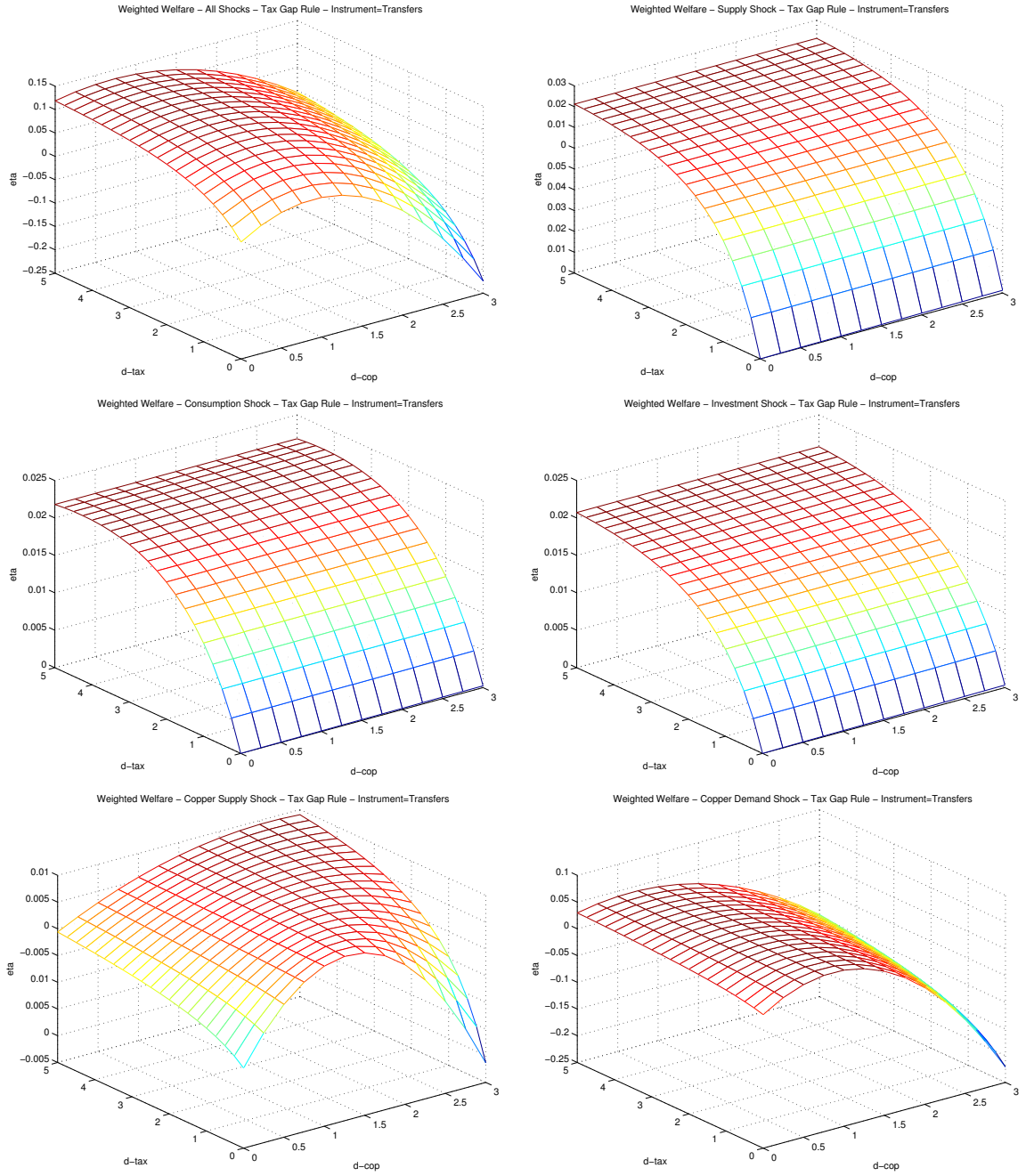


Figure 5. Fiscal Instrument Volatility for Tax Revenue Gap Rule

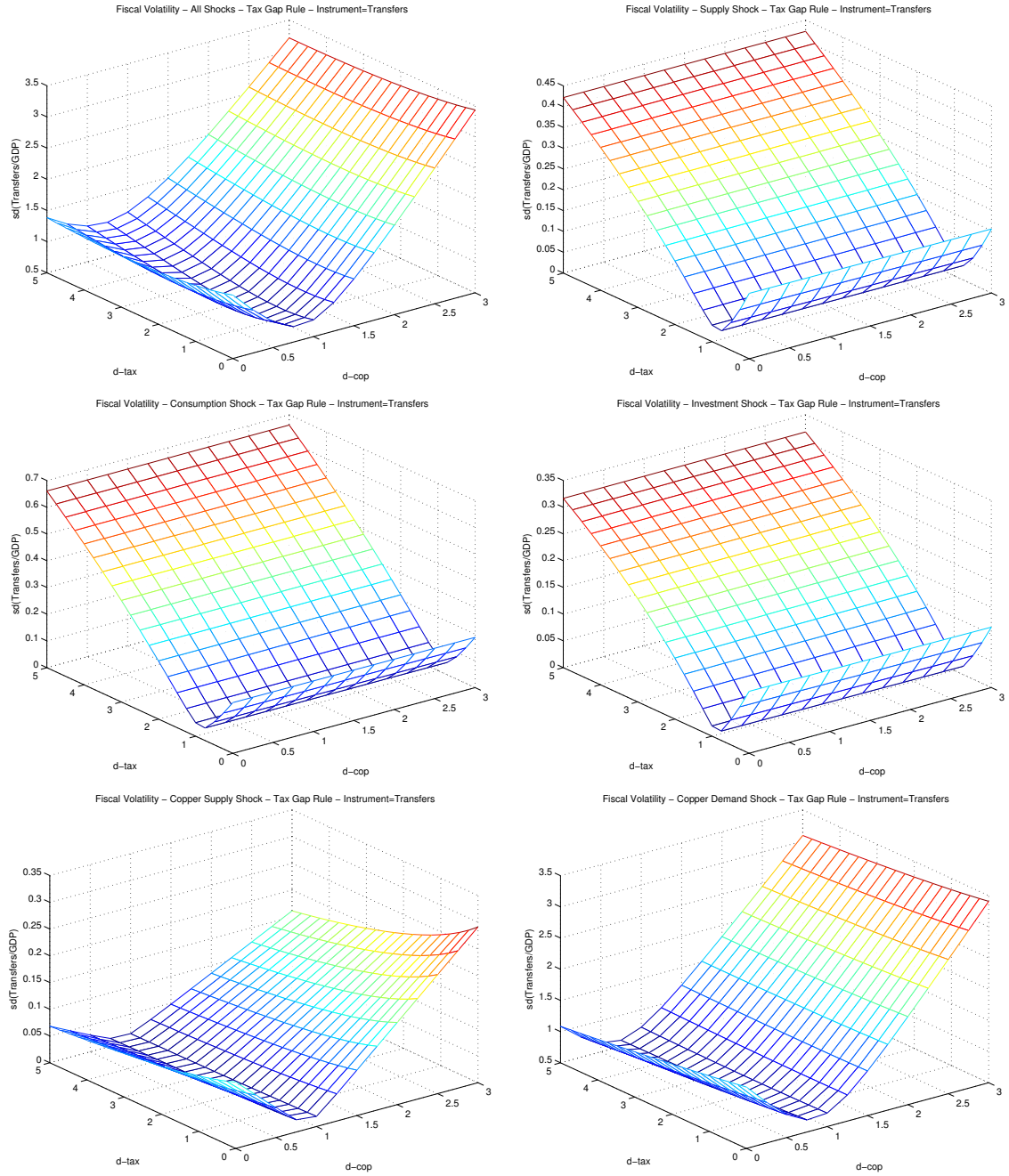


Figure 6. Efficiency Frontiers

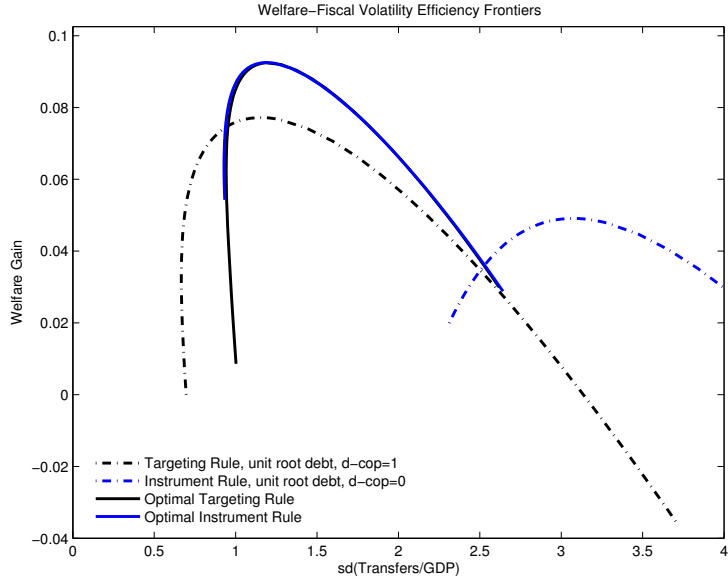


Figure 7. Macroeconomic Volatility for Tax Revenue Gap Rule

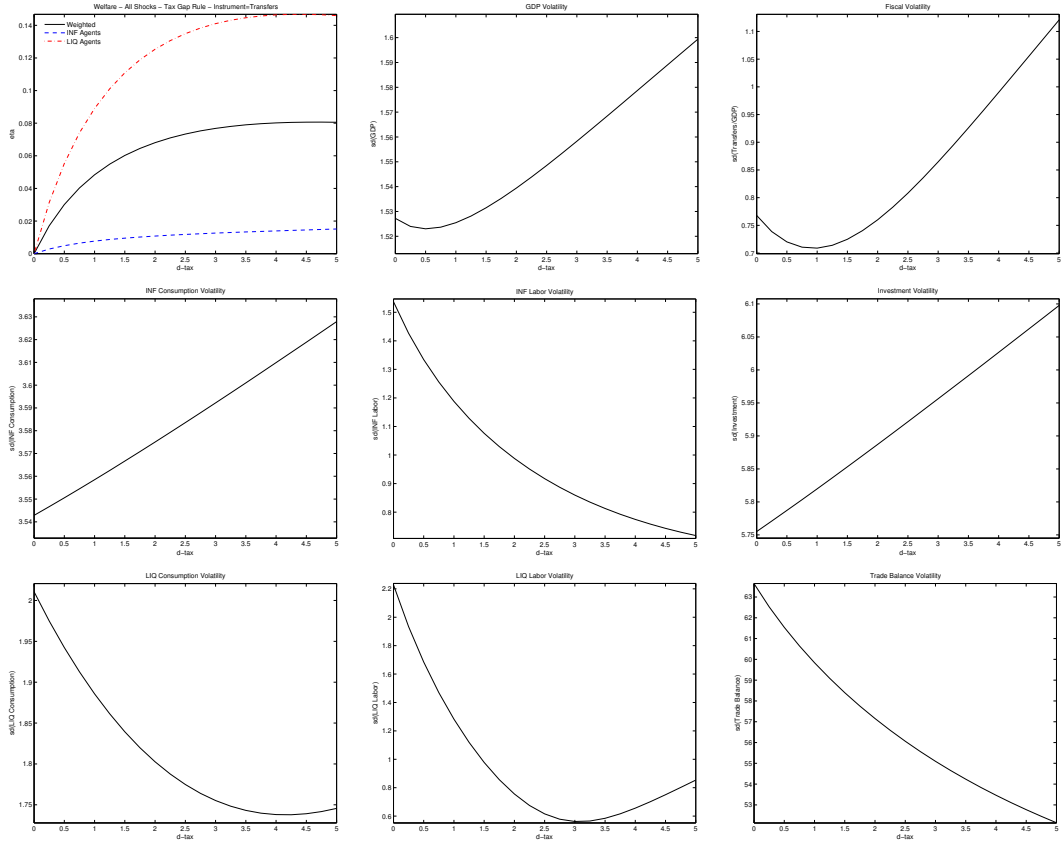


Figure 8. Openness

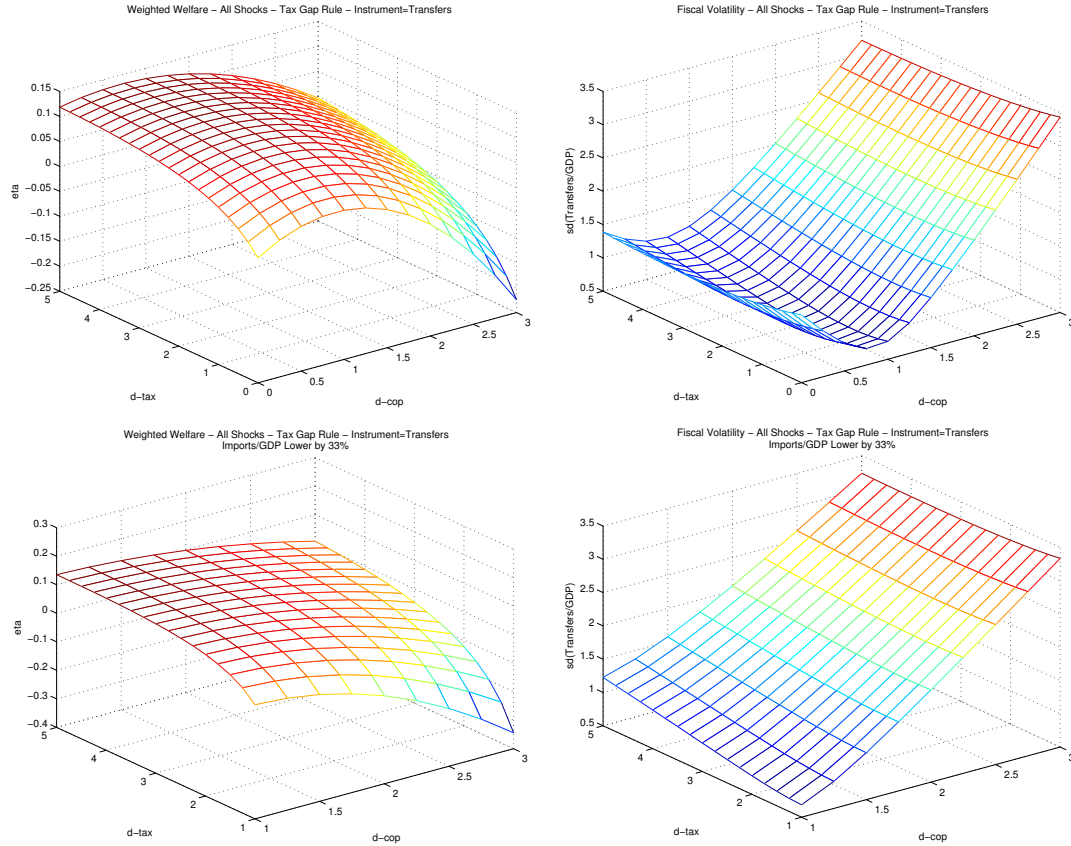
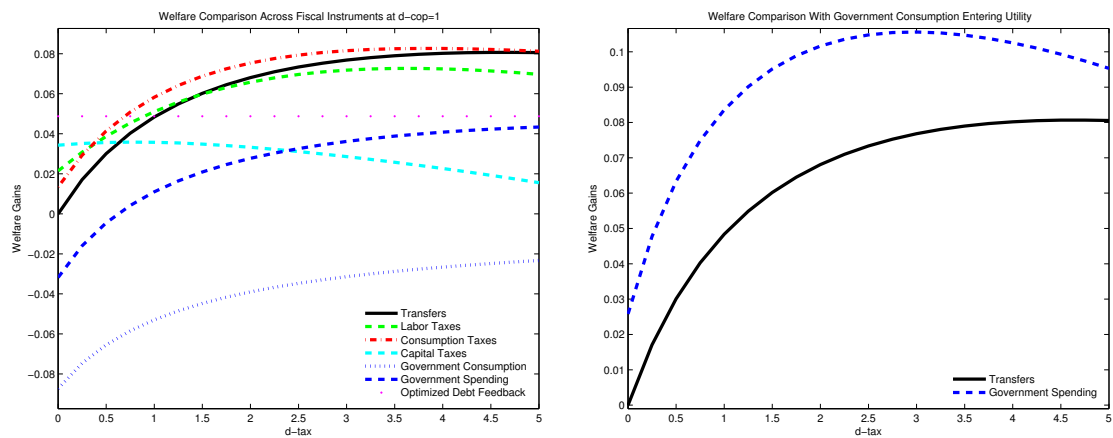


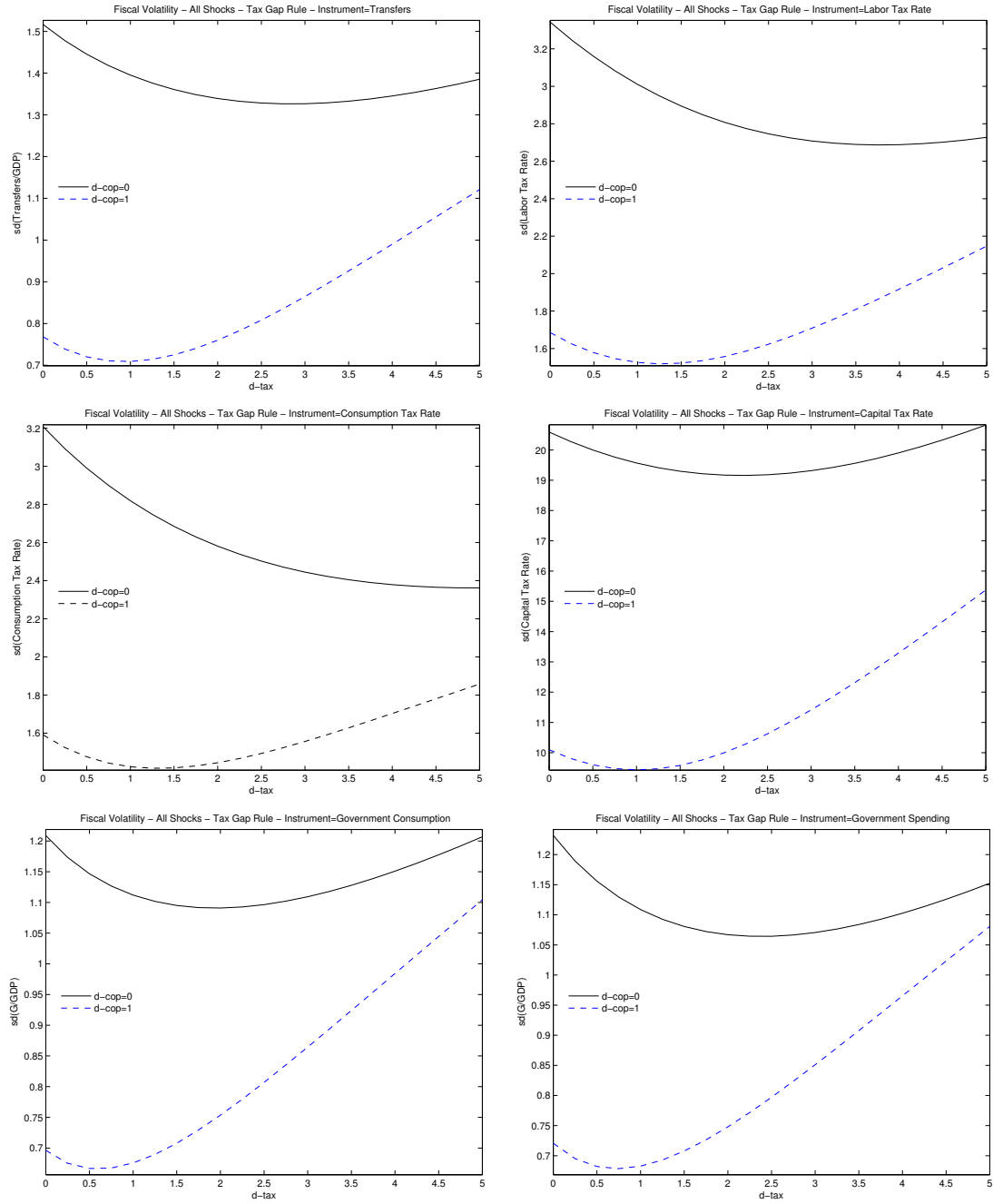
Figure 9. Welfare and Fiscal Instruments



9a: Welfare for Different Fiscal Instruments

9b: Welfare for G in Utility Function

Figure 10. Fiscal Volatility for Different Fiscal Instruments



Appendices

Optimality Conditions of the Model

The optimality conditions of *INF households* for domestic and foreign bonds, aggregate consumption and aggregate labor supply are, after rescaling by technology, given by

$$\check{\lambda}_t = \frac{\beta}{g} E_t \check{\lambda}_{t+1} \frac{i_t}{\pi_{t+1}}, \quad (43)$$

$$\check{\lambda}_t = \frac{\beta}{g} E_t \check{\lambda}_{t+1} \frac{i_t^* \varepsilon_{t+1} (1 + \xi_t^f)}{\pi_{t+1}}, \quad (44)$$

$$\frac{S_t^c}{\check{c}_t^{INF} - \frac{v}{g} \check{c}_{t-1}^{INF}} - \beta \frac{v}{g} \frac{S_{t+1}^c}{\check{c}_{t+1}^{INF} - \frac{v}{g} \check{c}_t^{INF}} = \check{\lambda}_t (1 + \tau_{c,t}) \frac{1 - \beta \frac{v}{g}}{1 - \frac{v}{g}}, \quad (45)$$

$$\kappa (\ell_t^{INF})^{\frac{1}{\gamma}} = \check{\lambda}_t \check{w}_t (1 - \tau_{L,t}). \quad (46)$$

The conditions for *LIQ households* are identical in form to (45)-(46), but with S_t^c absent and the multiplier of the liquidity constraint (5) replacing $\check{\lambda}_t$.

For the optimality conditions of **manufacturers** we denote the marginal physical products of the three factors of production by f_{ℓ_t} , f_{k_t} and f_{x_t} . Then the first-order conditions are, after normalizing, given by

$$\check{w}_t = p_t^H \check{f}_{\ell_t}, \quad (47)$$

$$p_t^X = p_t^H f_{x_t}, \quad (48)$$

$$q_t S_t^{inv} = 1 + \phi_I \left(\frac{\check{I}_t}{\check{I}_{t-1}} \right) \left(\frac{\check{I}_t}{\check{I}_{t-1}} - 1 \right) - E_t \beta \frac{\check{\lambda}_{t+1}}{\check{\lambda}_t} \phi_I \left(\frac{\check{I}_{t+1}}{\check{I}_t} \right)^2 \left(\frac{\check{I}_{t+1}}{\check{I}_t} - 1 \right), \quad (49)$$

$$1 = E_t \frac{\beta \check{\lambda}_{t+1}}{g \check{\lambda}_t} \frac{q_{t+1} (1 - \delta_k) + r_{t+1}^k - \tau_{t+1}^k (r_{t+1}^k - \delta_k q_{t+1})}{q_t}, \quad (50)$$

where the rental rate of capital is defined implicitly by

$$r_t^k = p_t^H f_{k_t}. \quad (51)$$

Distributors' cost-minimizing input choice yields:

$$\check{y}_t^H = \alpha_H \check{y}_t^T \left(\frac{p_t^H}{p_t^T} \right)^{-\xi_T}, \quad (52)$$

$$\check{y}_t^F (1 - G_{T,t}) = (1 - \alpha_H) \check{y}_t^T \left(\frac{p_t^F}{p_t^T} \right)^{-\xi_T} (\Xi_t)^{\xi_T}, \quad (53)$$

$$\Xi_t = 1 - G_{T,t} - \phi_T \frac{\mathcal{R}_t (\mathcal{R}_t - 1)}{\left(1 + (\mathcal{R}_t - 1)^2 \right)^2}, \quad (54)$$

$$p_t^D (\check{k}_{t-1}^G / g)^{\alpha_G} \mathcal{S} = p_t^T. \quad (55)$$

Welfare Computations

We present here the welfare computations for *INF* agents. The computations for *LIQ* agents are identical. Letting $\zeta = \left(1 - \frac{v}{g}\right) / \left(1 - \beta \frac{v}{g}\right)$, the period utility of a representative *INF* agent at time t is given by

$$u_t^{INF} = \zeta S_t^c \ln (c_t^{INF} - v c_{t-1}^{INF}) - \frac{\kappa}{1 + \frac{1}{\gamma}} (\ell_t^{INF})^{1 + \frac{1}{\gamma}} ,$$

where we have made use of the cashless limit assumption for money. The conditional expectation of welfare is given by

$$\mathcal{W}_t^{INF} = u_t^{INF} + \beta E_t \mathcal{W}_{t+1}^{INF} . \quad (56)$$

We define the compensating consumption variation η^{INF} of a given combination of fiscal rule parameters as the percentage reduction in average consumption that agents would be willing to tolerate under this combination while remaining indifferent between the unconditional expectations of welfare under this combination, say $E\mathcal{W}^{INF,fisc}$, and under the baseline combination of fiscal rule parameters, typically a version of the BBR, say $E\mathcal{W}^{INF,bbr}$. Then η^{INF} is given implicitly by

$$E\mathcal{W}^{INF,fisc} + \frac{\zeta \ln \left(1 - \frac{\eta^{INF}}{100}\right)}{(1 - \beta)} = E\mathcal{W}^{INF,bbr} ,$$

and explicitly by

$$\eta^{INF} = 100 \left(1 - \exp \left(\frac{(\beta - 1)}{\zeta} \left(E\mathcal{W}^{INF,fisc} - E\mathcal{W}^{INF,bbr} \right) \right) \right) . \quad (57)$$

The paper uses DYNARE++ second order approximations of the model to compute unconditional welfare, and then uses (42) to compute compensating consumption variations. As a robustness check we also computed welfare conditional on the nonstochastic steady state in DYNARE, but these computations generated numerical problems associated with the two large copper sector shocks of the model, which made an analysis of the optimal fiscal rule feedback to copper revenue shocks infeasible. To nevertheless check the robustness of our computations to the methodology used we performed a more limited comparison of unconditional and conditional welfare results using a version of the model without the copper sector shocks, but otherwise identical. The results are both qualitatively and quantitatively very similar.

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