Essays on Development Economics: Issues in Macroeconomics and Population

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(ABSTRACT)

This dissertation consists of three chapters on development economics. The first two chapters are in the area of international macroeconomics. The third chapter is in an area that is the intersection of macroeconomics and population economics.

The first chapter studies currency substitution in an environment where agents' inflation tax evasive demand for foreign money is balanced by the concern for the possibility that the government may impose economy-wide capital controls under which foreign currency transactions are costly. We contrast implications of constant beliefs regarding capital controls with those obtained under endogenous beliefs. With endogenous beliefs, agents expect a greater likelihood of capital controls as economy-wide currency substitution rises. Our results show a persistent demand for foreign money under endogenous beliefs despite efforts by the government to reduce inflation.

The second chapter is a theoretical study of currency substitution in an overlapping-generations economy. We focus on the role of beliefs in determining the relative demands for domestic and foreign money. Domestic money suffers from a lack of confidence leading agents to demand foreign money as an alternate store-of-value. We study equilibria in which the level of confidence in domestic money evolves as a function of expected future aggregate domestic money demand: agents increase their demand for domestic money only if aggregate economy-wide real domestic money demand is expected to rise.

The third chapter is a study of intertemporal substitution and fertility dynamics. The demographic experience of Iran after the revolution poses an interesting puzzle. A brief increase in period fertility after the 1979 revolution interrupted a trend of decline that had started in the 1950s. The rise in fertility, however, appears to have lasted only a few years: in the late 1980s fertility decline resumed its course at an even faster pace. We present evidence that suggests that the changes in Iranian fertility since the revolution were in part a birth timing phenomenon. The revolution may well have been a transient economic shock which temporarily depressed the relative "price" of children and caused adjustment in fertility patterns which, at least in an *ex post* sense, is suggestive of intertemporal substitution.

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This dissertation is dedicated to my parents.

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1.1 Introduction

Currency substitution (CS) refers to the demand for foreign money by domestic residents. The prevalence of CS has been especially endemic in several developing countries where governments have relied extensively on monetizing their budget deficits thereby causing inflation. However, even in highly inflationary environments, the substitution of the local currency with a stable-valued foreign currency has been a gradual drawn-out process.[1] Observed government responses to the encroachment of the inflation tax base by the increasing economy-wide CS have varied. These have ranged from an outright prohibition on the use of foreign money to more conciliatory policies such as those allowing foreign currency deposits in the domestic banking system (as in Peru and Mexico in the 1980s). Rarely, though, have governments tolerated a *complete* economy-wide replacement of the domestic currency with a foreign one. A casual observation of the empirical evidence on CS raises the following questions. How does the combination of a government's fiscal and monetary policies affect the degree of CS? How does CS limit a government's ability for inflationary finance? How do government's react to such limitations? What is the role of agents' beliefs regarding capital controls in determining the outcome? These are some of the questions the current paper is trying to address.

Several studies in the literature have focused on the interaction between government policies and CS.[2] In a classic paper, Nichols (1974) argues for inflationary finance to be accompanied with controls on the circulation of foreign money so as not to exacerbate domestic inflation. Fischer (1982) proposes against the relinquishment of a domestic money given the importance of seigniorage in industrializing countries. Others have argued for allowing CS as a discipline-inducing mechanism for recalcitrant governments.[3] Rostowski (1992) argues against foreign currency restrictions in high inflation situations so as to prevent the economy's possible degeneration to a low-output "illiquid" barter-type equilibrium. On a more general level, Hercowitz and Sadka (1987) study the social desirability of restrictions on foreign exchange in an inflationary finance regime.

Our paper is a theoretical study of the demand for foreign money in an economic environment characterized by inflationary finance and uncertain government policies regarding restrictions on foreign exchange. Specifically, the government in question monetizes an exogenously-given fiscal deficit in each period. In such a setting, naturally, agents demand foreign money in order to avoid the inflation tax on domestic money holdings. In order to preserve the inflation tax base, the government credibly maintains a probability under

[1] See Savastano (1996) for a recent study on CS in Latin America countries.

[2] See Giovannini and Turtleboom (1994) and Calvo and Végh (1992) for a general survey of the literature on CS.

[3] Liviatan (1992) provides a panel discussion on this issue.

which economy-wide capital controls will be imposed. As in the Hercowitz-Sadka paper, we consider that foreign currency transactions are restricted (and hence costly) for agents in the event of capital controls. The demand for foreign money, therefore, also depends upon expectations of future government policies regarding capital controls. We distinguish our discussion between two specifications of agents' expectations regarding future capital controls. As a benchmark, following previous studies [Lapan and Enders (1983); Nickelsburg (1984)], we first examine the case in which agents' beliefs are exogenous and fixed. We then allow agents' expectations regarding future capital controls to depend upon the extent of economy-wide CS. In this second scenario, given the government's proclivity for inflationary finance (and in the absence of impending monetary reform), we postulate that agents perceive a greater likelihood of capital controls as the economy-wide demand for foreign money rises. The rationale for considering this relationship between perceptions of future capital controls and observations of economy-wide CS is simple: higher CS implies a greater erosion of the inflation tax base and is therefore expected to evoke a more stringent and credible response (in terms of limiting the circulation of foreign money) from a government reliant on seigniorage revenues. Consequently, in this case, agents' beliefs regarding government policies on capital controls are *endogenous* and *time-varying*.

Under exogenous beliefs, where agents perceive a constant likelihood of future capital controls, we show that there is a unique equilibrium with CS corresponding to each level of the government fiscal deficit that is below the maximum seigniorage. However, the equilibrium with CS is rather fragile, for it disappears when money growth rate is low enough. The Laffer curve indicates that there is another equilibrium without CS that also meets the same government deficit financing target. This implies that, with fixed agents' beliefs, it is possible for the government to eliminate CS by monetary reforms (inflation reductions) alone without fiscal reforms.

In contrast to the simpler benchmark, endogenizing agents' beliefs generates qualitatively different properties regarding steady states as well as more interesting dynamics. We show that the interplay between expectations and economy-wide CS introduces the possibility of multiple *stable* steady states associated with different levels of CS. This result is consistent with the persistence and the different levels of CS observed in different countries.[4] Furthermore, among the multiple steady states, agents' welfare can be ranked by the level of CS with agents being worse off in a steady state with a higher level of CS. Such a multiplicity is very much akin to that found in a typical environment with coordination problems. In deriving the Laffer curve, we find that CS always exists as long as there is positive money growth. Hence, when agents' beliefs are endogenous, monetary reforms are no longer sufficient to eliminate CS in the absence of fiscal reforms. This outcome under endogenous beliefs accords with the empirically-observed robustness in CS even with government stabilization programs (as in several Latin American countries). We also demonstrate that, under some regularity conditions, there exists a "standard", single-peaked Laffer curve for steady-state seigniorage. The stability analysis suggests that the economy tends to end up

[4]See, for example, Uribe (1995), Kamin and Ericsson (1993), and Guidotti and Rodriguez (1992).

on the downward-sloping side of Laffer curve with high domestic inflation and a high level of CS.

Our paper is also related to the extant literature on open-economy overlapping generations models. In a seminal paper, Karekan and Wallace (1981) establish that a standard two-money overlapping generations model suffers from exchange rate indeterminacy: if the two monies are perfect substitutes, then the demand for foreign money is not well-defined. The notion that the possibility of future capital controls may be an important factor influencing the demand for foreign money was proposed in Wallace (1979). This idea was formalized in an extension of the basic Kareken-Wallace framework by Lapan and Enders (1983) and Nickelsburg (1984) who study the demand for foreign money with government policies on capital controls that are similar to our framework. In both papers, the fixed (exogenous) possibility of future capital controls is introduced and this is demonstrated to be sufficient to pin down the exchange rate and result in distinguishable demands for local and foreign money. Our paper differs from this literature by focusing specifically on the demand for foreign money rather than on the issue of exchange rate determinacy *per se*. At the same time, we extend this literature by endogenizing the likelihood of controls and introduce an explicit motivation on the part of the government for imposing capital controls, namely preservation of the inflation tax base. Our paper also elaborates upon the linkage between *confidence* and money demand, as examined by Weil (1987) and Bertocchi and Wang (1995), in a two-money framework: the key difference in our approach is that "confidence", or lack of it, in a given monetary asset is linked directly to public's perceptions of government policies.

In the next section we lay out the basic structure of the model. Sections 3 and 4 discuss equilibrium properties and the Laffer curve under constant and endogenous beliefs, respectively. Section 5 considers stability of steady states and dynamics. Section 6 concludes with a brief discussion of the results. We relegate all proofs to the Appendix.

1.2 The Basic Model

The model is that of a discrete-time small, open overlapping generations economy. At the beginning of each period, a generation of identical agents is born that lives for two periods. There is no population growth and the size of the population is normalized to one. Each agent is endowed with ω units of a non-storable consumption good when young. There are two assets that serve as stores of value across periods: domestic money and foreign money. To focus discussion on CS, we assume that consumption takes place only when agents are old.

1.2.1 Agents' Maximization Problem

Young agents born at time t maximize Von Neumann-Morgenstern expected utility $E_t[u(c_{t+1})]$. The utility function is assumed strictly concave with $u(0) = 0$, $u'(\cdot) > 0$ and $u''(\cdot) < 0$. To ensure an interior solution, the Inada condition at zero is invoked, i.e., $u'(0)$ is infinite. For most of our discussion, the utility function $u(\cdot)$ is also assumed to have a relative risk aversion that is less than one,[5] i.e.,

$$(A) \qquad -\frac{cu''(c)}{u'(c)} < 1.$$

To formulate agents' beliefs at time t, we assume that agents expect capital controls to be imposed with a subjective probability of π_t, and no capital controls to be imposed with a probability of $(1-\pi_t)$. As in Chang (1994), the price of the good in foreign currency is assumed to be fixed over time and normalized to one.

In the event of no controls, agents face the following constraints: $P_t\omega = m_t + P_t m_t^*$ and $P_{t+1}c_{t+1} = m_t + P_{t+1}m_t^*$ where P_t is the domestic price level and $m_t(m_t^*)$ are the domestic (foreign) money holdings of the young at time t. Define f_t as the share of savings held as foreign money and $(1-f_t)$ as the share held as domestic money, we have $f_t\omega = m_t^*$ (since the price level in foreign currency is assumed to be 1) and $(1-f_t)P_t\omega = m_t$. Hence, the constraint for second-period consumption can be rewritten in terms of f_t as:

$$c_{t+1} = \frac{P_t}{P_{t+1}}(1-f_t)\omega + f_t\omega \tag{1}$$

With population normalized to one, f_t represents economy-wide CS at time t.

One can see from (1) that, if in equilibrium the domestic price level rises over time (as it would under an inflationary regime) and in the absence of concerns regarding any restrictions on the use of foreign money (which has a stable value), agents will not want to hold domestic money as a store of value. In our model, however, monetary diversification arises because the government threatens, or is expected, to impose capital controls with a positive probability π_t. In the event of capital controls, the government "cracks down" on the use of foreign money, bringing certain costs to agents who hold and conduct transactions in foreign currency.[6] To reflect these transaction costs, we postulate that agents' foreign money balances held from the first period will be reduced under capital controls by a factor of $\frac{1}{h}$, where $h > 1$. Therefore, the counterpart of equation (1) in the event of capital controls is:

$$c^c_{t+1} = \frac{P_t}{P^c_{t+1}}(1-f_t)\omega + \frac{f_t\omega}{h}, \tag{2}$$

where the superscript c of variables refers to their respective values once capital controls are imposed.

[5]This assumption of the utility function is fairly standard in these types of models. In a more general setting where consumption is valuable in both periods, this assumption is equivalent to assuming a positive interest rate elasticity of savings.

[6]These costs represent a real loss of resources and may be interpreted as costs of entering the foreign exchange market under more stringent conditions, costs of evading certain government restrictions on foreign currency transactions and/or costs of administering those restrictions.

The behavior of agents of generation t can now be formalized as choosing f_t in order to maximize expected utility:

$$(1-\pi_t)u(c_{t+1})+\pi_t u(c^c_{t+1})$$

where c_{t+1} and c^c_{t+1} are given by equations (1) and (2), respectively. The first-order condition from the agents' maximization problem yields

$$\begin{aligned}&(1-\pi_t)\left(\omega-\frac{P_t}{P_{t+1}}\omega\right)u'\left[\frac{P_t}{P_{t+1}}(1-f_t)\omega+f_t\omega\right]\\&+\pi_t\left[\frac{\omega}{h}-\frac{P_t}{P^c_{t+1}}\omega\right]u'\left[\frac{P_t}{P^c_{t+1}}(1-f_t)\omega+\frac{f_t\omega}{h}\right]=0.\end{aligned}\tag{3}$$

Equilibrium entails that money market clears. In period t, the domestic price level is determined by the condition that money demand equals money supply. Therefore, $(1-f_t)P_t\omega = \overline{m}_t$, or

$$P_t=\frac{\overline{m}_t}{(1-f_t)\omega}$$

where $\overline{m}_t$ is the domestic money supply at time t. Hence, the ratio of prices over time is given by

$$\frac{P_t}{P_{t+1}}=\frac{(1-f_{t+1})(1-z_{t+1})}{(1-f_t)}\tag{4}$$

and, similarly,

$$\frac{P_t}{P^c_{t+1}}=\frac{(1-f^c_{t+1})(1-z_{t+1})}{(1-f_t)}\tag{5}$$

where f^c_{t+1} is the demand for foreign money under capital controls (if any) and $z_{t+1}=\frac{(\overline{m}_{t+1}-\overline{m}_t)}{\overline{m}_{t+1}}$ is the rate of growth of domestic money supply.[7] Substituting (4) and (5) into (3), we have

$$\begin{aligned}&\pi_t\left[\frac{(1-f^c_{t+1})(1-z_{t+1})\omega}{(1-f_t)}-\frac{\omega}{h}\right]u'\left[(1-f^c_{t+1})(1-z_{t+1})\omega+\frac{f_t\omega}{h}\right]=\\&(1-\pi_t)\left[\omega-\frac{(1-f_{t+1})(1-z_{t+1})\omega}{(1-f_t)}\right]u'[(1-f_{t+1})(1-z_{t+1})\omega+f_t\omega]\end{aligned}\tag{6}$$

As can be seen, the evolution of CS over time depends upon factors such as the rate of monetary growth and the future demand for foreign money under controls (f^c_{t+1}). The next subsection addresses the determination of these factors.

[7] For notational convenience, we are using a somewhat non-standard definition of the money growth rate: the denominator is $\overline{m}_{t+1}$ instead of $\overline{m}_t$. Once the government budget constraint is introduced, the money growth rate z then ranges from 0 to 1 in our model, with $z=1$ representing an infinite increase in money supply.

1.2.2 Inflationary Finance and the Government's Budget Constraint

We now formally introduce the government's dependence on inflation taxation that is central to both the motivation for CS and the incentive for (and expectations of) capital controls. The government of this economy is assumed to finance an exogenously-given primary fiscal deficit $G(>0)$ every period with seigniorage revenue. This expenditure represents the portion of the government's total expenditure that is not covered by other taxes. Therefore, as long as capital controls are not imposed, the government's budget constraint entails that the real value of the increase in the money supply must equal the targeted level, or

$$G = \frac{(\overline{m}_{t+1} - \overline{m}_t)}{P_{t+1}}.$$

From the money market-clearing condition, this constraint may be rewritten as

$$G = (1 - f_{t+1})\omega z_{t+1},$$

where z_{t+1} is money growth rate as defined earlier. Therefore, the monetary policy of the government that is compatible with its given fiscal policy is dictated by

$$z_{t+1} = \frac{G}{(1 - f_{t+1})\omega}. \tag{7}$$

Consequently, given that the amount of seigniorage financing G is positive, the government monetary policy is necessarily expansionary.

We are primarily interested in the dynamics of CS prior to the actual imposition of capital controls, when agents are still facing the trade off between the depreciation in domestic money due to the expansionary monetary policy and the potential cost of holding foreign money under controls.[8] The equilibrium path in our model also depends on f^c_{t+1}, but only to the extent that it provides an anchor point for foreign money demand after controls are actually imposed. To simplify the determination of f^c_{t+1}, given our main interest in the equilibrium prior to controls, we assume that once capital controls are actually imposed they are expected to stay in place indefinitely. Therefore, once capital controls are imposed, there is no longer uncertainty regarding government policy and hence the problem of the demand for foreign money versus domestic money reduces to a simple one of choosing the currency that offers the higher return. In particular, among other reasons, when h is large enough, domestic money will offer a better store of value than foreign money under capital controls (i.e., $f^c_{t+1} = 0$).[9]

[8]The probability of capital controls, π_t, does not have to be construed in our model as the objective probability of the event. Our analysis goes through so long as the government credibly maintains such a subjective probability in agents' expectations. Hence, the actual event of capital controls may never have to occur.

[9]The only possibility for an equilibrium after controls with positive CS is the special case in which the returns on the two currencies are the same (complete CS is not possible given the government's budget constraint). This is, however, a very fragile and unstable equilibrium. Suppose $f^c > 0$ constitutes the

Substituting (7) and $f^c_{t+1} = 0$ into (6), we obtain the law of motion that describes the dynamical equilibrium as follows:

$$\pi_t \left[\frac{(1-f_{t+1})\omega - G}{(1-f_{t+1})} - \frac{(1-f_t)\omega}{h}\right] u' \left[\frac{(1-f_{t+1})\omega - G}{(1-f_{t+1})} + \frac{f_t\omega}{h}\right] =$$
$$(1-\pi_t)[(1-f_t)\omega - (1-f_{t+1})\omega + G]u'[(1-f_{t+1})\omega - G + f_t\omega]. \tag{8}$$

Clearly, there will be no steady-state equilibrium in the economy if the costs associated with capital controls are zero (i.e., $h = 1$), because then the return on foreign money would dominate that of the inflationary domestic money regardless of whether or not controls are imposed. This would imply complete CS and hence violate the government's budget constraint. The same argument can also be made even if the transaction costs under controls are sufficiently small. For a meaningful discussion, therefore, we will maintain the following assumption about the cost parameter h:

$$(B) \qquad h > \frac{\omega}{G} \;\; or \;\; \frac{1}{h} < \frac{G}{\omega}.$$

Next, we consider separately two specifications of π_t. The first is the benchmark case where agents' beliefs are constant and exogenous in that they do not react to economic variables. In the second case, we allow for the possibility that beliefs evolve over time in accordance with endogenous variables.

1.3 Constant Beliefs

Suppose that agents' beliefs are constant and, in particular, do not react to the extent of economy-wide CS, i.e., $\pi_t = \pi$ for all t. In this case, the law of motion described by (8) becomes

$$\pi \left[\frac{(1-f_{t+1})\omega - G}{(1-f_{t+1})} - \frac{(1-f_t)\omega}{h}\right] u' \left[\frac{(1-f_{t+1})\omega - G}{(1-f_{t+1})} + \frac{f_t\omega}{h}\right] =$$
$$(1-\pi)[(1-f_t)\omega - (1-f_{t+1})\omega + G]u'[(1-f_{t+1})\omega - G + f_t\omega] \tag{9}$$

For now we are only interested in the steady state, in which (9) reduces to

$$\pi = \frac{Gu'(c)}{\left[c^c - \frac{\omega}{h}\right] u'(c^c) + Gu'(c)} \tag{10}$$

steady-state equilibrium after controls. The equality of returns implies that $1 - \frac{G}{(1-f^c)\omega} = \frac{1}{h}$. Then a small increase in h or decrease in f^c will make domestic money a better choice, annihilating the existing equilibrium. In fact, when h satisfies the condition in Proposition 1 or Proposition 3 in later sections, foreign money always offers a poorer return under controls. Furthermore, when the returns on the two monies are equal, agents are indifferent between the two monies and any decrease in their foreign money holdings, however, would result in a higher return on domestic money and indeed a higher consumption level. In light of all these, $f^c = 0$ is the only reasonable outcome after controls.

where the steady-state consumption levels in the two states, with and without capital controls, are given by, respectively,[10]

$$c^c = \omega - \frac{G}{(1-f)} + \frac{f\omega}{h} \quad \text{and} \quad c = \omega - G. \tag{11}$$

We can now state the result regarding the existence of a steady-state equilibrium with (positive) CS under this regime.

PROPOSITION 1. *Under assumptions (A) and (B), there exists a unique interior steady-state equilibrium with currency substitution* ($0 < f < 1$) *if and only if* $\pi(1 - \frac{1}{h}) > \frac{G}{\omega}$.

Readers are referred to the Appendix for the proof. Intuitively, this sufficient and necessary condition implies that, in the long run, inflationary domestic money can survive as a store of value along with stable-valued foreign money if and only if the expected loss $\pi(1 - \frac{1}{h})$ on foreign money holdings is relatively large compared with the amount of deficit finance by inflation. Such beliefs then prevent an excessive degree of CS and hence preserve a sufficient amount of the inflation tax base for meeting the government's financing target. Therefore, in our model, agents' beliefs play a central role in determining whether or not a dual currency equilibrium exists in a steady state. This result contrasts standard CS models, such as Chang (1994), that appeal to the prevalent transactions technology in order to preclude the degeneration of the economy to one where "superior" foreign currency survives as the sole store of value in the long run.

The existence of a CS equilibrium can also be illuminated from the perspective of the Laffer curve for seigniorage. The above-mentioned condition shows that there is a unique steady state with positive CS that allows the government to raise G by seigniorage. However, it does not imply that this is the only equilibrium that satisfies the government budget constraint. The following Laffer curve analysis shows that, with constant beliefs π, there exists another steady state that is compatible with the government budget constraint but is associated with *zero* CS and lower inflation. If the government were free to choose the rate of money growth, steady-state seigniorage is given by

$$S(z) = (1-f)\omega z, \tag{12}$$

where z is the rate of money growth and f is the steady-state level of CS, which in general is a function of z. Here, $(1-f)\omega$ can be interpreted as the inflation tax base and z as the inflation tax rate. In order to derive the Laffer curve, we then need to examine how the money growth rate z affects the level of CS f in a steady state.

The steady-state relationship between money growth and CS can be found from (6) by removing all time subscripts. This procedure yields

$$\pi \left[c^c - \frac{\omega}{h} \right] u'(c^c) = (1-\pi) z (1-f) \omega u'(c), \tag{13}$$

[10]Condition (B) also guarantees that the consumption level with controls (c^c) is less that without controls (c), and that c^c decreases with the level of CS (f).

where $c = (1-z)\omega + zf\omega$ and $c^c = (1-z)\omega + \frac{f\omega}{h}$ are the steady-state consumption levels in the two states. The following result is proved in the Appendix.

PROPOSITION 2. *Under (A), there exists a unique interior steady-state equilibrium with currency substitution* $(0 < f < 1)$ *if and only if* $z > \pi(1-\frac{1}{h})$.

The necessary and sufficient condition in this proposition can be rewritten as $\frac{\pi}{h} + (1-\pi) > (1-z)$. The intuitive interpretation for this condition is straightforward. Agents will diversify their portfolio (i.e., hold both currencies) in the long run if and only if the expected return on foreign money exceeds the return on domestic money. The condition then indicates that a *risk premium* on foreign money is required for it to be held in steady-state equilibrium along with the (safe) domestic money.[11] While the condition in Proposition 1 is concerned with the possibility that "inferior" domestic money might not be held, this condition in Proposition 2 is making sure that risky foreign money will be included in agents' portfolios. Both conditions are consistent with one another as they reflect, in fact, the two sides of a CS, or dual currency, equilibrium.

For a money growth rate $z \leq \pi(1-\frac{1}{h})$, from Proposition 2, the agents' maximization problem yields a corner solution with $f = 0$ in the steady state. In this case, the economy reverts back to the simple standard model with domestic money being the sole store of value. Therefore, from (12), the seigniorage function $S(z)$ is simply a linear function for $0 \leq z \leq \pi(1-\frac{1}{h})$. For $z > \pi(1-\frac{1}{h})$, however, by differentiating (13) with respect to z, we can derive

$$\frac{\partial f}{\partial z} = \frac{\pi[u'(c^c) + c^c u''(c^c) - \frac{\omega}{h}u''(c^c)] + (1-\pi)(1-f)[u'(c) - \omega z(1-f)u''(c)]}{\frac{\pi}{h}[u'(c^c) + c^c u''(c^c) - \frac{\omega}{h}u''(c^c)] + (1-\pi)z[u'(c) - \omega z(1-f)u''(c)]}, \tag{14}$$

which is positive under (A). In other words, if agents are not too risk averse, then an increase in z increases CS. Again, from (12), we have

$$S'(z) = (1-f)\omega - \omega z\frac{\partial f}{\partial z}.$$

Substituting from (14) it is easy to see that $S'(z) < 0$. Hence, we have the Laffer curve linearly increasing in z and characterized by zero CS for $z \leq \pi(1-\frac{1}{h})$; it is decreasing and characterized by an increasing degree of CS for $z > \pi(1-\frac{1}{h})$. A picture of the Laffer curve is depicted in Figure 1. As is easy to verify, the maximum occurs at $z = \pi(1-\frac{1}{h})$ at which point seigniorage equals $\pi\omega(1-\frac{1}{h})$. In light of this, the condition in Proposition 1 for a dual currency equilibrium is then simply a requirement that G be lower than the maximum seigniorage that can be extracted from the economy.

[11] Weil (1987) considers a one-money production economy where risky money circulates along with safe physical capital. He finds a similar risk-premium equilibrium requirement on money to be held along with physical capital.

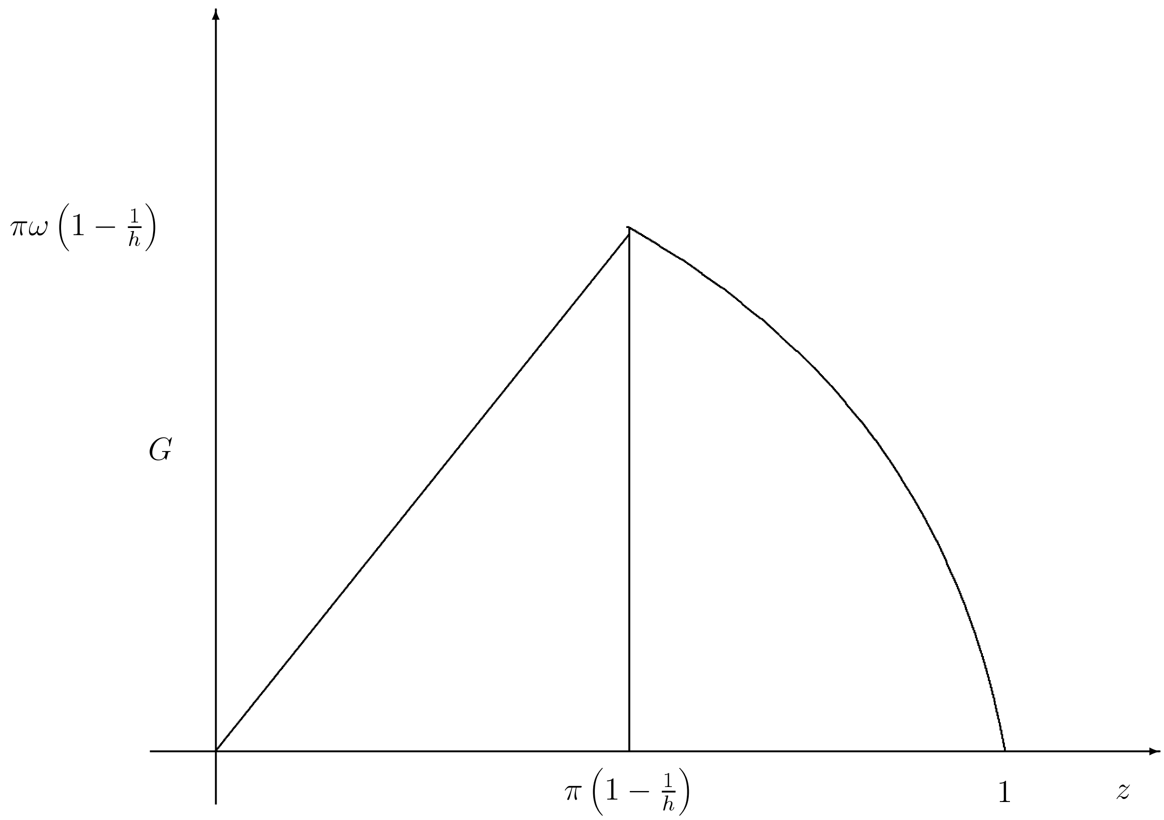


Figure 1: Laffer Curve with Constant Beliefs

The maximum revenue that a government can generate from inflationary finance is usually a function of the elasticity of money demand. In other terms, maximum seigniorage revenue is typically considered a function of preferences. Chang (1994) elaborates a model in which maximum seigniorage is also a function of the available financial technology. In our paper, maximum seigniorage $\pi\omega(1-\frac{1}{h})$ is directly related to the ability of the government to influence the public's beliefs characterized by π, which in turn affects the degree of substitutability of domestic for foreign money. A higher value for π implies a greater perceived likelihood of future controls; this makes foreign money an increasingly unattractive asset to substitute into and, thereby, increases the maximal level of seigniorage revenue the government can derive.[12]

It is also worth pointing out that, with CS ($f > 0$), expected seigniorage revenues under constant beliefs always decline with increases in money growth. This must mean that the elasticity of substitution between domestic and foreign money is relatively high: a given increase in money growth induces a relatively large substitution into foreign money and, as a result, seigniorage declines. The intuition of this implication lies in assumption (A), which is a sufficient condition for CS to rise with an increase in domestic inflation. Since relative risk aversion is relatively low under (A), a given increase in z can (and will) induce a relatively large shift into the risky asset: foreign money. As a result, with positive CS, expected seigniorage always declines with a rise in z because of the high elasticity of substitution between domestic and foreign money.

To summarize, under constant beliefs, there are always two rates of money growth, corresponding to qualitatively different steady states, that will generate the same amount of seigniorage G [$< \pi\omega(1-\frac{1}{h})$]: one is associated with high domestic inflation and positive CS and the other is associated with low domestic inflation and zero CS. This suggests that CS could be eliminated by changes in monetary policy alone *without* changing fiscal policy: for given expectations of capital controls and an amount of deficit, lowering z alone is sufficient to eliminate the demand for foreign money. This result is somewhat at odds with the empirically-observed persistence of CS in Latin America and Eastern Europe: once in place, a decline in domestic inflation does not eliminate CS. As we shall see later, allowing for endogenous beliefs supports persistence in foreign money demand – a result that is more consistent with real world observations.

1.4 Endogenous Beliefs

In this section, we assume that agents' beliefs evolve endogenously with the observed level of economy-wide CS: the probability of controls π_t is assumed to be an increasing function of the level of economy-wide CS f_t. In other terms, agents are less confident that foreign currency

[12]The notion that governments can, in effect, somewhat control the maximum amount of seigniorage by limiting the availability of alternatives to domestic money is discussed in Nichols (1974).

will be allowed to circulate if there is an increase in aggregate CS.[13] This belief-updating mechanism can be justified as follows. A rise of CS in the economy implies a greater depletion of the domestic inflation tax base. It is then quite plausible that a government dependent upon seigniorage will be increasingly inclined (and expected) to limit the circulation of foreign money, and hence preserve the inflation tax base as the level of economy-wide CS rises. The incorporation of this endogeneity in beliefs removes one major unattractive feature of constant beliefs: the assumption that the likelihood of controls remains the same whether CS is non-existent or is complete.

Mathematically, we assume that $\pi_t = \pi(f_t)$ with $\pi(0) = 0$, $\pi(1) = 1$, $0 \leq \pi(f_t) \leq 1$, and $\pi'(f_t) > 0$ for $0 < \pi(f_t) < 1$. Intuitively, this characterization implies that if all savings are held as foreign money then it is certain that capital controls will be in place in the subsequent period. If, however, foreign money demand is zero, the government issues *no* threats of ensuing capital controls. Intermediate between these extreme cases, the threat of capital controls rises as CS rises in the economy.[14] With this modification, the law of motion (3.7.1) describing the evolution of CS becomes

$$\begin{aligned} &\pi(f_t)\left[\frac{(1-f_{t+1})\omega - G}{(1-f_{t+1})} - \frac{(1-f_t)\omega}{h}\right] u'\left[\frac{(1-f_{t+1})\omega - G}{(1-f_{t+1})} + \frac{f_t\omega}{h}\right] \\ &= [1-\pi(f_t)][(1-f_t)\omega - (1-f_{t+1})\omega + G]u'[(1-f_{t+1})\omega - G + f_t\omega] \end{aligned} \tag{15}$$

In a steady state, this reduces to

$$\pi(f) = \frac{Gu'(c)}{\left[c^c - \frac{\omega}{h}\right] u'(c^c) + Gu'(c)} \tag{16}$$

where c and c^c are specified as before in (11). Unlike in the previous section, the existence of multiple equilibria with positive CS are now possible (Figure 2).

PROPOSITION 3. *Under (A), (B) and the assumptions regarding $\pi(\cdot)$, there can exist an even number of steady-state equilibria with $f \in (0,1)$ and $\pi(f)(1-\frac{1}{h}) > \frac{G}{\omega}$ in each steady state.*

Proof. The left-hand side of (16) is an increasing function of f and rises from zero to $\pi(\tilde{f}) < 1$ as f rises from zero to $\tilde{f}$ (the point at which $c^c = \frac{\omega}{h}$). As in the previous section, under (A)

[13]This probabilistic framework is similar to that in Bertocchi and Wang (1995). They present a one-money overlapping generations model; there is a certain probability that money will lose value in the subsequent period. But this probability evolves as a function of aggregate real money balances in the economy: a wider circulation of money in the present suggests a greater likelihood that the currency will be valued in the future. Agents, therefore, adjust their beliefs regarding the value of money in the future based upon the observation of aggregate real money balances in the present.

[14]A more general specification of π could assume less extreme limits. For example, below a certain level of economy-wide CS $\underline{f}$, the possibility of controls is negligible, or $\pi(f_t) = 0$ for $f_t \in [0, \underline{f}]$. Above a certain upper level $\overline{f}$, it is certain that CS will not be tolerated, or $\pi(f_t) = 1$ for $f_t \in [\overline{f}, 1]$. And, in the range $f_t \in (\underline{f}, \overline{f})$ the likelihood of controls rises. Our analysis will hold for such general specifications.

and (B), the right-hand side of (16) monotonically increases from $\frac{h}{(h-1)}\frac{G}{\omega}$ to 1 as f increases from 0 to $\tilde{f}$. Figure 2 depicts both sides of (16) graphically. As can be seen, there can be an even number of intersections of the two schedules (we ignore points of tangency as exceptional possibilities) and, in each case $\pi(f) > \frac{h}{(h-1)}\frac{G}{\omega}$, or, $\pi(f)(1-\frac{1}{h}) > \frac{G}{\omega}$.

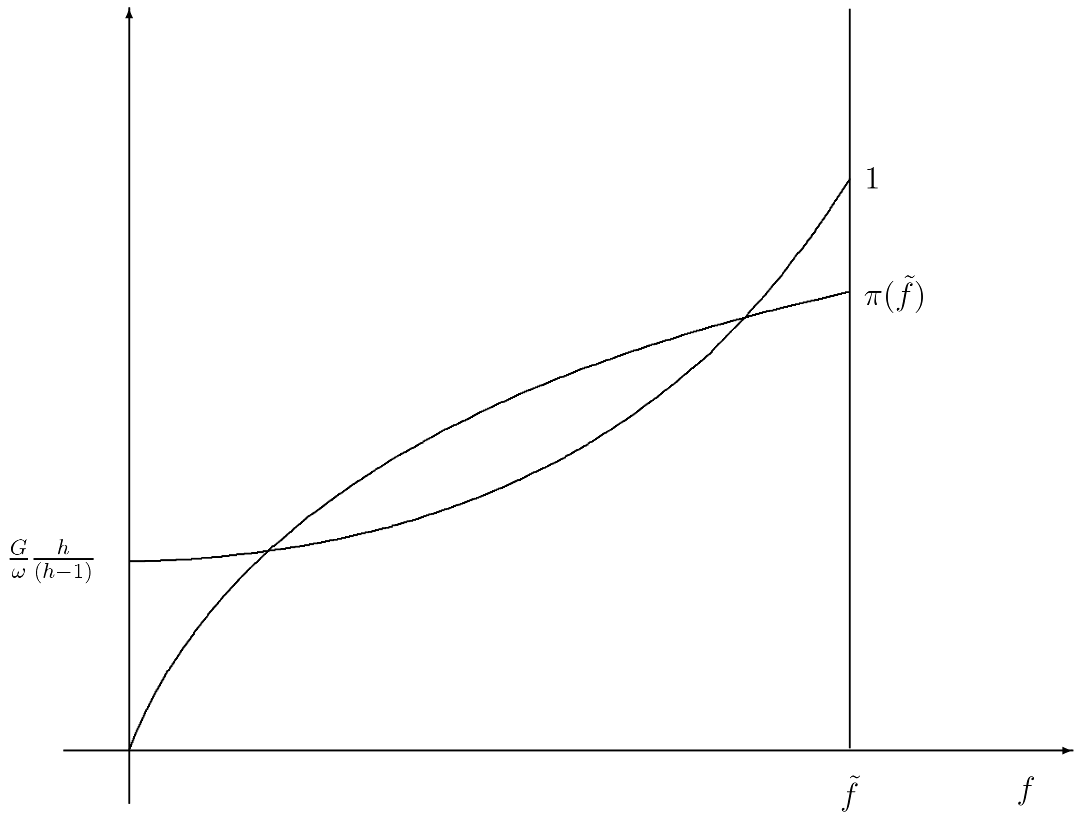


Figure 2: Existence of Equilibria with Endogenous Beliefs

Intuitively, as in Proposition 1, the necessary condition here implies that the expected loss under controls adjusts in such a manner as to be relatively high in a steady state where both monies circulate simultaneously. This relatively-high probability of capital controls ensures a large enough tax base for the amount of inflation financing that is necessary in meeting the government's budget constraint. Unlike the previous case, here agents' beliefs adjust over time so as endogenize the extent of substitutability and relative attractiveness of the two monies: as the level of CS changes, so does the (perceived) riskiness of foreign money measured by $\pi(f)$. It is this endogeneity of beliefs that introduces the multiplicity of steady states with CS, which is absent in the case with constant beliefs. One of the direct implications of this result is that the multiplicity helps to explain the different levels of CS observed in different countries.

As is often the case with multiple equilibria, we can rank all potential steady states in terms of the agents' welfare measured by the expected utilities. In a steady state, the expected utility of a representative agent can be written as $[1-\pi(f)]u(c)+\pi(f)u(c^c)$, where c and c^c are described in (11). Since c is invariable with f, c^c is decreasing [under (B)] and $\pi(\cdot)$ is increasing in f, agents are worse off in a steady state with a higher f. Therefore, the steady states in our model can be Pareto ranked by the level of CS. As different equilibria are supported by different expectations regarding capital controls, a high level of CS here may be interpreted as an outcome of "coordination failure".

Parallel to the discussion in the previous section, we will derive the Laffer curve for seigniorage under endogenous beliefs. To this end, we need again to examine the relation between money growth and CS in a steady-state. Under endogenous beliefs, (13) is modified to

$$\pi(f)\left[c^c-\frac{\omega}{h}\right]u'(c^c)=[1-\pi(f)]z(1-f)\omega u'(c), \tag{17}$$

where again $c=(1-z)\omega+zf\omega$ and $c^c=(1-z)\omega+\frac{f\omega}{h}$. Similarly, we prove the following result in the Appendix.

PROPOSITION 4. *Under endogenous beliefs, there always exists a unique steady state with positive currency substitution for any given $z\in(0,1)$.*

Therefore, in contrast to the earlier case, with endogenous beliefs the unique steady state is always associated with a positive level of CS as long as $z>0$. This shows that CS is a robust outcome in that it cannot be eliminated by reducing inflation alone – a result in sharp contrast with that obtained under constant beliefs. As pointed out earlier, this robust demand for foreign money is consistent with the empirically-observed persistence in CS. It is easy to see why zero CS cannot be a steady state under endogenous beliefs. With zero CS, beliefs will adjust so that future capital controls are perceived with zero probability since there is currently no threat to the government's inflation tax base. Such beliefs will then induce agents to substitute into foreign money and out of inflationary domestic money, hence resulting in positive CS.

Analogously, we can study the Laffer curve by examining the response of CS to changes in inflation. From (17),

$$\frac{\partial f}{\partial z}=\frac{\pi(f)[u'(c^c)+c^cu''(c^c)-\frac{\omega}{h}u''(c^c)]+[1-\pi(f)](1-f)[u'(c)-\omega z(1-f)u''(c)]}{\frac{\pi(f)}{h}[u'(c^c)+c^cu''(c^c)-\frac{\omega}{h}u''(c^c)]+[1-\pi(f)]z[u'(c)-\omega z(1-f)u''(c)]+\tilde{A}}, \tag{18}$$

with

$$\tilde{A}\equiv\frac{\pi'(f)}{\omega}\left\{\left[c^c-\frac{\omega}{h}\right]u'(c^c)+z(1-f)\omega u'(c)]\right\}.$$

Since $\tilde{A} > 0$ from (17), one can see that $\frac{\partial f}{\partial z} > 0$ holds under (A). An increase in money growth in fact introduces two opposing effects on CS under our specification of endogenous beliefs. On the one hand, higher domestic inflation obviously bring a greater incentive to hold more foreign money. On the other hand, as the demand of foreign money rises, so does the perceived likelihood of future capital controls which, in turn, somewhat dissuades substitution into foreign money. The above analysis shows that, overall, CS still increases with money growth rate despite the adjustment of expectations under endogenous beliefs.

With some additional assumptions, we show that (in Appendix) the Laffer curve in this case has a "standard" shape with a single peak in the range of $z \in [0, 1]$, as depicted in Figure 3. With endogenous beliefs, the change in f for a given change in z is reduced because of the adjustment in $\pi(f)$. Therefore, the elasticity of substitution between domestic and foreign money is not globally as high as was the case with constant beliefs. This allows for seigniorage revenues to first increase as money growth increases, as opposed to the case with constant beliefs where, in a CS equilibrium, seigniorage revenues always decrease as money growth rate increases. As the money growth rate rises higher, it depresses both the consumption levels c and c^c. Assuming non-decreasing relative risk aversion, this leads to more risk taking and hence a higher elasticity of demand for foreign money, which ultimately causes the Laffer curve to be downward sloping with high enough money growth. With the "standard" single-peaked Laffer curve, as long as the government's deficit target is less than the maximum seigniorage that can be extracted, there are two steady-state equilibria: one characterized by low inflation and a low level of CS and the other with high inflation and a high level of CS.

So far, we have focused primarily on the steady-state equilibria. In the next section, we examine the dynamics and the stability properties of the steady-state equilibria.

1.5 Dynamics

1.5.1 Constant Beliefs

When agents' expectations are constant, Proposition 1 shows that there is a unique steady state with CS under certain conditions. We first investigate the stability of this unique steady state.

The equilibrium dynamics under constant beliefs and a government spending target of G are governed by the equation (9). Taking the partial derivative with respect to f_t at the both sides of (9) we have (evaluating at the steady state),

$$\left[\frac{\partial f_{t+1}}{\partial f_t}\right]_{f_t = f_{t+1}} = \frac{(1-\pi)\omega[u'(c) - Gu''(c)] + \frac{\pi\omega}{h}[u'(c^c) + (c^c - \frac{\omega}{h})u''(c^c)]}{(1-\pi)\omega[u'(c) - Gu''(c)] + \frac{\pi G}{(1-f)^2}[u'(c^c) + (c^c - \frac{\omega}{h})u''(c^c)]}.$$

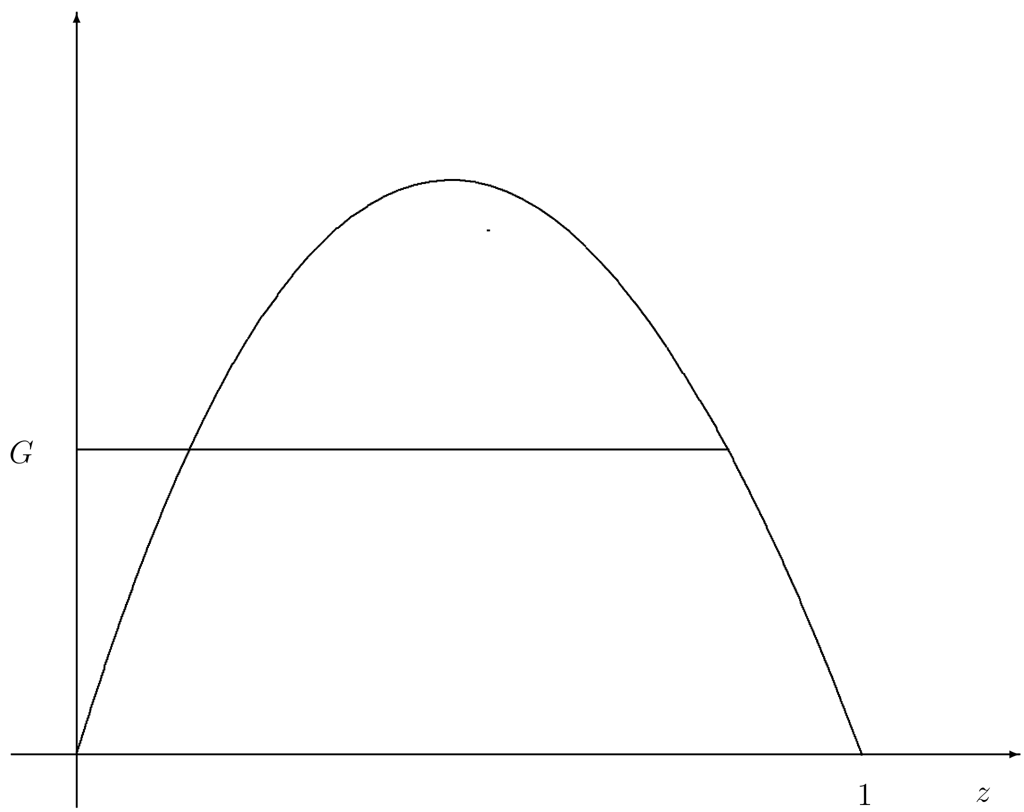


Figure 3: Laffer Curve with Endogenous Beliefs

Therefore, one can see that under (A) and (B),

$$0 < \left[\frac{\partial f_{t+1}}{\partial f_t}\right]_{f_t = f_{t+1}} < 1.$$

Consequently, the unique steady state with positive CS under constant beliefs, when exists, is locally stable.

This result implies that, once extant, CS is unlikely to disappear automatically from the economy, even when agents' beliefs are constant. This, however, does not in itself imply that CS would still persist with monetary reforms. As shown previously, under constant beliefs, the government is in fact able to eliminate CS by reducing the money growth rate while still meeting its fiscal target – an implication contrary to many real world observations. Taken together, we do not view the stability of the CS steady state in this case as being directly supportive of the hypothesis that agents' beliefs are constant.

1.5.2 Endogenous Beliefs

The stability of the various equilibria in the endogenous beliefs case are more difficult to ascertain. In the following, we make some additional assumptions and consider the case where there are two equilibria (i.e., there is a single-peaked Laffer curve).

Under endogenous beliefs, from (15), one can obtain the derivative of f_{t+1} with respect to f_t as:

$$\frac{\partial f_{t+1}}{\partial f_t} = \frac{[1-\pi(f_t)]\omega[u'(c_{t+1}) - (\omega - c_{t+1})u''(c_{t+1})] + \frac{\pi(f_t)\omega}{h}[u'(c^c_{t+1}) + (c^c_{t+1} - \frac{\omega}{h})u''(c^c_{t+1})] + \tilde{B}}{[1-\pi(f_t)]\omega[u'(c_{t+1}) - (\omega - c_{t+1})u''(c)] + \frac{\pi(f_t)G}{(1-f)^2}[u'(c^c_{t+1}) + (c^c_{t+1} - \frac{\omega}{h})u''(c^c_{t+1})]},$$

where

$$\tilde{B} \equiv \pi'(f_t)[(\omega - c_{t+1})u'(c_{t+1}) + \left(c^c_{t+1} - \frac{\omega}{h}\right)u'(c^c_{t+1})].$$

$\tilde{B}$ is positive from (15), therefore, $\frac{\partial f_{t+1}}{\partial f_t} > 0$ under (A). Hence f_{t+1} is globally increasing with f_t. In addition, we can see from (15) that f_{t+1} tends to $-G/\omega$ as $f_t \to 0$, and f_{t+1} equals $1 - \frac{G}{\omega}$ when f_t equals one. Furthermore, with additional assumptions of concave beliefs and non-decreasing relative risk-aversion (the same assumptions that support a single-peaked Laffer curve as shown in the Appendix), one can show that the following condition

$$\left[\frac{\partial f_{t+1}}{\partial f_t}\right]_{f_t = f_{t+1}} = 1$$

can be satisfied *at most* once, suggesting that the trajectory of f_{t+1} may tangent to the 45^0 line at *at most* one point. Since there are two steady states under the assumptions, the above properties of the relationship between f_t and f_{t+1} imply dynamics that are characterized as in Figure 4.

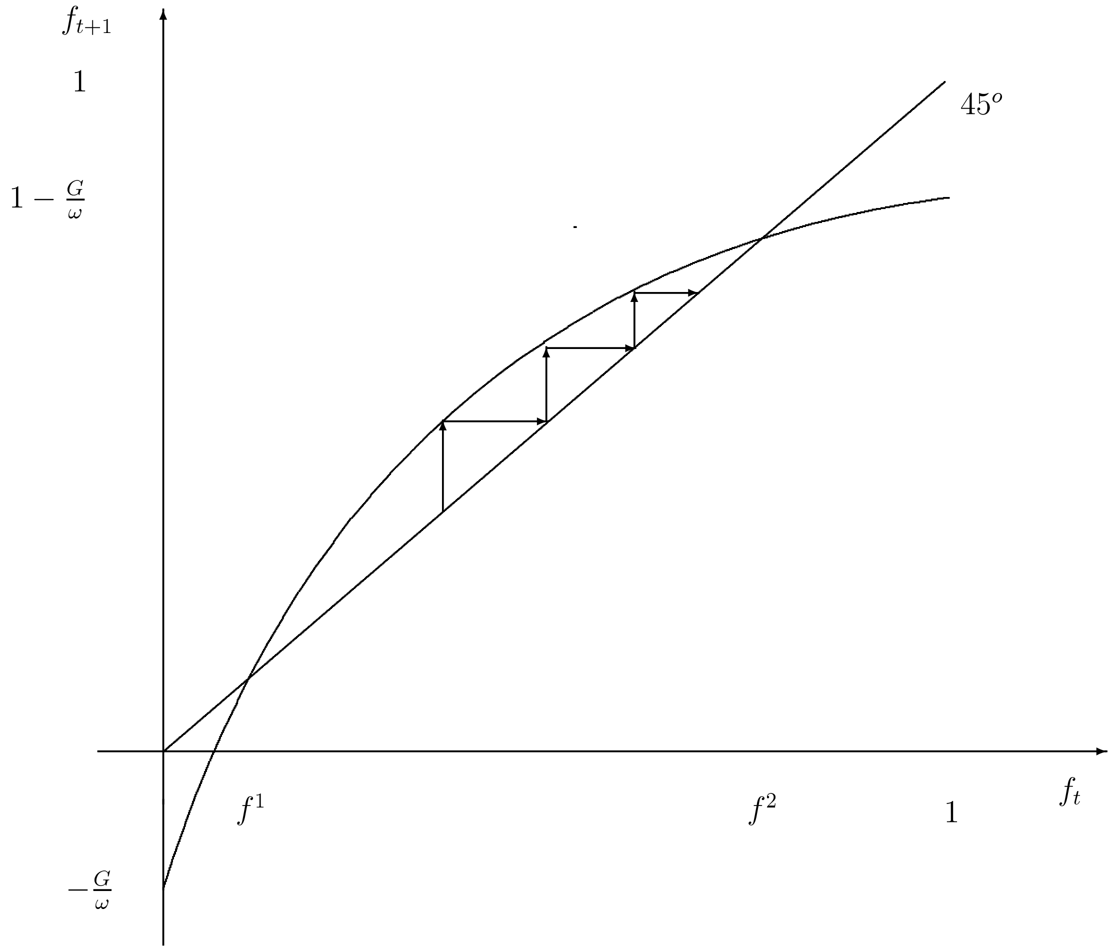


Figure 4: Dynamics: Endogenous Beliefs

Suppose that $f^1 < f^2$ are the two interior steady-state equilibria. The phase diagram depicted in Figure 4 implies that the low-CS steady state f^1 is unstable and the high-CS steady state f^2 is (globally) stable. In other words, with a standard, single-peaked Laffer curve, the economy is likely to settle on the "wrong side" of the Laffer curve with a steady state that is characterized by high domestic inflation and a high level of CS, confirming the conventional "slippery side of Laffer curve" in the seigniorage literature. Therefore, under endogenous beliefs, monetary austerity alone is not sufficient to eradicate CS, and it may not even be able to reduce the extent of CS as the adjustment dynamics converge to the same high-CS steady state. This result reinforces the robustness of CS, and is supportive of empirical findings and hence of a model with dynamic belief specifications. In general, without some of the restrictions, the Laffer curve can have a complicated shape that results in more than two (an even number of) steady-states with CS. We can reasonable conjecture that, for each pair of adjacent steady states, starting from the lowest one, the one with both higher inflation and CS will be stable and the one with both lower inflation and CS will unstable. In other words, there can be multiple *stable* steady states, implying convergence toward different levels of CS for countries with different initial conditions.

1.6 Concluding Remarks

We have examined in a dynamic general equilibrium model the interaction between CS and public perceptions of government policies regarding restrictions on foreign exchange. Specifically, we consider an economy in which the government monetizes its deficit, hence causing domestic inflation, and the public holds beliefs that capital controls may be imposed. Public beliefs regarding future capital controls stem from the government's motive for preserving the inflation tax base in order to finance its deficit. Throughout the paper, we have contrasted the implications of exogenous (constant) beliefs regarding government policies on capital controls with those obtained with endogenous beliefs. With endogenous beliefs, agents update their perceptions of the likelihood of capital controls based on observed levels of CS: as economy-wide CS rises, to preserve the inflation tax base, the probability that government would impose limitations on foreign currency circulation increases.

We find that, in general, dual money equilibria – where inflationary domestic money coexists with stable-valued foreign money – can exist only when the perceived likelihood of controls on foreign money is relatively high so that enough of a tax base is preserved for meeting the government inflation financing target. With given government fiscal policy, we show that, while CS disappears with a low enough money growth rate when agents' beliefs are constant, CS cannot be eliminated by reducing inflation alone with endogenous beliefs. We also show that the interplay between expectations and economy-wide CS reflected in endogenous beliefs is essential to introducing the possibility of multiple, steady states with different levels of CS, possibly accounting for the different levels of CS observed in different countries. Such a multiplicity is very much akin to that found in a typical environment with coordination problems. Furthermore, we demonstrate that under some regularity conditions there exists a "standard", single-peaked Laffer curve for steady-state seigniorage. The stability analysis suggests that, under endogenous beliefs, the economy converges to the inferior steady state on the downward-sloping side of the Laffer curve with high domestic inflation and a high level of CS.

Overall, our analysis suggests that models in which agents update their beliefs of future capital controls according to endogenous economic variables is more consistent with some stylized facts regarding CS. Under such a scenario, monetary reforms alone are unlikely to succeed in eradicating, or even reducing, economy-wide CS. More generally, we believe that the interaction between public beliefs and economic fundamentals is important in shedding light on a host of issues including those pertaining to currency substitution.

1.7 Appendix

Proof of Proposition 1: The left-hand side of (10) is an exogenously-given constant. The right-hand side of (10) is a monotonically increasing function of f under (A) and (B). At $f = 0$, the right-hand side is equal to $\frac{h}{(h-1)}\frac{G}{\omega}$. It is then clear that there is a unique interior intersection of the two sides of (10) in the relevant range of f if and only if $\pi > \frac{h}{(h-1)}\frac{G}{\omega}$ or, $\pi(1 - \frac{1}{h}) > \frac{G}{\omega}$.

Proof of Proposition 2: While the left-hand side of (13) increases monotonically from $\pi[(1-z)\omega - \frac{\omega}{h}]u'[(1-z)\omega]$ to $\pi(1-z)\omega u'[(1-z)\omega + \frac{\omega}{h}] > 0$ as f increases from 0 to 1, the right-hand side decreases monotonically from $(1-\pi)z\omega u'[(1-z)\omega]$ to 0. Clearly, (13) indicates that a dual-currency equilibrium exists if and only if $\pi[(1-z)\omega - \frac{\omega}{h}]u'[(1-z)\omega] < (1-\pi)z\omega u'[(1-z)\omega]$ or, $z > \pi(1 - \frac{1}{h})$.

Proof of Proposition 4: From the assumptions regarding $\pi(\cdot)$, the left-hand side of (17) increases monotonically from zero to $(1-z)\omega u'[(1-z)\omega + \frac{\omega}{h}] > 0$ as f increases from zero to one, while at the same time the right-hand side of (17) decreases monotonically from $(1-\pi)z\omega u'[(1-z)\omega]$ to 0. It is clear then that there *always* exists a unique interior solution with CS for all $z \in (0, 1)$.

CLAIM: *Under endogenous beliefs, in addition to (A), assume that (i) $\pi(\cdot)$ is increasing and concave and (ii) relative risk aversion is nondecreasing in consumption, then the Laffer curve is single peaked in the range $z \in [0, 1]$.*

Proof. Seigniorage is given by (12). It is easily verified that $S(0) = 0$ and $S(1) = 0$. Differentiating,

$$S'(z) = (1-f)\omega - z\omega\frac{\partial f}{\partial z},$$

where $\frac{\partial f}{\partial z} > 0$ is given in (18). Then,

$$\lim_{z \to 0} S'(z) = \omega > 0 \quad \text{and} \quad \lim_{z \to 1} S'(z) = \lim_{z \to 1} \left[-\omega \frac{\partial f}{\partial z} \right] < 0.$$

The necessary condition for maximum seigniorage is $S'(z) = 0$, or

$$\frac{(1-f)}{z} = \frac{\partial f}{\partial z},$$

which upon substitution from (18) yields

$$\begin{aligned} &\pi(f)[hz - (1-f)] \left[u'(c^c) + c^c u''(c^c) - \frac{\omega}{h} u''(c^c) \right] \\ &= \pi'(f)(1-f)\{[h(1-z) - (1-f)]u'(c^c) + hz(1-f)u'(c)\}. \end{aligned} \tag{19}$$

One can show that, under (A) and non-decreasing relative risk aversion, the derivative of the left-hand side of (19) with respect to z is positive. Noticing that $f \to 0$ as $z \to 0$ and $f \to 1$ as $z \to 1$, hence the left-hand side of (19) increases from zero to $hu'(\frac{\omega}{h})$ as z rises from zero to one. The right-hand side decreases, if one assumes that $\pi(\cdot)$ is increasing as well as concave, from $\pi'(0)(h-1)u'(\omega)$ to zero in the same range. As a result, there will be a *unique* point at which seigniorage is maximum. One possibility is depicted in Figure 3.

2 Endogenous Beliefs and the Demand for Foreign Money

2.1 Introduction

Currency substitution (CS) refers to the demand for foreign money by domestic residents. The prevalence of CS is endemic in several Latin American and East European countries. Traditional explanations of the phenomenon tend to focus on its association with high levels of domestic inflation: foreign money is a convenient hedge against the erosion of purchasing power over time.[15] Therefore, increases in domestic inflation are theorized to lead to an increase in the demand for foreign money (as has been empirically observed). Interestingly, a complete and rapid elimination of local currency has been rarely observed even with high inflation levels.[16] Similarly, a decrease in domestic inflation should lead to a decline in CS. This latter prediction has not been observed empirically: in several instances, decreases in inflation to minimal levels subsequent to episodes of high inflation have not reversed the demand for foreign money. This persistence or "hysteresis" in CS has been the subject of several theoretical and empirical studies.[17]

Theoretical explanations of the observed irreversibility of CS found in the literature have focused primarily on the *transactions technology* associated with the use of two monies. Guidotti and Rodriguez (1992) argue that there are costs associated with switching from the use of one currency to the other. Once an economy is "dollarized", these costs deter the switch back to the use of domestic money after inflation has abated. Uribe (1995) elaborates a similar model of CS hysteresis in which the transactions costs are endogenous in that they are a decreasing function of the aggregate level of CS in the economy. Sturzenegger (1992) postulates a model in which inflation instigates financial adaptation (i.e., a move away from domestic money to the use of foreign money or other assets). Transactions costs associated with CS are assumed to decline with an increase in the denomination of purchases. This precludes a complete "dollarization" of the economy when there is inflation. Nevertheless, certain sectors of the economy do become "dollarized" and reversion to the use of domestic money, subsequent to a decline in inflation, need not occur. In more general terms, Dornbusch *et al.* (1990) characterize this process of adaptation as a shift in money demand: for every rate of inflation there is now a lower demand for domestic money, leading to hysteresis.

An alternate (and complementary) explanation of the persistence in CS focuses on public perceptions that stabilization policies – such as those leading to a decline in inflation – *lack credibility*. Essentially, the argument is that persistence in CS is, in all likelihood, a transitory phenomenon: the demand for domestic money will rise as stabilization policies

[15] See Giovannini and Turtleboom (1994) and Calvo and Végh (1992) for a survey of the literature.

[16] See Savastano (1996).

[17] See, for example, Uribe (1995), Brand (1993), Clements and Schwartz (1993), Kamin and Ericsson (1993), Liviatan (1993), Calvo and Végh (1992), Guidotti and Rodriguez (1992), Sturzenegger (1992), and Dornbusch *et al.* (1990).

earn credibility. Melvin and Fenske (1992) propose this as one explanation for the persistence of foreign money demand in Bolivia, monetary reform in the late 1980s notwithstanding. A similar conclusion is discussed by Clements and Schwartz (1993).

The principal contribution of our paper is the incorporation of *psychological* factors as determinants of the choice underlying the use of domestic and/or foreign money. We extend the analysis of partial confidence in money, as examined by Weil (1987) and Bertocchi and Wang (1995), to a two-money environment. Our paper proposes an overlapping-generations model in which agents are uncertain about the ability of domestic money to survive as a legitimate store-of-value. The basic scenario we postulate is similar to that in Melvin (1988): the adoption of high-confidence foreign money and a substitution away from low-confidence domestic money (to the extent possible) results from a market-based monetary reform on the demand side. In addition, though, we propose a framework whereby confidence in domestic money is bolstered *only if* aggregate economy-wide real domestic money demand is expected to increase. Relative money demand is, therefore, influenced by a "bandwagon" effect: one reason why rational agents might demand less of the domestic currency *today* is simply because less of it is expected to be circulating in the economy, in real terms, *tomorrow*. In other terms, we focus on inter-agent interactions as an additional factor influencing relative money demand while maintaining elements of the transactions-costs and government-policy-credibility explanations of CS and its persistence.

The rationale behind allowing confidence in the future value of domestic money to be bolstered by expectations of its increased economy-wide usage in the future is simple. Increases in aggregate real domestic money demand: (a) increase the inflation tax base thereby making a seigniorage-induced hyperinflation less likely and/or, (b) forebode an increase in the possibility for and ease in money-for-output exchange denominated in the domestic currency.[18] Allowing beliefs regarding the future value of domestic money to be *endogenous* and *time-varying* in the fashion specified above yields several interesting results. We demonstrate the existence of steady-state stable equilibria that always admit some degree of currency substitution. Furthermore, the model also predicts that CS will be persistent: reductions in domestic inflation will not eliminate the demand for foreign money. In our model, the entrenchment of foreign money demand is caused by the externality embodied in the expectation-formation of agents. This leads to coordination failure and a multiplicity of stationary equilibria with robust demands for foreign money.

In the next section we set out the basic structure of the model and define the concept of partial confidence. We demonstrate conditions for the existence of a stationary equilibrium with CS. Section 3 introduces an adjustment process in beliefs regarding the future value of money and the associated implications for monetary equilibria. Section 4 discusses implications of the model in terms of illustrating persistence in CS. Section 5 concludes with a brief

[18] In other terms, the young are more confident about holding savings in the form of domestic money if they expect future aggregate domestic money demand to be higher since it indicates a greater likelihood they will be able to exchange domestic money for output when they are old. This idea is similar to that in Diamond (1982): an increase in the number of trading partners makes trade easier.

discussion of the results.

2.2 The Basic Model

The basic model is that of a small, open overlapping generations economy. Time is discrete. At every time t, a generation of agents is born that lives for two periods. For simplicity, it is assumed that there is no population growth and the size of the population is normalized to one. Each agent is endowed with ω units of a non-storable tradable good when young. Consumption c takes place only when old. There are two assets that serve as stores-of-value over time: domestic money and foreign money. The price of foreign money is exogenously-given and fixed over time and normalized to one.[19] In addition, purchasing power parity (PPP) holds in every period: the exchange rate equilibrates the price of the two monies.

Agents would like to exchange their endowment for the two monies when young. In order to do so, they must be reasonably certain that they will be able to trade either money for output when old. The two monies are not identical assets. Domestic money suffers from a lack of confidence. As in Weil (1987), we assume that with probability q agents expect to be able to exchange domestic money for output when old. With probability $(1-q)$, on the other hand, domestic money is expected to be worthless.[20] Therefore, q is broadly interpretable as a measure of the degree of confidence agents place on domestic money. Confidence in foreign money is more robust, but its use involves transactions costs.

Young agents born in time t maximize von Neumann-Morgenstern expected utility $E_t[u(c_{t+1})]$. The utility function is assumed strictly concave with $u'(\cdot) > 0$ and $u''(\cdot) < 0$. To ensure an interior solution, the Inada condition at zero is invoked [i.e., $u'(0)$ is infinite]. If domestic money retains value, agents face the following constraints: $\omega = P_t m_t + hP_t^* m_t^*$ and $c_{t+1} = P_{t+1} m_t + P_{t+1}^* m_t^*$ where P_t is the price of domestic money and m_t are nominal money holdings of the young at time t. Starred variables correspond to the price of foreign money and nominal holdings of foreign money. The term h captures transactions costs associated with entering the market for foreign exchange. It is assumed that these transactions costs are time-invariant, finite, and strictly greater than one, or $1 < h < \infty$.[21]

Since the price of foreign money is fixed at one for all t, the budget constraint in the

[19] Chang (1994) adopts a similar assumption.

[20] Lack of confidence in domestic money could stem from several factors including sunspots. Another explanation could be due to the expectation that the government may hyperinflate.

[21] Transactions costs associated with the use of foreign money may be characterized as a policy variable as well as an attribute of the economic environment. Hercowitz and Sadka (1987), in their study of the optimality of the inflation tax in an inventory-theoretic model of CS, adopt a framework in which foreign money transaction costs are a policy variable. Arguably, though, transactions costs may be characterized as an *endogenous* attribute of the economic environment. Uribe (1995), for instance, details a two-money cash-in-advance model in which foreign money transaction costs are a decreasing function of economy-wide CS.

event domestic money retains value can be rewritten as:

$$c_{t+1}^{+} = \frac{P_{t+1}}{P_t} d_t \omega + \frac{(1 - d_t)\omega}{h} \tag{1}$$

where d_t is the share of savings held in the form of domestic money and $(1 - d_t)$ is the share held as foreign money. The superscript '+' refers to the state in which domestic money has a positive value. With population normalized to one, $(1 - d_t)$ also represents economy-wide CS.

As is evident from equation (1), agents' choices regarding which money to hold as store-of-value is dependent upon domestic inflation and transactions costs associated with the use of foreign money. Monetary diversification also arises because, with (constant) probability $(1-q)$, agents expect not to be able to exchange local money for output when old. Therefore, the budget constraint in the event that domestic money loses value is given by:

$$c_{t+1}^{-} = \frac{(1 - d_t)\omega}{h} \tag{2}$$

The superscript '-' refers to the state in which domestic money is expected to be worthless.

Agents choose d_t in order to maximize expected utility:

$$qu(c_{t+1}^{+}) + (1 - q)u(c_{t+1}^{-})$$

where c_{t+1}^{+} and c_{t+1}^{-} are given by equations (1) and (2), respectively. The first-order condition from the agents' maximization problem is:

$$q\left[h\frac{P_{t+1}}{P_t} - 1\right] u'\left[\frac{P_{t+1}}{P_t} d_t \omega + \frac{(1 - d_t)\omega}{h}\right] = (1 - q)u'\left[\frac{(1 - d_t)\omega}{h}\right] \tag{3}$$

Equilibrium entails money and goods market clearing. With domestic money having value, $P_t m_t = d_t \omega$ and

$$P_t = \frac{d_t \omega}{\overline{m}_t}$$

where $\overline{m}_t$ is time t domestic money supply. The ratio of prices over time is given by

$$\frac{P_{t+1}}{P_t} = \frac{d_{t+1}}{d_t}(1 - z)$$

where $z = (\overline{m}_{t+1} - \overline{m}_t)/\overline{m}_{t+1}$ is the (exogenously-determined) constant money growth rate.[22] Substituting for the intertemporal price ratio in equation (3) yields:

$$q\left[h\frac{d_{t+1}}{d_t}(1 - z) - 1\right] u'\left[d_{t+1}(1 - z)\omega + \frac{(1 - d_t)\omega}{h}\right] = (1 - q)u'\left[\frac{(1 - d_t)\omega}{h}\right] \tag{4}$$

[22] For notational convenience, we are using a somewhat non-standard definition of the money growth rate: the denominator is $\overline{m}_{t+1}$ instead of $\overline{m}_t$.

Equation (4) is a first-order nonlinear difference equation in d. It captures the evolution of economy-wide CS [i.e., $(1-d_t)$] over time. In a stationary equilibrium, real money balances will be constant over time. Therefore, in steady-state the following relationship holds:

$$\frac{q}{(1-q)} = \frac{1}{[h(1-z)-1]} \frac{u'(c^-)}{u'(c^+)} \tag{5}$$

where

$$c^+ = d(1-z)\omega + \frac{(1-d)\omega}{h} \tag{6}$$

and

$$c^- = \frac{(1-d)\omega}{h} \tag{7}$$

From (5) we can derive the following proposition.

PROPOSITION 1. *A unique, stationary domestic money portfolio share* $d \in (0,1)$ *exists if and only if* $q > 1/[h(1-z)]$.

Proof. This follows from (5). Under the assumptions regarding marginal utility, we have

$$\frac{q}{(1-q)} > \frac{1}{[h(1-z)-1]}$$

which implies that $q > 1/[h(1-z)]$ is a necessary and sufficient condition for the existence of an interior stationary equilibrium. The left-hand side of (5) is an exogenously-given constant. The right-hand side increases monotonically from $1/[h(1-z)-1]$ to infinity as d rises from zero to one. Figure 5 plots the left-hand side and right-hand side of (5) as a function of d. The two schedules will intersect if and only if $q/(1-q) > 1/[h(1-z)-1]$ and, as can be verified graphically, the intersection will be unique.

Proposition 1 implies that relatively low-confidence domestic money cannot survive in the long run. The condition on q implied in Proposition 1 can be interpreted as evidence of a *risk premium* requirement on domestic money: $q(1-z)$ is expected return on domestic money and $1/h$ is the return on foreign money. Therefore, $q(1-z)$ must be greater than $1/h$ in order to induce agents to hold any domestic money.[23] Proposition 1 also implies that there is an upper bound on domestic money growth. If z is greater than $(h-1)/h$ then foreign money is the preferred store-of-value in *both* states: domestic money is losing value to such a relatively large extent that nobody will hold any of it even if q is high enough.

The conditions in Proposition 1 highlight an important implication regarding the demand for domestic money in our model. Lack of confidence does *not* stem directly from current

[23] Weil (1987) considers a one-money production economy where risky money circulates along with safe physical capital. He finds a similar risk-premium requirement on money to be held along with physical capital.

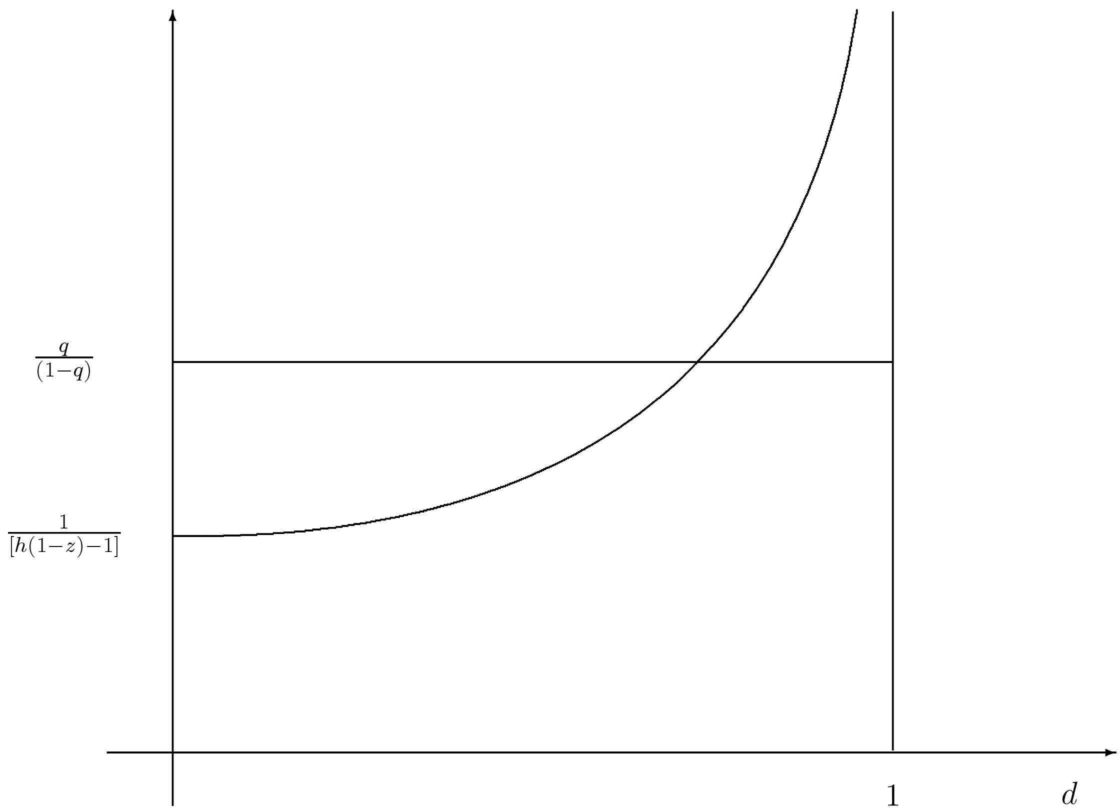


Figure 5: Currency Substitution with Exogenous Beliefs

inflation. It rather reflects expectations regarding the future valuation of domestic money either because: (a) monetary authorities cannot be trusted not to hyperinflate and/or, (b) fears that other agents may refuse to exchange output for domestic money in the future. If current inflation is too high agents will not demand any domestic money regardless of the level of confidence they may place on its future valuation.

From the equilibrium condition, it follows that the demand for domestic money is a function of confidence q, foreign money transactions costs h, and the domestic money growth rate z. Differentiating both sides of (5) with respect to q gives us

$$\frac{\partial d}{\partial q} = \frac{-hu'(c^-) - h[h(1-z)-1]u'(c^+)}{\omega(1-q)u''(c^-) + q\omega[h(1-z)-1]^2 u''(c^-)} > 0$$

where c^+ and c^- are defined in equations (6) and (7), respectively. As intuition would suggest, an increase of confidence in domestic money leads agents to increase their steady-state demand for it.

Similarly, we have the following:

$$\frac{\partial d}{\partial z} = \frac{qh\left\{hu'(c^+) + d\omega[h(1-z)-1]u''(c^+)\right\}}{q\omega[h(1-z)-1]^2 u''(c^+) + \omega(1-q)u''(c^-)} < 0$$

This follows from the positive interest elasticity when $q \equiv 1$ which implies $hu'(c^+) + d\omega[h(1-z)-1]u''(c^+) > 0$.

Also, we have:

$$\frac{\partial d}{\partial h} = \frac{-qh(1-z)u'(c^+) + A}{B} > 0$$

where A and B are given by

$$A \equiv \frac{(1-d)\omega}{h}\Big[q[h(1-z)-1]u''(c^+) - (1-q)u''(c^-)\Big] < 0$$

and

$$B \equiv \frac{[h(1-z)-1]^2}{h} q\omega u''(c^+) + \frac{(1-q)\omega}{h} u''(c^-) < 0$$

Non-increasing absolute risk aversion implies marginal utility is convex or $u'''(\cdot) > 0$.[24] Therefore, $u''(c^+) > u''(c^-)$ since $c^+ > c^-$. From Proposition 1, at an interior steady-state, $q[h(1-z)-1] > (1-q)$. This means that A is negative. So, the demand for domestic money *increases* as transactions costs associated with foreign money rise if marginal utility is convex. One interpretation of this result can be understood based upon the analysis of precautionary savings in Kimball (1990): decreasing absolute risk aversion implies that

[24] This is easy to see. Mathematically, non-increasing absolute risk aversion means $\frac{d}{dx}\left[\frac{-u''(x)}{u'(x)}\right] \leq 0$ which implies $u'''(\cdot) > 0$. See Arrow (1971) for more on this assumption. Intuitively, non-increasing absolute risk aversion implies that agents are not more averse to making risky investments as they become wealthier.

absolute prudence (a measure of ones inclination to "forearm" oneself against uncertainty) is greater than absolute risk aversion. An increase in h implies a lower return on foreign money. This encourages a move towards risky domestic money *only if* the distaste agents have for risk is overshadowed by their desire to increase savings in domestic money in order to keep expected consumption at the same level as before.

Corollary 2.1 summarizes how d is related with q, h, and z.

COROLLARY 2.1. *The steady-state domestic money portfolio share d is: (i) an increasing function of confidence in domestic money, (ii) a decreasing function of the money growth rate z if interest elasticity is positive for $q \equiv 1$ and, (iii) an increasing function of foreign money transactions costs if absolute risk-aversion is non-increasing.*

2.2.1 Dynamics

In this subsection, we explore out-of-steady-state behavior. The following proposition summarizes properties of the (unique) steady state in terms of local stability.

PROPOSITION 2. *Assume interest elasticity is positive for $q \equiv 1$. Then the unique interior steady-state domestic money portfolio share d is locally unstable.*

Proof. Please see the Appendix.

Proposition 2 implies that, under "standard" assumptions, the unique steady-state d is unstable. Suppose the share of domestic money demand at $t = 0$ is denoted by d_0. If $d_0 < d$ then the economy will tend to a state in which only foreign money will survive as store-of-value. Alternatively, if $d_0 > d$, then domestic money will eventually replace foreign money as store-of-value. Therefore, in this model, both Gresham's Law (which states that "bad" money drives out "good" money) and its reverse are possible depending upon initial conditions. One other implication of the unstable stationary equilibrium is with regard to the potential role of government policy. If h is interpreted as a policy variable then an increase in h will lower steady-state d thereby making it more likely that domestic money eventually emerges as the sole store-of-value.

So far, we have assumed that confidence in domestic money is static and exogenous. The model predicts that, unless the economy starts trivially from the steady-state (i.e., $d_0 = d$), the economy tends to a state in which one money completely replaces the other as the sole store-of-value. This prediction is somewhat unattractive especially when reconciled with empirical observations of CS whereby robust dual-money situations are the norm when domestic money lacks confidence. In the next section, we relax the assumption of exogenous beliefs by allowing confidence in domestic money to evolve in accordance with expected economy-wide relative money demand. As we shall see, these modifications yield more interesting and realistic predictions in terms of the existence of and convergence towards steady-state equilibria.

2.3 Currency Substitution with Dynamic Expectations

In this section, we allow for endogeniety of beliefs. We propose that lack of confidence in domestic money is *not* static but rather adjusts to changes in economic fundamentals. One plausible characterization of dynamic beliefs that we consider is that agents gain confidence in domestic money as more of it is expected to be used in the economy. The rationale for considering this sort of a relationship is simple: an increase in aggregate domestic money demand increases the inflation tax base and makes a seigniorage-induced hyperinflation less likely. Furthermore, as more people are expected to hold domestic money, agents perceive that it will be easier to conduct money-for-output transactions denominated in the domestic currency.

Mathematically, we characterize endogenous beliefs as follows. With population normalized to one, d_t represents the (real) economy-wide demand for domestic money. Endogenous beliefs would imply that confidence q is an increasing function of expected future real domestic money balances. In other terms, $q_t = q(d_{t+1})$ with $q(0) = 0$, $q(\overline{d}) = 1$, $0 \leq q(d_{t+1}) \leq 1$, and $q'(d_{t+1}) > 0$ for $0 < q(d_{t+1}) < 1$. Intuitively, this implies that if all economy-wide savings are expected to be held as foreign money, then it is certain that domestic money will not be valued today. If, on the other hand, domestic money demand is expected to equal or be greater than some upper bound $\overline{d} \in (0, 1)$ then agents will have full confidence in domestic money. With expected domestic money demand being in the interval $d_{t+1} \in (0, \overline{d})$, confidence in the value of domestic money *decreases* when there is an expectation that CS will rise in the economy.[25]

This characterization of beliefs has a straightforward interpretation as a learning mechanism whereby agents update confidence in domestic money based upon expectations of its future circulation in the economy. If the use of dollars is expected to rise in the economy, agents place lower confidence in pesos today (and vice-versa).[26] Intuition might suggest that, in the absence of a inflation, the economy should converge to a state in which domestic

[25] This probabilistic framework is somewhat similar to that in Bertocchi and Wang (1995). They present a one-money overlapping generations model; there is a certain probability that money will lose value in the subsequent period. But this probability evolves as a function of aggregate real money balances in the economy: a wider circulation of money in the present suggests a greater likelihood that the currency will be valued in the future. Agents, therefore, adjust their beliefs regarding the value of money in the future based upon the observation of aggregate real money balances in the present.

[26] Matsuyama *et al.* (1993) have implemented a similar idea in a search-theoretic monetary model with two countries each of which issues its own currency. In their model, as in ours, agents are more willing to accept a certain currency if they believe others to be willing to do the same in the future. But, unlike our paper, in their model it is the relative size of the two economies and their degree of integration which are determinants of the extent of circulation of a given currency in both countries.

money eventually replaces foreign money as store-of-value. Unfortunately, coordination failure precludes that possibility. Lack of domestic inflation will be associated with a long-term entrenchment of foreign money demand even if we allow agents to update expectations.

With dynamic beliefs, the equation of motion describing the evolution of domestic money balances over time can be rewritten as:

$$q(d_{t+1})\left[h\frac{d_{t+1}}{d_t}(1-z)-1\right]u'\left[d_{t+1}(1-z)\omega+\frac{(1-d_t)\omega}{h}\right]=[1-q(d_{t+1})]u'\left[\frac{(1-d_t)\omega}{h}\right] \quad (8)$$

A steady-state value for d is obtained by solving:

$$\frac{q(d)}{[1-q(d)]}=\frac{1}{[h(1-z)-1]}\frac{u'(c^-)}{u'(c^+)} \quad (9)$$

where c^+ and c^- are given by (6) and (7), respectively. Under exogenous probability, the left-hand side of (9) is an exogenously-given constant. With dynamic endogenous beliefs, it is a function of d. Proposition 3 summarizes conditions for the existence of a stationary equilibrium.

PROPOSITION 3. *Under the assumptions regarding $q(\cdot)$, there exist multiple stationary equilibria with $d \in (0,1)$.*

Proof. Rewriting (9) as

$$q(d)=\frac{u'(c^-)}{[h(1-z)-1]u'(c^+)+u'(c^-)} \quad (10)$$

Under the assumptions regarding probability, the left-hand side of (10) rises monotonically from zero to one as d rises from zero to $\overline{d}$. The right-hand side increases monotonically from $1/[h(1-z)]$ to $1/\left\{E[h(1-z)-1]+1\right\}$ in the same interval, where

$$E\equiv\frac{u'\left[\overline{d}\omega(1-z)+\frac{(1-\overline{d})\omega}{h}\right]}{u'\left[\frac{(1-\overline{d})\omega}{h}\right]}<1$$

An odd number of interior stationary equilibrium will always exists which satisfy $q(d) > 1/[h(1-z)]$ and $z \in [0,(h-1)/h)$.[27]

We are guaranteed existence of a stationary equilibrium but not uniqueness. Figure 6 plots one possibility for the two sides of equation (10) when the equilibrium could be unique.

[27]We are excluding the possibility that the left-hand side of (10) is tangential to the right-hand side. If those are included then the number of interior stationary equilibria need not be odd.

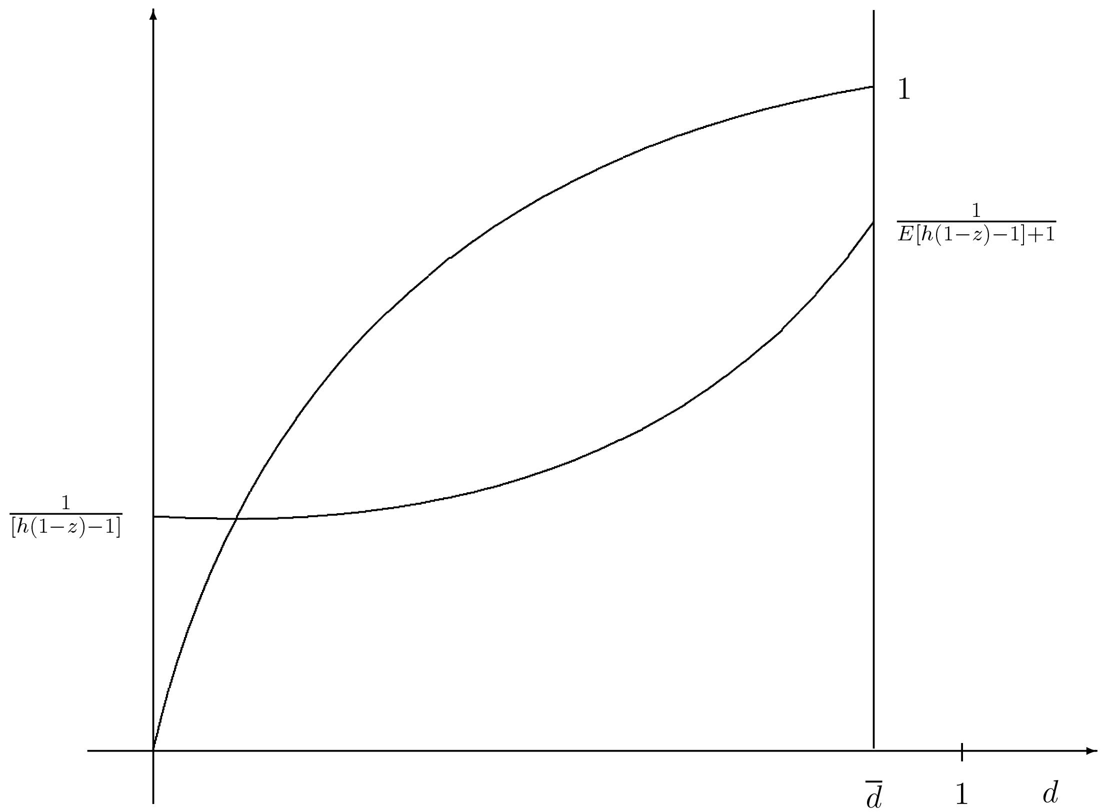


Figure 6: Currency Substitution with Dynamic Beliefs

We can rank the multiple equilibria and their implied values of d in terms of welfare as measured by expected utility. Steady-state expected utility is given by

$$U = q(d)u(c^+) + [1 - q(d)]u(c^-) \tag{11}$$

Differentiating (11) with respect to d yields

$$\frac{\partial U}{\partial d} = q'(d)\left[u(c^+) - u(c^-)\right] + \frac{[h(1-z)-1]\omega q(d)}{h}u'(c^+) - \frac{\omega[1-q(d)]}{h}u'(c^-)$$

From equation (9) we have the condition that in a steady-state equilibrium $q(d)(h-1)u'(c^+) = [1-q(d)]u'(c^-)$. Therefore:

$$\frac{\partial U}{\partial d} = q'(d)\left[u(c^+) - u(c^-)\right] > 0$$

This implies that an economy having a higher share of domestic money as savings in steady-state will have greater welfare as measured by expected utility. The multiple stationary equilibria can therefore be Pareto-ranked on the basis of the associated share of domestic money circulating in the economy. Corollary 3.1, summarized below, underscores the importance of institutional innovations (such as currency boards which issue credibly "backed" money) that could result in greater welfare by augmenting confidence in domestic money and helping overcome the coordination failure problem.

COROLLARY 3.1. *The multiple steady-states in this economy can be Pareto-ranked with low levels of confidence in domestic money being associated with lower welfare.*

2.3.1 Dynamics

Dynamics with endogenous beliefs are difficult to characterize without specifying the precise functional form of $q(\cdot)$. In general, though, if $q(\cdot)$ is concave (i.e., beliefs are not too sensitive) then we can derive the following proposition.

PROPOSITION 4 *Assume, (i) $q(\cdot)$ is increasing and concave and, (ii) interest elasticity is positive when $q \equiv 1$. Suppose $d^1 < d^2 < ... < d^{2n+1}$ are n stationary equilibria.*

- *if $d_0 < d^1$, then $d_t \to d^1$ as $t \to \infty$.*
- *if $d^{2i-1} < d_0 < d^{2i}$, then $d_t \to d^{2i-1}$ as $t \to \infty$, for $1 \leq i \leq n$.*
- *if $d^{2i} < d_0 < d^{2i+1}$, then $d_t \to d^{2i+1}$ as $t \to \infty$, for $1 \leq i \leq n$.*
- *if $d_0 > d^{2n+1}$, then $d_t \to d^{2n+1}$ as $t \to \infty$.*

Proof. Local stability is given by:

$$\left[\frac{\partial d_{t+1}}{\partial d_t}\right]_{d_t=d} = \frac{C - \frac{\omega}{h}[1-q(d)]u''(c^-)}{D'}$$

where c^+ and c^- are given in equations (6) and (7). And C equals

$$C \equiv \frac{h(1-z)q(d)}{d}u'(c^+) + q(d)\frac{\omega}{h}[h(1-z)-1]u''(c^+) > 0$$

and

$$D' \equiv \frac{h(1-z)q(d)}{d}u'(c^+) + q(d)(1-z)\omega[h(1-z)-1]u''(c^+) + q'(d)\left\{[h(1-z)-1]u'(c^+)\right\} + q'(d)u'(c^-)$$

Under our assumptions, the derivative of d_{t+1} with respect to d_t evaluated at the steady state can *never* equal one. For the slope evaluated at the steady-state to equal one, it must be true that:

$$-[h(1-z)-1]\left\{u'(c^+) + \frac{[h(1-z)-1]}{h}\frac{q(d)}{q'(d)}\omega u''(c^+)\right\} = u'(c^-) + \frac{\omega}{h}\frac{[1-q(d)]}{q'(d)}u''(c^-)$$

The right-hand side is always positive. This can be seen as follows. From the positive interest elasticity condition we have:

$$u'(c^-) + \frac{\omega}{h}(1-d)u''(c^-) > 0$$

From concavity of and monotonicity beliefs we have

$$(\overline{d} - d)q'(d) > [1-q(d)]$$

which implies that

$$(1-d)q'(d) > [1-q(d)]$$

since by assumption $\overline{d} < 1$. Therefore, with concave beliefs,

$$u'(c^-) + \frac{\omega}{h}\frac{[1-q(d)]}{q'(d)}u''(c^-) > 0$$

For equality to hold, the left-hand side must also be positive or

$$u'(c^+) < -\frac{[h(1-z)-1]}{h}\frac{q(d)}{q'(d)}\omega u''(c^+)$$

Again, from the positive interest elasticity condition, we have

$$u'(c^+) > -\frac{[h(1-z)-1]}{h}d\omega u''(c^+)$$

From concavity and monotonicity, we now that

$$-dq'(d) > -q(d)$$

Therefore, we can conclude that:

$$u'(c^+) > -\frac{[h(1-z)-1]}{h}\frac{q(d)}{q'(d)}\omega u''(c^+)$$

Therefore, the left-hand side is never positive so the steady-state derivative slope is *never* equal one. Also, from the equation of motion, at $d_t = 0$ weh have d_{t+1} also equal to zero. Also, $d_t > \overline{d}$ when $d_{t+1} = \overline{d}$. Therefore, with one interior steady-state, dynamics can be characterized as in Figure 7. As can be seen, the unique steady-state will be locally stable. Figure 8 depicts the case with three steady-states: the middle steady-state will be locally unstable.

Proposition 4 implies that a unique interior steady-state, if extant, will be locally stable. If there are three steady-states, then the middle one will be locally unstable. Therefore, given initial conditions, the economy will always converge to an interior steady-state. Lack of confidence in domestic money, when influenced by speculation regarding the future circulation of domestic money, always leads us to a dual-money equilibrium. Confidence in domestic money will remain partial even in the long run *despite* the adjustment in expectations. The multiplicity of equilibria is a direct result from the externality in expectation formation which leads to the possibility for coordination failure.

2.4 Persistence of Currency Substitution

One intriguing stylized fact regarding CS is often characterized as "persistence" or "hysteresis": abatement of inflation does not restore the demand for domestic money. As mentioned in the Introduction, there are myriad explanations for this phenomenon. In our paper, psychological and speculative factors are central in determining the demand for foreign money. We find that a decline in the money growth rate z (and hence inflation) *does not eliminate the demand for foreign money* when beliefs are allowed to adjust based upon expectations of future relative money demand. Therefore, one contribution afforded by our model is the demonstration of a certain form of long-term persistence in CS that does not depend solely upon transactions costs as an explanation.

From the steady-state equilibrium condition, we can derive the following proposition.

PROPOSITION 5. *Assume a positive interest elasticity for $q \equiv 1$. Than a decline in domestic money growth z does not eliminate currency substitution.*

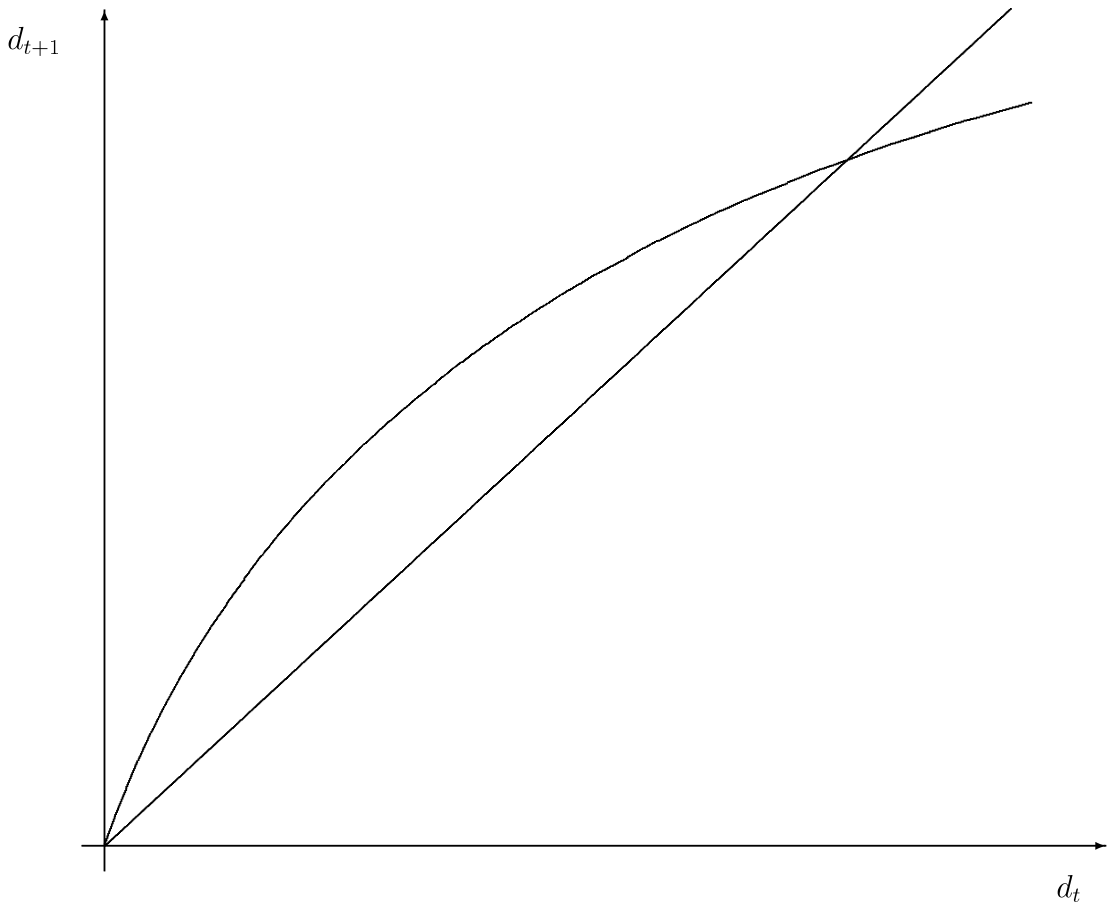


Figure 7: Dynamics with Concave Beliefs

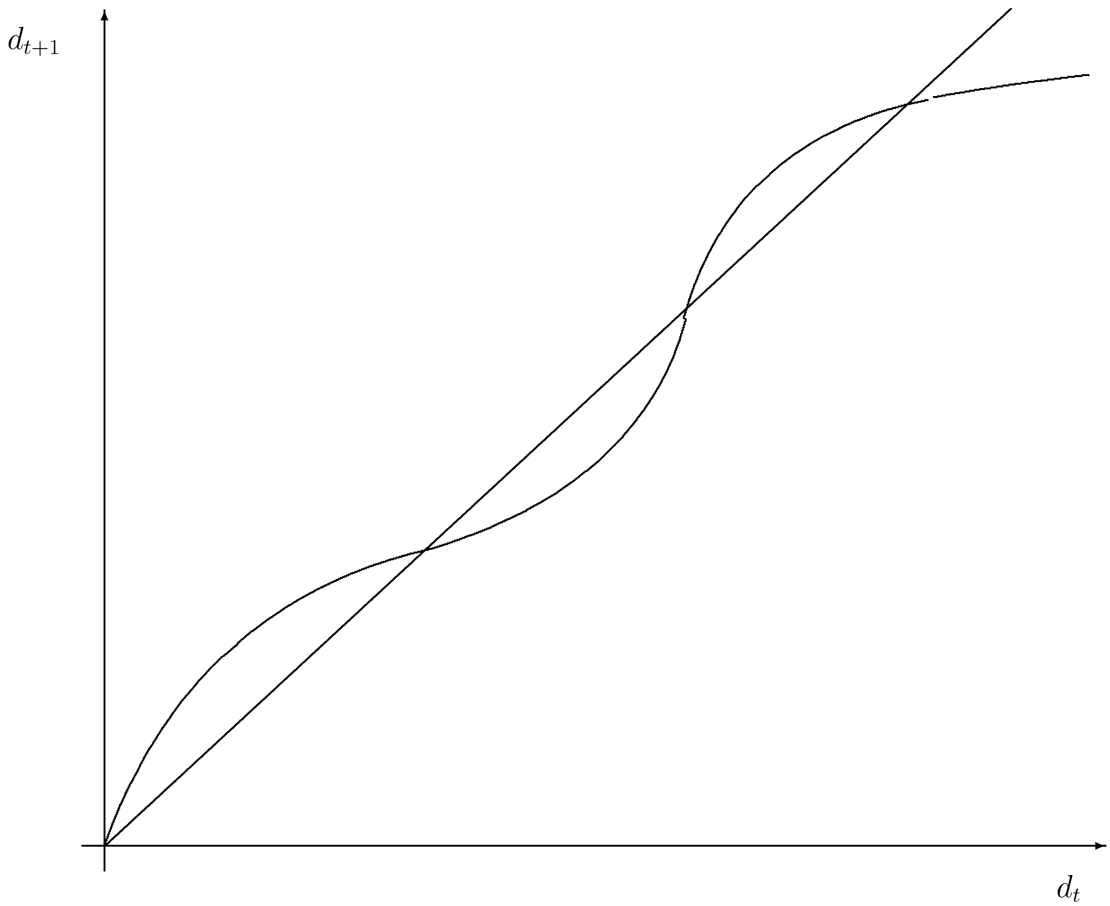


Figure 8: Dynamics with Concave Beliefs

Proof. The first-order equilibrium condition is given by:

$$q(d) = \frac{u'(c^-)}{[h(1-z)-1]u'(c^+) + u'(c^-)}$$

As can be seen, the right-hand side is a function of z. Differentiating the right-hand side with respect to z gives us:

$$\frac{u'(c^-)\left\{hu'(c^+) + [h(1-z)-1]u''(c^+)\right\}}{\left\{[h(1-z)-1]u'(c^+) + u'(c^-)\right\}^2} > 0$$

which is positive under the assumption of a positive interest elasticity. Figure 9 plots one possibility for a new steady- state.

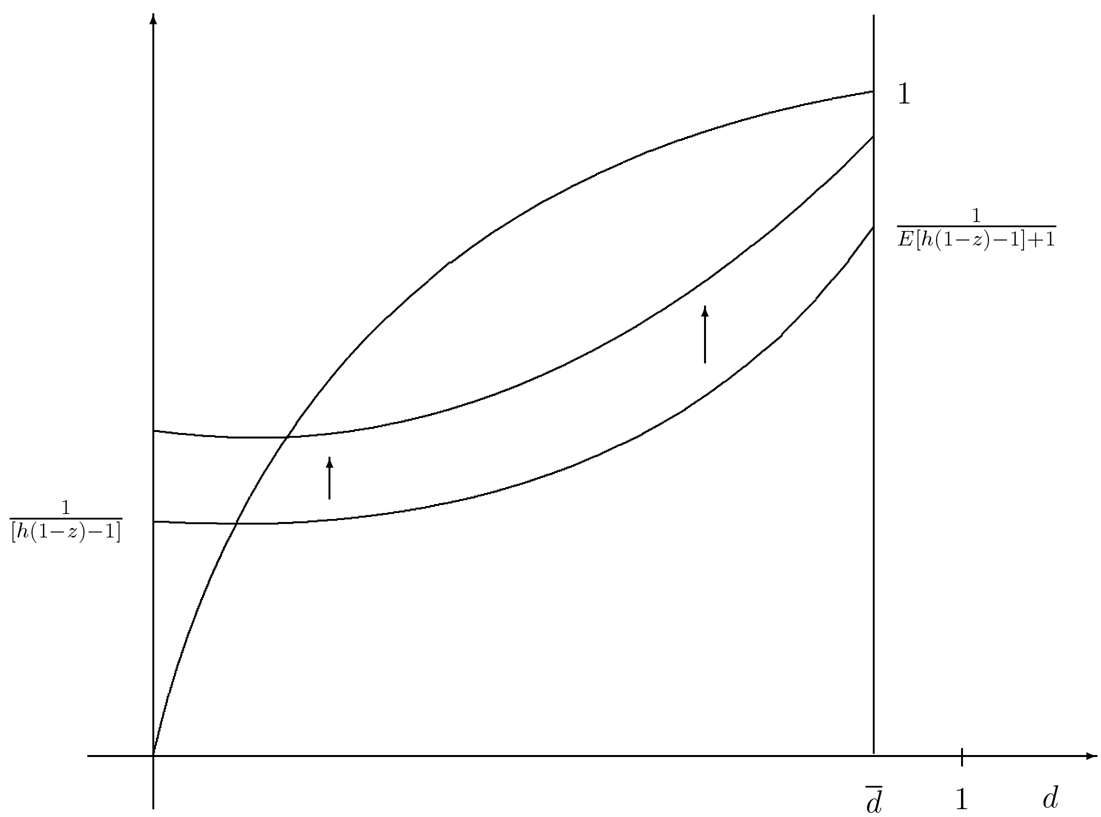


Figure 9: Persistence of Currency Substitution

Proposition 5 implies that a decline in money growth z decreases the right-hand schedule giving us a lower steady-state values of d if, for example, the steady-state is unique. Even if inflation drops to zero, we are guaranteed the existence of interior equilibria admitting some degree of CS. The stability properties remain the same as earlier. Since lack of confidence is related to expectations of future domestic money demand, a decline in current inflation does not eliminate currency substitution. As mentioned earlier, this is a result that has been extensively documented in the empirical literature on CS. Our model implies that persistence in CS is theoretical demonstrable on the basis of expectation-adjustment processes such as a speculative updating of expectations. A mechanism for coordinating expectations or institutional innovations would be necessary to overcome the lack of confidence in domestic money. A decline in inflation alone is *not* sufficient to eliminate CS.

2.5 Conclusions

This paper has demonstrated one explanation of persistence in CS that underscores the importance of speculative behavior. In doing so, we complement other explanations in the literature that have not examined the possible psychological underpinnings of the phenomenon. If beliefs regarding the future valuation of domestic money are static and exogenous, then a dual-money equilibrium exists only when the economy starts trivially from the steady-state. Any other initial condition will lead the economy towards a situation where only one money survives as store-of-value. If agents gain confidence in domestic money when they expect more of it to be circulating in real terms, then dual-equilibria steady-states always exist. The economy generally converges to a state in which two monies circulate as stores-of-value. This robustness in the demand for foreign money is not contingent upon domestic inflation: even if inflation drops to zero, CS will not be eliminated.

2.6 Appendix

This Appendix details some of the proofs of propositions in the main text.

PROPOSITION 1. The right-hand side of (5) is a monotonically increasing function of d. This can be seen by differentiating the right-hand side of (5) with respect to d:

$$\frac{-\omega u'(c^+)u''(c^-) - [h(1-z)-1]\omega u'(c^-)u''(c^+)}{h[h(1-z)-1][u'(c^+)]^2} > 0$$

PROPOSITION 2. Differentiating the equation of motion of relative money demand (4) with respect to d_t and evaluating $\partial d_{t+1}/\partial d_t$ at the steady-state yields:

$$\left[\frac{\partial d_{t+1}}{\partial d_t}\right]_{d_t=d} = \frac{C - \frac{\omega}{h}[1-q(d)]u''(c^-)}{D} > 1$$

where c^+ and c^- are given in equations (6) and (7), respectively. And C equals

$$C \equiv \frac{h(1-z)q(d)}{d}u'(c^+) + q(d)\frac{\omega}{h}[h(1-z)-1]u''(c^+) > 0$$

and

$$D \equiv \frac{h(1-z)q(d)}{d}u'(c^+) + q(d)(1-z)\omega[h(1-z)-1]u''(c^+) > 0$$

The expressions denoted by C and D are positive when the interest elasticity of domestic money savings is positive. Therefore, the steady-state is locally unstable.

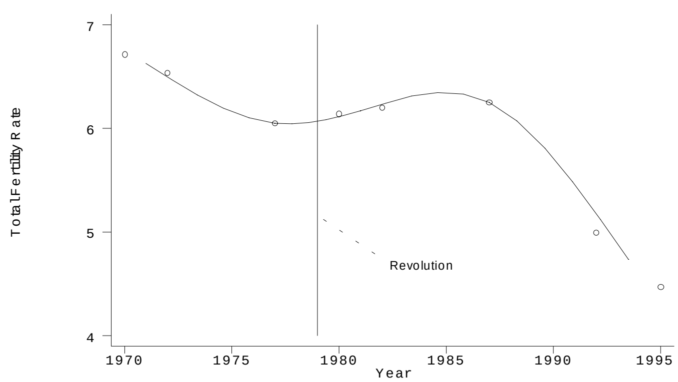
PROPOSITION 3. The first derivative of the right-hand side of (10) is given by:

$$\frac{\frac{-\omega}{h}[h(1-z)-1]u'(c^+)u''(c^-) - \frac{\omega}{h}[h(1-z)-1]^2u'(c^-)u''(c^+)}{\{[h(1-z)-1]u'(c^+) + u'(c^-)\}^2} > 0$$

3 Intertemporal Substitution and Fertility Dynamics in Post-Revolution Iran

3.1 Introduction

The demographic experience of Iran after the revolution poses an interesting puzzle. A brief increase in period fertility after the 1979 revolution interrupted a trend of decline that had started in the 1950s. This increase in fertility led to speculation of a "stall" in Iran's demographic transition.[28] The rise in fertility, however, appears to have lasted only a few years: in the late 1980s fertility decline resumed its course at an even faster pace. The Total Fertility Rate (TFR) dropped by almost 30% from 6.2 in 1987 to 4.5 in 1995.[29] This rapid decline has been very surprising, especially given the experience of other developing countries during their demographic transitions.[30] Figure 10 plots the TFR – in units of births per woman – from 1970 to 1995.



Source: World Bank (1997)

Figure 10: Total Fertility Rate in Iran: 1970-1995

The fertility increase in Iran in the aftermath of the revolution is generally understood to be a response to pro-natalist policies of the Islamic government. The leaders of the

[28]See Aghajanian (1991). Demographic transition refers to the process whereby countries move from a situation of high birth and death rates to one of low rates. Typically, as development occurs, death rates fall more rapidly than do birth rates leading to rapid population growth. Later, as birth rates also decline, population growth declines.

[29]The TFR is the sum of age-specific fertility rates in a given year. It is the total number of children a woman would have if she were subject to the period fertility rates of women that year.

[30]Bulatao and Richardson (1994) contrast the rapid fall of Iranian fertility with the relatively slower pace of decline in Egypt and Turkey.

revolution, the Islamic clergy, expounded on virtues of a large family and, in particular, emphasized the role of women in society as mother and homemaker.[31] Early marriages were strongly endorsed by the government and the legal age at marriage was lowered from 18 to 9. Family planning was de-emphasized and the Family Planning Council was dissolved. Furthermore, Iran officially discontinued the previous government's fertility control policy and contraceptive supply was severely restricted.[32] Less than a year after the revolution the war with Iraq started which brought additional implicit and explicit statements from the leadership that elevated the having of large families to national duty. War-induced rationing of a wide array of consumer goods provided additional incentives for larger families as the rations were based on family size, with children receiving equal rations to adults. In addition to these measures that affected the costs and benefits of children, the revolution appears to have reduced the opportunity cost of time of parents, in particular of women, thereby encouraging fertility. Restrictions placed on public places reduced the value of leisure outside the home that competed with children such as movies, television, and restaurants. More importantly, women were discouraged from seeking formal employment. Women were barred from participating in several professions, including in the legal sphere and in upper-level government positions. Various other policies such as early retirement schemes and closure of day-care facilities were enacted to encourage women to stay at home.[33] Perhaps as a result of these measures, labor force participation of women declined by 20%.

Few studies have addressed the post-revolution fluctuations in Iranian fertility. Salehi-Isfahani (1997) and Tabibian and Mehryar (1997) have argued that factors related to the revolution and the war were responsible for the rise in fertility in the early 1980s. In later years, as the effects from the revolution and the war declined, fertility began to decline. Paydarfar and Moini (1995) underscore the elimination of the family planning as a significant factor contributing to the rise in fertility immediately following the revolution. Bulatao and Richardson (1994) also highlight the impact of government policies on Iranian fertility fluctuations. Mansoorian and Rajulton (1993) have examined the effect of age at marriage and education on the relative risk of early births before and after the revolution.

Our paper explores Iranian fertility fluctuations in greater detail using household survey data. Unlike previous studies, we present evidence that suggests that the changes in Iranian fertility since the revolution were in part a *birth timing* phenomenon: cohort fertility (i.e., desired lifetime family size) has no doubt fallen, but not by as much as the 2 births indicated by the TFR. The fertility increase which immediately followed the revolution of 1979 appears to have been a response to a temporary reduction in the cost of children, a longer version of a "blackout" during which couples chose to have births rather than participate in the labor market or in leisure activities in public spaces. This appears to have caused some births that might have otherwise occurred in the latter part of the decade to happen early.

[31]See Paydarfar and Moini (1995) for additional details.
[32]See Aghajanian (1996).
[33]See Moghadam (1988).

Thus the question we ask in this paper is: do changes in TFR represent changes in lifetime fertility, or are they the result of intertemporal substitution? As might be expected, demographic projections for labor market and education policies are very sensitive to the resolution of this question. In addition, there are important implications for population control policies as well as for the age distribution of the population in the future. If it can be established that there was indeed some intertemporal substitution, it could explain the rapid pace of fertility decline which is at odds with the experience of other developing countries in demographic transition. Furthermore, this would imply that fertility rates in the near future may not continue to fall as rapidly, and indeed may rise a bit to offset the "corrective" decline. In this regard, Iran's experience is more in line with the demographic experience of several industrialized economies following the Second World War whereby sharp fluctuations in period birth rates were observed even though completed fertility had been falling steadily.[34] Hence, the road ahead, before the demographic transition in Iran is completed, may be longer than it appears following the dramatic decline in TFR in the 1990s.

If data spanning long durations were available and the eventual completed fertility of all cohorts contributing to the TFR in a given year known, then changes in TFR can easily be decomposed into those reflecting changes in completed fertility and those reflecting birth timing. A demonstration of this decomposition using historical US data is found in a seminal paper by Butz and Ward (1979). In order to use their technique to analyze *current* TFR changes, however, projections of completed fertility are required. In their paper, these projections are based upon current and expected future wages as well as other variables influencing the cost of births.[35] Using data from the US from 1949-75, they determine that wage increases that were expected to occur in the near future depressed current fertility, whereas those expected to occur further in the future had a smaller negative effect. They interpret this as evidence of intertemporal substitution. An alternative to the Butz-Ward approach of forecasting completed fertility to analyze period fertility fluctuations is to utilize a proxy. Cigno and Ermisch (1989) and Barmby and Cigno (1990), for instance, use completed fertility after 10 years of marriage as an indicator of desired family size. In the former paper, tempo of fertility is captured by the proportion of fertility at 10 years which is completed during the first 3 to 4 years of marriage. In the latter paper, the probability of a birth in each of the first 10 years of marriage is estimated. Using a combination of cross-section survey data and time-series data on information regarding the macro-level environment facing women in the UK, they find that a general rise in women's wages lengthened the expected time to first birth (change in tempo) and also reduced expected completed fertility. They argue that rising wages, indicative of a greater rate of return to human capital, induced

[34] See Hopflinger (1984). Cigno (1991) argues that the baby boom in the UK during the 1950s and 1960s was a result of an increase in the tempo of fertility as women rapidly accumulated human capital and married later. They tended to have a fewer total number of children, but had them sooner after marriage. In the 1970s, the tempo of fertility fell as labor productivity rose and women's labor force participation increased.

[35] See also Ward and Butz (1980).

intertemporal substitutions away from early parenthood.[36]

Most of the above-mentioned studies analyzing fluctuations in fertility accord a central role to the effects of women's wages and labor force participation on childbearing. It is important to note that in Iran's case, however, the "blackout" effect of the revolution was not limited to the impact on women's economic status. There was, in general, a decline in the value of leisure outside the household. In addition, as mentioned earlier, there were important ideological, sociological, and institutional changes that contributed to a reduction in the cost of children.

In this paper, we use duration analysis of survey data collected in 1987 and 1995 to analyze changes in fertility. Analysis of data reveals that post-revolution marriage cohorts, when compared with pre-revolution cohorts, were more likely to have births sooner after marriage. Furthermore, there is evidence of temporal adjustment in fertility behavior: in later marriage years – concomitant with the unraveling of the policies adopted during the revolution and the war – these cohorts compensated by having relatively fewer births. The revolution may well have been a transient economic shock which temporarily depressed the intertemporal relative "price" of children and caused adjustment in fertility patterns which, at least *ex post*, is suggestive of intertemporal substitution.[37]

The remainder of the paper is organized as follows. Section 2 discusses fertility in post-revolution Iran. Section 3 outlines our data sources. Section 4 details the econometric model used in the paper. Section 5 summarizes the results from model estimation. Section 6 concludes with a brief discussion.

3.2 Fertility in Post-Revolution Iran

A key premise of this paper is that after the revolution the process of fertility decline was briefly reversed before continuing its course in the 1990s. The broad picture of a rise and fall in fertility gleaned from the intercensal rates of population growth supports this view. The rate of growth fell from 3.1% for the 1956-66 period to 2.7% for 1966-76, but unexpectedly increased to 3.8% during the 1976-86 period. Correspondingly, the share of 0-4 year olds in the population fell from 17.6% in 1966 to 16.1% in 1976, but increased to 18.2% in 1986.[38] The first accurate sign of a turnaround was provided by the 1991 national population survey. The growth rate for 1986-91 dropped to 3.2%, and the share of 0-4 year olds fell to an all time low of 14.6% in 1991. The latter indicated a rapid decline in fertility. Since then,

[36]This effect is similar to a decline in early investment caused by an increase in interest rates in typical capital accumulation models.

[37]An adjustment in birth timing – which leaves overall desired family size unchanged – is consistent with the predictions from a two-period theoretical model in which the substitution effect resulting from the decline in the intertemporal relative "price" of children dominates the income effect. See Appendix A for a simple theoretical exposition.

[38]Although the size of this age group has never been accurately reported, the phenomenal increase in the latter intercensal period is indication of increased population growth.

annual surveys conducted by the Ministry of Health in 1992-95 show a steady drop in the growth rate from 2.7% to 1.75% per year.

Estimates of fertility based on census and survey data disagree on the extent of the fluctuations in fertility. Bulatao and Richardson (1994) present various estimates from census and survey data which show a decreasing trend until 1976, followed by an increase until 1986 and then a decline to a low level of 3.3 in 1993. Although there is a wide range for the mid-1980s, from 5.6 in 1985 to 7.7 in 1986, these data are consistent with the idea of a rise and fall in fertility. Hill (1994), who carefully examined the 1986 and 1991 population data, also supports the view of an increase in the birth rate in the early 1980s followed by a sharp drop – of as much as 40% – from around 1986 to the early 1990s. Thus, on balance, various studies support the picture presented in Figure 10.

3.2.1 Changes in Age at Marriage

Further support for a reversal in fertility decline is evident from marriage data. The mean age at first marriage for women, which was increasing from 1966 to 1976, came to a halt after the revolution, resuming its course thereafter (see Table 1). The same pattern is observed in the proportion of women married aged 15-19 which registered an actual increase between 1976 and 1986. For women aged 20-24, the proportion married did not increase but it did slow down considerably after the revolution. Evidence from the 1987 and 1992 household surveys show a similar upward trend in age at marriage.[39]

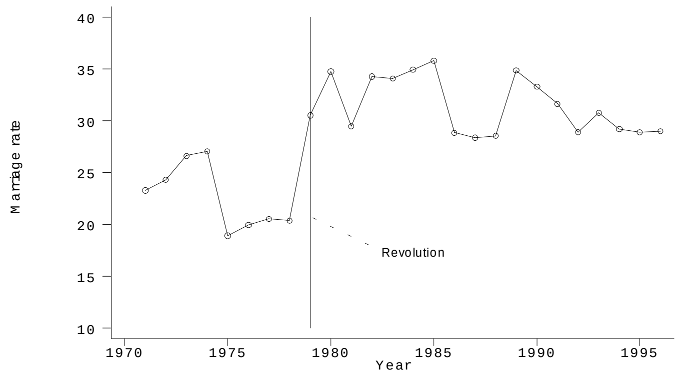
Table 1. Age of First Marriage.[40]

Year	Mean Age at First Marriage	Proportion Married	
		15-19	20-24
1966	18.7	46.8	86.7
1976	19.7	34.1	78.6
1986	19.9	36.8	74.6
1991	20.9	25.6	67.2
1996	22.4	18.6	60.7

Data on the annual number of marriages registered shows a remarkable increase in the 12 months immediately following the revolution (see Figure 11).

This increase can be attributed to strong support by the Islamic government for marriage on the one hand, and strict rules against contacts between unmarried men and women on the other. This is consistent with our notion of a “blackout” as the cause for the rise in fertility.

[39]See Salehi-Isfahani (1996).



Source: Statistical Center of Iran Yearbook (Various Years)

Figure 11: Number of Marriages per 1000 Women Aged 15-64 in Iran: 1971-1996

3.3 Data

Data for our analysis are derived from two panel surveys of Social and Economic Characteristics of Households in Iran (SECHI) collected by the Statistical Center of Iran during 1987-89 and 1992-95. In each survey, about 5,000 households were followed over the time period of two and three years, respectively. The data sets are unique in Iran in that they contain information on both economic and demographic variables.

Our analytical sample is constructed from the first round of the survey data in 1987 and the last round in 1995. A retrospective birth history was then constructed based upon information regarding the year of marriage of the parents, number of children born to the mother in the household, as well as the birth year of children living in the household. There were two problems that were encountered in constructing retrospective birth histories. First, birth dates of children living outside the household were not available in the data. Secondly, birth dates of deceased children were also unknown (although the number of deceased children was known). In order to minimize the effects of the first problem, we focus attention on marriage year cohorts with marriage durations of less than 18 years at the time of survey. One limitation of doing this is that we were unable to assess the fertility behavior of marriage cohorts prior to 1969. However, restricting our sample to households with a maximum marriage duration of 18 years implies that the oldest child in the household would be less than 18 years old. As might be expected, the proportion of these households with children living outside the household is fairly small (less than 5%). Among these households with a maximum marriage duration of 18 years, we eliminated this small proportion which had any children living outside. There may be some bias in the results due to elimination of these households if – instead of being random – there was some sample selection problem. For instance, if households with more children were more likely to have children living outside the household, then our estimates might indicate a somewhat lower fertility than exists in

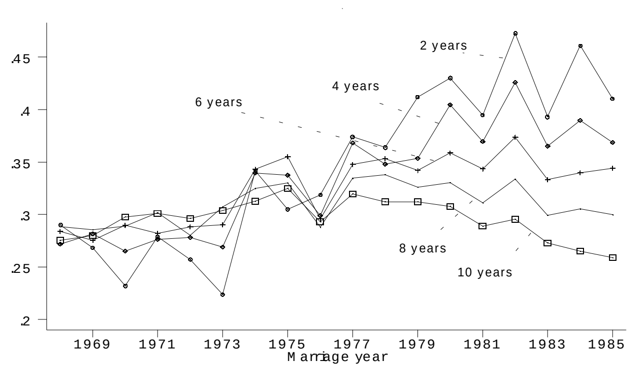


Figure 12: Average Number of Children Per Year of Marriage: 1969-1985

the population.

The problem of child mortality also merits some discussion. When looking at the number of births as indication of desired fertility, including deceased children would overestimate demand for children because fertility may in part be "replacement" of deceased children. On the other hand, not considering deceased children might lead to birth spacing estimates that are biased upwards. In our analytical sample, roughly 20% of households had deceased children. We decided to include these households in our analysis but mark them with a dummy variable that allows for the possibility that these households may have a lower likelihood of a birth in any given time period.

3.4 The Timing of Births

The simplest way to study the timing of births is to examine the rate at which households accumulate births after they get married. The substitution hypothesis states that there is a difference between the rate of accumulation among couples before and after the revolution. Using the survey data, Figure 12 depicts the average number of children per year of marriage for the different marriage cohorts up to the first 10 years of marriage. Fertility at 10 years of marriage is assumed to be a proxy for completed lifetime fertility.[41] We examine the changes in the fertility rates per year of marriage by different marriage durations. We are interested in how fertility rates per year of marriage change as marriage duration increases. We, therefore, examine fertility rates per year of marriage for marriage durations of 2,4,6,8, and 10 years.

There is a remarkable "fanning" out after the revolution. The average number of children born per year of marriage is higher in the early years of marriage for post-revolution marriage cohorts. The same cohorts when examined 8 to 10 years after marriage appear to have a lower birth rate per year of marriage. In other words, despite a lower 10 year fertility, post-

[41] This follows Cigno (1991).

revolution marriage cohorts have more children in their early marriage years. If we assume that 10 year fertility is a good proxy for completed fertility, as we do in the remainder of this paper, we notice that fertility decline from a cohort perspective is much less than the period fertility decline as measured by the TFR reported earlier.

3.4.1 Birth Timing in a Multivariate Model

The change in birth timing indicated in Figure 12 is consistent with intertemporal substitution. In general, however, secular changes in desired family size may also be associated with changes in the timing of births.[42] Hence, differences in timing before and after the revolution could be a result of secular changes in income and education, or other similar factors. Therefore, to re-examine the data in Figure 12 controlling for these factors we must resort to multivariate analysis. In our econometric model, we hold constant the effect of secular changes in education and income, and use a dummy variable for marriage year cohort to capture the effects of the remaining variables that we have identified as representing the "blackout". In a sense then, we are comparing the timing of births of women of like income and education before and after the revolution.

We model birth timing using duration analysis. There are three important advantages of using duration analysis over other techniques to model fertility. First, duration analysis provides an easy way to model birth process dynamics in a probabilistic sense, thereby enabling us to capture changes in the tempo of fertility. Secondly, duration analysis allows for censoring – i.e., adjusting for women who may not have completed their fertility at the time of the survey. This is an important consideration since the data are derived from surveys of households in 1987 and 1995, and the focus of the analysis is on the fertility behavior of marriage cohorts from 1969 through 1993. Hence, most of the women in our analytical sample had not completed their fertility at the time of survey. A third advantage of duration analysis is that it incorporates time-varying covariates.

We use a proportional hazards model for time to birth at each parity.[43] The proportional hazard model is especially useful in this regard since no parametric assumption on the shape of the baseline hazard for time to birth is imposed, and we can estimate the shape from the data and test for changes before and after the revolution. In the event of intertemporal substitution behavior following the revolution, we expect post-revolution marriage cohorts to be at greater risk of birth at lower parities, and at lower risk of birth at higher parities when compared with those married before the revolution (after controlling for the effects of secular changes). This would indicate an increase in the tempo of fertility following marriage, with a compensating decline in later marriage years.[44]

[42] For example, Cigno (1991) has argued that higher levels of human capital at marriage for women lead to lower desired family sizes but raise the tempo, resulting in bunching of children sooner after marriage.

[43] By parity we mean number of existing children. Hence, parity is 0 at marriage, 1 after the birth of the first child, and so on.

[44] This framework to assess changes in birth timing has been used by others. A recent study on US fertility

More formally, we assume that a woman becomes at risk of first birth at the time of marriage, at risk of second birth after her first birth, and so on. The hazard of a birth at any given parity h_{it} for woman i at duration t is a product of two factors: a nonnegative baseline hazard function h_{0t} (left unspecified), and a linear function of covariates:

$$h_{it} = h_{0t}exp(\beta'\mathbf{x_{it}})$$

or,

$$logh_{it} = \alpha_t + \beta'\mathbf{x_{it}} \tag{1}$$

where $\alpha_t = logh_{0t}$.[45]

The data set reports only the year in which an individual got married. Hence, the duration to the event of a birth can be computed only in units of years after marriage. For instance, time to first birth for a woman is computed in terms of discrete time units $t = 1, 2, ..., 11$, where $t = 1$ corresponds to births in the same year as the marriage year, and $t = 2$ indicates a birth in the year following the year of marriage, and so on. For the purposes of this paper, the occurrence of a birth up to (and including) the tenth year of marriage ($t = 11$) is considered, after which the duration to birth is assumed to be censored. This implies that, not only is duration to birth computed in discrete time units, but that there are a large number of "ties" in the data (i.e., two or more individuals experiencing the event of a birth at apparently the same time). Hence, standard partial likelihood methods of estimation for equation (1) cannot be utilized.[46] However, an alternate estimation is elaborated following Prentice and Gloecker (1978). Suppose that a woman i becomes at risk of first birth at marriage time $t = 0$, and that T_i is a random variable denoting the underlying unobserved duration to first birth after marriage (in continuous time). After marriage time $t = 0$, she is observed at discrete intervals of time $t = 1, ..., k$ where $t = k$ is the final time of observation. Then the probability P_{it} that woman i did not have a birth up until $t - 1$ and has a birth observed at time t is the discrete-time analog of the hazard rate.[47] It can be shown that, if the data are generated by a continuous-time proportional hazards model, then the corresponding discrete-time hazard function is:

$$P_{it} = 1 - exp\{-exp[\alpha_t + \beta'\mathbf{x_{it}}]\} \tag{2}$$

where the parameters α_t for $t = 1, ..., k$ are associated with the k time intervals. Alternatively, equation (2) implies that

$$log\{-log[1 - P_{it}]\} = \alpha_t + \beta'\mathbf{x_{it}} \tag{3}$$

finds first birth probabilities to be increasing at higher ages and decreasing at lower ages since the 1960s. At the same time, the hazard of second and third birth is lower at all durations for more recent cohorts thereby indicating lower cohort fertility following the baby boom. See Hotz *et al.* (1997).

[45] If $\alpha_t = \alpha$, we get the exponential model; if $\alpha_t = \alpha t$, we have the Gompertz model; if $\alpha_t = \alpha logt$, we have the Weibull model.

[46] Standard partial likelihood estimation of (1) assumes that there is only one individual with an event at a given time t.

[47] Note that, unlike the hazard rate in continuous-time, the discrete-time hazard must lie between 0 and 1.

This is a linear model for the complementary log-log transformation of P_{it}. Details of the derivation can be found in Appendix B. An alternate model for the discrete-time hazard probability – which does not depend upon the assumption that the data are generated by a continuous-time proportional hazards model – is the logit function:

$$P_{it} = \frac{exp[\alpha_t + \beta' \mathbf{x_{it}}]}{1 + exp[\alpha_t + \beta' \mathbf{x_{it}}]} \tag{4}$$

or,

$$log\{P_{it}/(1 - P_{it})\} = \alpha_t + \beta' \mathbf{x_{it}} \tag{5}$$

Given the above formulation, the likelihood of the data for n independent individuals $(i = 1, ..., n)$ for times to first birth (or times to end of observation for those censored) is

$$L = \prod_{i=1}^{n} [Pr(T_i = t_i)]^{\delta_i} [Pr(T_i > t_i)]^{1-\delta_i}$$

where δ_i equals 1 if i is uncensored; otherwise it is 0. From the definition of conditional probability, the probability that the event occurs at time t is given by:

$$Pr(T_i = t) = P_{it} \prod_{j=1}^{t-1} (1 - P_{ij})$$

and similarly the probability that it will occur after time t is:

$$Pr(T_i > t) = \prod_{j=1}^{t} [1 - P_{ij}]$$

Hence, we have the log-likelihood function given by:

$$logL = \sum_{i=1}^{n} \delta_i log \left\{ \frac{P_{it_i}}{(1 - P_{it_i})} \right\} + \sum_{i=1}^{n} \sum_{j=1}^{t_i} log(1 - P_{ij})$$

We can now substitute for P_{it} from (2) or (4) and then maximize $logL$ with respect to α_t and β's. If we define y_{it} as a dummy variable taking the value 1 if woman i experiences an event at time t, otherwise 0, then the log-likelihood function can be written as:

$$logL = \sum_{i=1}^{n} \sum_{j=1}^{t_i} y_{it} log \left\{ \frac{P_{ij}}{(1 - P_{ij})} \right\} + \sum_{i=1}^{n} \sum_{j=1}^{t_i} log(1 - P_{ij})$$

which is the same as the log likelihood for the regression analysis of dichotomous dependent variables. Hence, discrete-time hazard models can be estimated in the same way as are models for dichotomous data. Separate observations are created for each year that the woman was observed, up to the year in which a birth occurred (or last year of observation if censored). For instance, women who had their first birth in year 1 contributed one person-year each; those having their first birth in year 4 contributed four person-years. In addition, those censored – say those not having had a birth by the (last) year 7 of observation – contributed a maximum of seven person-years. For example, in our analytical sample for time to first birth for 3,172 women, there were a total of 10,463 person-years (See Table 3). The dependent variable for each person-year was coded as 1 if the woman had a birth in that year; otherwise it was coded 0 (for no birth or censored observations).[48] In the ensuing presentation of the empirical analysis, results from both the logit model as well as the complementary log-log model are reported.[49]

3.5 Results

Estimates of the discrete-time hazard function without covariates are reported before presenting the results of a duration model with covariates. Table 3 shows the number of women who had a first birth in each of the years after marriage under consideration. An estimate of the hazard rate at each discrete time $t = 1, ..., 11$ is simply the ratio of those experiencing births at time t divided by the number at risk. For time to first birth: all women in the sample are at risk at $t = 1$; for $t = 2$, those having had a birth at $t = 1$ (or those censored) are no longer considered at risk of first birth at $t = 2$, and so on.

Table 3. Distribution of Year of First Birth
(Marriage Cohorts:1969-1993).

Years After Marriage	Number Having First Birth	Number At Risk	Baseline Hazard
1	268	3172	0.084
2	983	2904	0.338
3	834	1866	0.447
4	405	996	0.407
5	202	559	0.361
6	108	345	0.313
7	72	221	0.326
8	29	142	0.204
9	18	108	0.167
10	17	86	0.198
11	9	64	0.141
> 11	55		
Total	3172	10463	

Table 3 shows that, for those marrying in the years 1969 through 1993, the hazard function exhibits an inverted-U shape: peaking at 3 years after marriage. An alternate way of nonparametrically estimating the baseline hazard is to estimate the complementary log-log or logit formulation of the model for the hazard (as described in the previous section) as a function solely of a set of time-specific constants (i.e., α_t). In other terms, $log[-log(1-P_{it})] = \alpha_t$ and $log[P_{it}/(1-P_{it})] = \alpha_t$ are estimated. Table 4 reports the coefficient estimates

[48] The methodology elaborated follows Allison (1982).

[49] One key difference between the two formulations is that the logit model assumes that events can only occur at discrete units of time. The complementary log-log model, on the other hand, assumes that events can occur in continuous time but are only observed coarsely. See Allison (1995).

Table 4. Baseline Hazard Estimates for Time to First Birth
Marriage Cohorts:1969-1993.[50]

Variable	Complementary Log-Log	Baseline Hazard	Logit	Baseline Hazard
CONSTANT	-2.43**	0.084	-2.38**	0.084
	(0.061)		(0.064)	
t_2	1.54**	0.338	1.71**	0.338
	(0.069)		(0.075)	
t_3	1.90**	0.447	2.17**	0.447
	(0.070)		(0.079)	
t_4	1.78**	0.407	2.00**	0.407
	(0.079)		(0.091)	
t_5	1.62**	0.361	1.81**	0.361
	(0.094)		(0.109)	
t_6	1.45**	0.313	1.60**	0.313
	(0.114)		(0.132)	
t_7	1.50**	0.326	1.65**	0.326
	(0.133)		(0.157)	
t_8	0.95**	0.204	1.02**	0.204
	(0.196)		(0.218)	
t_9	0.72**	0.167	0.77**	0.167
	(0.244)		(0.266)	
t_{10}	0.91**	0.198	0.98**	0.198
	(0.250)		(0.278)	
t_{11}	0.54	0.141	0.57	0.141
	(0.339)		(0.365)	
N	10463		10463	

and the baseline hazard computed from these estimates. The baseline hazard rates in the third column of Table 4 are estimated from the complementary log-log transformation $1 - exp\{-exp(\alpha_t)\}$ for $t = 1, ..., 11$. Similarly, the baseline hazards in column 5 are computed using the logit transformation $\frac{exp(\alpha_t)}{1+exp(\alpha_t)}$. As can be seen, the estimates of the baseline hazard from the two models are identical to the ones estimated "directly" in Table 3.

Figure 13 plots estimates of the baseline hazard for time to first birth separately for two sets of marriage cohorts: pre-revolution (i.e., those married in 1969-1978), and post-revolution (i.e., those married in 1979-1993). It appears that, at least until the first 4 years of marriage, post-revolution marriage cohorts are at greater risk of first birth.

Figure 14 is a plot of the time to second birth (time measured in years since first birth). The inverted-U shape remains; however there appears to be no difference in the shape of the hazard function for pre- and post-revolution marriage cohorts.

Figure 15 shows the hazard rate for time to third birth. As can be seen, the hazard for a third birth appears to be significantly lower for post-revolution marriage cohorts.

In order to test if the difference in the baseline hazard estimates (as graphed in Figures 13,14, and 15) for the pre- and post-revolution marriage cohorts are significant, we estimate the complementary log-log and logit models with dummies for each of the time intervals, dummies for the two marriage year cohorts, and interaction terms. Table 5 reports the difference between post-revolution and pre-revolution α_t's, and a t-test of significance.

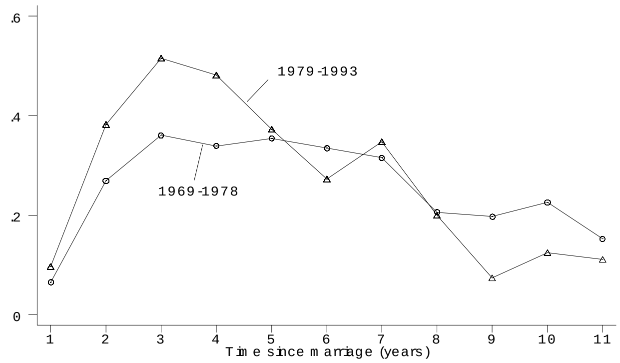


Figure 13: Baseline Hazard for Time to First Birth

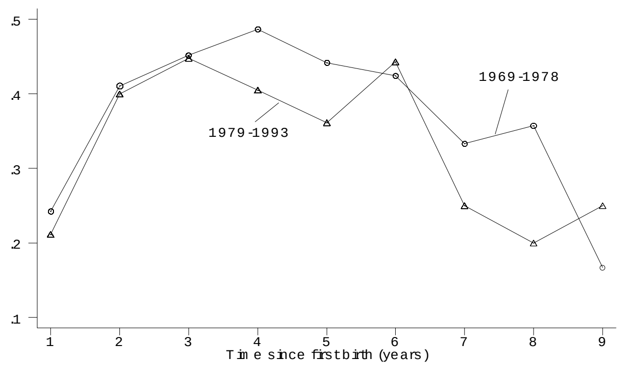


Figure 14: Baseline Hazard for Time to Second Birth

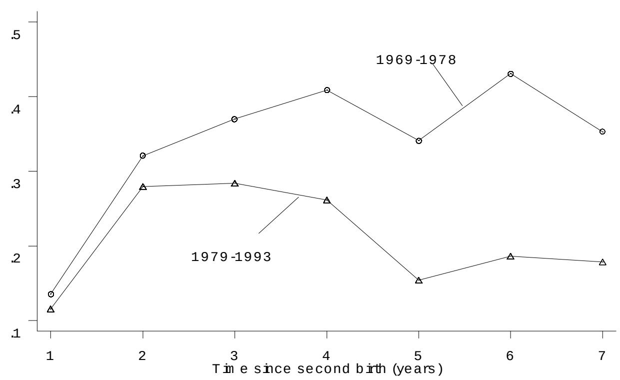


Figure 15: Baseline Hazard for Time to Third Birth

Table 5. Pre- and Post-Revolution Differences in α_t for Time to First, Second, and Third Birth Marriage Cohorts: Pre-Revolution (1969-1978) and Post-Revolution (1979-1993).[51]
(Not Controlling for Secular Changes)

Time	$0 \rightarrow 1$ ($\hat{\alpha_t} - \alpha_t$) Complementary Log-Log	Logit	$1 \rightarrow 2$ ($\hat{\alpha_t} - \alpha_t$) Complementary Log-Log	Logit	$2 \rightarrow 3$ ($\hat{\alpha_t} - \alpha_t$) Complementary Log-Log	Logit
$t = 1$	0.41**	0.43**	-0.15*	-0.17*	-0.17	-0.19
	(0.134)	(0.140)	(0.080)	(0.091)	(0.121)	(0.129)
$t = 2$	0.43**	0.51**	-0.03	-0.04	-0.16*	-0.19*
	(0.069)	(0.083)	(0.071)	(0.091)	(0.088)	(0.105)
$t = 3$	0.48**	0.63**	-0.01	-0.02	-0.32**	-0.39**
	(0.073)	(0.095)	(0.091)	(0.121)	(0.110)	(0.133)
$t = 4$	0.46**	0.59**	-0.25*	-0.33*	-0.55**	-0.67**
	(0.101)	(0.130)	(0.130)	(0.173)	(0.148)	(0.178)
$t = 5$	0.06	0.078	-0.26	-0.34	-0.91**	-1.05**
	(0.145)	(0.181)	(0.198)	(0.253)	(0.263)	(0.298)
$t = 6$	-0.25	-0.294	0.06	0.07	-1.01**	-1.20**
	(0.210)	(0.248)	(0.264)	(0.346)	(0.322)	(0.383)
$t = 7$	0.12	0.143	-0.34	-0.40	-0.79	-0.92
	(0.249)	(0.304)	(0.488)	(0.577)	(0.608)	(0.708)
$t = 8$	-0.03	-0.04	-0.68	-0.80	–	–
	(0.416)	(0.465)	(0.733)	(0.853)		
$t = 9$	-1.05	-1.12	0.45	0.51	–	–
	(0.750)	(0.786)	(1.227)	(1.366)		
$t = 10$	-0.650	-0.71	–	–	–	–
	(0.637)	(0.688)				
$t = 11$	-0.337	-0.36	–	–	–	–
	(0.802)	(0.855)				

Notice from Table 5 that post-revolution marriage cohorts were significantly at greater risk of first birth when compared with pre-revolution marriage cohorts for times $t = 1, 2, 3, 4$. There was no significant difference for times thereafter, either individually or in a joint test. For time to second birth, a joint test yielded no statistically significant difference between pre- and post-revolution cohorts for all durations since first birth. Time to third birth was significantly lower among post-revolution cohorts for most of the time since second birth ranges. A joint test on all durations also indicated a significant lower risk of third birth for those married following the revolution. In summary, Table 5 confirms the trend observed in Figure 12: those married after the revolution increased their tempo of fertility with a compensating decline in later marriage years.

We have not controlled for unobserved individual heterogeneity (akin to the error term in standard regression models) in our model. One of the problems associated with the presence of unobserved heterogeneity in the data is that it tends to introduce a negative duration dependence in the hazard function – even if none is present in the underlying data. This is because if some unobserved factors increase the risk of fertility then, over time, the sample will consist of those with lower hazard of a birth. There is no reason to believe that the distribution of unobserved factors between the pre- and post-revolution time periods changed in a systematic way. Hence, any effect from unobserved heterogeneity should disappear when we look at the difference in the hazard function.

Table 6. Abbreviations for some of the independent variables.

Variable Name	Description
URBAN	Dummy=1 if place of residence urban; 0=rural
AFM	Age at first marriage
LHHINC	Log of total household income
MORT	Dummy=1 if any child died
PMALE	Dummy=1 if one previous child male
PTWOMALE	Dummy=1 if both previous male children

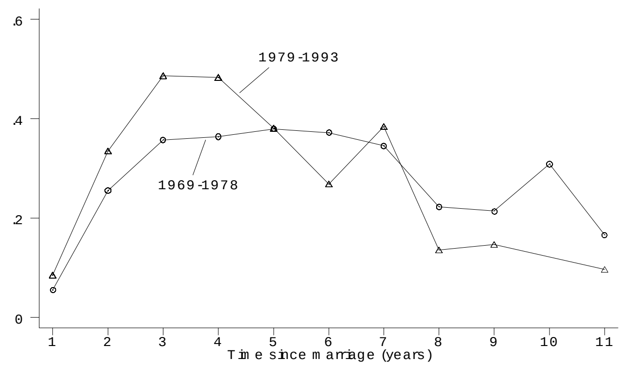


Figure 16: Baseline Hazard for Time to First Birth (Controlling for Secular Changes)

So far, we have not controlled for secular changes that may have influenced the change in birth timing following the revolution. Next, we re-estimate the baseline hazards after controlling for several explanatory variables such as age at first marriage, household income, parental education, place of residence, etc.. Table 6 reports the abbreviations for some of the independent variables used in the regressions. Marriage year cohort dummies are used to represent the "blackout" effects in the aftermath of the revolution, after controlling for secular changes.

Figures 16,17, and 18 plot the baseline hazards after controlling for secular changes. The difference in the hazard of first birth appears to be similar to that in Figures 14.

As seen in Figure 17, there appears to be some difference in the shape of the baseline hazard for time to second births when compared to Figure 14: in later durations, the hazard of second birth for post-revolution marriage cohorts is higher.

For time to third birth, the baseline hazard appears similar to that in Figure 15.

In the following, we test to see if the differences in the baseline hazards between pre- and post-revolution marriage cohorts are significant. Tables 7 and 8 report estimates from both the complementary log-log and logit formulations of the model with conditional probability of a birth being the dependent variable, and time-specific dummies and other explanatory variables on the right-hand side [i.e., equations (3) and (5)]. As in Table 5, Table 7 reports differences in α_t between post- and pre-revolution marriage cohorts derived from the time

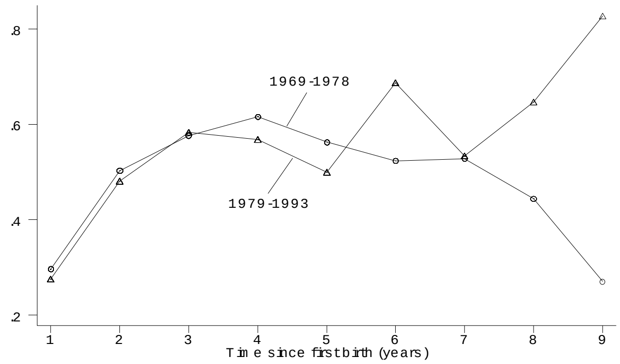


Figure 17: Baseline Hazard for Time to Second Birth (Controlling for Secular Changes)

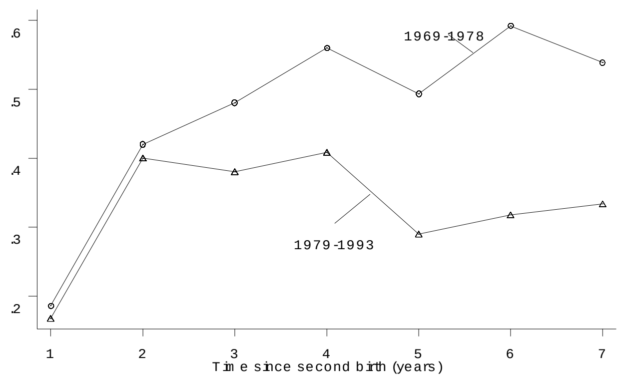


Figure 18: Baseline Hazard for Time to Third Birth (Controlling for Secular Changes)

Table 7. Pre- and Post-Revolution Differences in α_t for Time to First, Second, and Third Birth
Marriage Cohorts: Pre-Revolution (1969-1978) and Post-Revolution (1979-1993).[53]
(Controlling for Secular Changes)

Time	$0 \rightarrow 1$ ($\hat{\alpha_t} - \alpha_t$) Complementary Log-Log	Logit	$1 \rightarrow 2$ ($\hat{\alpha_t} - \alpha_t$) Complementary Log-Log	Logit	$2 \rightarrow 3$ ($\hat{\alpha_t} - \alpha_t$) Complementary Log-Log	Logit
$t = 1$	0.42**	0.43**	-0.06	-0.04	-0.08	-0.06
	(0.161)	(0.168)	(0.095)	(0.109)	(0.151)	(0.163)
$t = 2$	0.29**	0.36**	-0.03	-0.05	-0.02	-0.04
	(0.082)	(0.098)	(0.086)	(0.111)	(0.115)	(0.137)
$t = 3$	0.38**	0.53**	0.05	0.04	-0.27*	-0.34*
	(0.085)	(0.111)	(0.106)	(0.143)	(0.149)	(0.178)
$t = 4$	0.35**	0.47**	-0.10	-0.15	-0.41**	-0.51**
	(0.113)	(0.148)	(0.153)	(0.204)	(0.188)	(0.226)
$t = 5$	-0.03	0.001	-0.14	-0.20	-0.64**	-0.78**
	(0.167)	(0.211)	(0.238)	(0.302)	(0.316)	(0.360)
$t = 6$	-0.44*	-0.53*	0.49	0.63	-0.81**	-1.00**
	(0.247)	(0.294)	(0.306)	(0.403)	(0.408)	(0.477)
$t = 7$	0.08	0.13	0.05	0.07	-0.63	-0.73
	(0.293)	(0.369)	(0.511)	(0.645)	(0.654)	(0.774)
$t = 8$	-0.60	-0.69	0.62	0.71	–	–
	(0.630)	(0.688)	(0.787)	(0.995)		
$t = 9$	-0.48	-0.55	1.83	2.21	–	–
	(0.767)	(0.842)	(1.431)	(1.817)		
$t = 10$	-16.67	-17.00	–	–	–	–
	(1184.498)	(1235.893)				
$t = 11$	-0.65	-0.77	–	–	–	–
	(1.093)	(1.174)				

and marriage cohort dummies – the interpretation being a change in the risk of birth after controlling for secular changes.[52]

Table 7 indicates that, on controlling for secular changes, post-revolution marriage cohorts remain at significantly greater risk of first birth for $t = 1, 2, 3, 4$, relative to pre-revolution marriage cohorts – the magnitude of the increase being slightly less than before. There is no significant impact of the revolution on the hazard for second births. The lower risk of third births for post-revolution cohorts in Table 5 is also evident after controlling for secular changes for $t = 3, 4, 5, 6$ – with the magnitude of the decrease being lower than before. Overall, these results seem to suggest that some of the fertility fluctuations observed in Iran may be caused by secular changes (e.g., increases in women's education over time). However, there is still evidence of intertemporal adjustment in fertility after controlling for secular changes. Table 8 reports the β's for the independent variables in the regression.

As reported in Table 8, women who were relatively older at the time of marriage, and those in households with higher income, were at a greater risk of first birth. Household income does not influence the hazard rate for second and third births. Women's education, on the other hand, decreases the risk of second and third births, but does not have a significant

[52]The coefficients on the time-specific dummies are allowed to be different for pre- and post-revolution cohorts – hence yielding different α_t's for the two groups. The coefficients for variables other than the time-period dummies are constrained to be the same for both marriage year cohorts.

Table 8. Hazard Rate for Time to First, Second, and Third Birth.[54]

Variable	0 → 1 Complementary Log-Log	0 → 1 Logit	1 → 2 Complementary Log-Log	1 → 2 Logit	2 → 3 Complementary Log-Log	2 → 3 Logit
AFM	0.02**	0.02**	-0.02**	-0.02**	-0.01	-0.02
	(0.006)	(0.008)	(0.008)	(0.009)	(0.011)	(0.013)
LHHINC	0.08**	0.09**	-0.01	-0.01	0.02	0.03
	(0.018)	(0.022)	(0.021)	(0.027)	(0.030)	(0.035)
Mother's Education (Illiterate=0)						
Less than 5 years	-0.06	-0.08	-0.12	-0.15	-0.16	-0.19
	(0.075)	(0.092)	(0.084)	(0.109)	(0.102)	(0.124)
Primary	0.14**	0.18**	-0.45**	-0.55**	-0.41**	-0.49**
	(0.075)	(0.093)	(0.085)	(0.109)	(0.105)	(0.125)
Less than 8 years	0.01	-0.01	-0.28**	-0.32*	-0.73**	-0.85**
	(0.118)	(0.148)	(0.135)	(0.170)	(0.178)	(0.203)
Middle school	0.13	0.14	-0.55**	-0.67**	-0.66**	-0.76**
	(0.094)	(0.119)	(0.110)	(0.173)	(0.153)	(0.176)
Less than 12 years	-0.03	-0.05	-0.54**	-0.67**	-0.68**	-0.79**
	(0.122)	(0.155)	(0.140)	(0.173)	(0.209)	(0.236)
High school	-0.13	-0.17	-0.60**	-0.73**	-1.07**	-1.20**
	(0.100)	(0.123)	(0.114)	(0.141)	(0.171)	(0.193)
Post-secondary	-0.21	-0.29	-0.89**	-1.09**	-1.13**	-1.23**
	(0.157)	(0.198)	(0.185)	(0.219)	(0.332)	(0.359)
Father's Education (Illiterate=0)						
Less than 5 years	0.20**	0.24**	0.03	0.01	-0.07	-0.09
	(0.079)	(0.097)	(0.087)	(0.113)	(0.102)	(0.126)
Primary	0.05	0.06	0.03	0.02	0.06	0.07
	(0.076)	(0.091)	(0.085)	(0.110)	(0.100)	(0.122)
Less than 8 years	0.01	-0.01	-0.09	-0.12	0.00	0.00
	(0.122)	(0.152)	(0.141)	(0.177)	(0.190)	(0.222)
Middle school	-0.01	-0.02	0.01	-0.01	-0.04	-0.06
	(0.093)	(0.114)	(0.107)	(0.136)	(0.142)	(0.167)
Less than 12 years	0.13	0.12	-0.04	-0.07	0.26	0.29
	(0.119)	(0.149)	(0.137)	(0.172)	(0.174)	(0.207)
High school	0.17*	0.20*	-0.12	-0.16	-0.27*	-0.31*
	(0.095)	(0.118)	(0.109)	(0.137)	(0.145)	(0.168)
Post-secondary	0.04	0.04	-0.08	-0.11	-0.06	-0.08
	(0.121)	(0.152)	(0.137)	(0.169)	(0.194)	(0.221)
MORT	-0.30**	-0.35**	-0.30**	-0.36**	0.06	0.09
	(0.059)	(0.070)	(0.067)	(0.085)	(0.080)	(0.098)
URBAN	0.08	0.12*	-0.01	-0.01	-0.20**	-0.24**
	(0.051)	(0.063)	(0.058)	(0.074)	(0.075)	(0.090)
PMALE	–	–	-0.06	-0.07	-0.09	-0.11
			(0.048)	(0.060)	(0.079)	(0.095)
PTWOMALE	–	–	–	–	-0.03	-0.04
					(0.091)	(0.109)
CONSTANT	-2.87**	-2.85**	-0.98**	-0.76**	-1.52**	-1.37**
	(0.149)	(0.159)	(0.099)	(0.121)	(0.139)	(0.161)
N	8168	8168	5361	5361	4513	4513

Table 9. Pre- and Post-Revolution Differences in α_t for Time to First, Second, and Third Birth Marriage Cohorts: Pre-Revolution (1969-1978) and Post-Revolution (1979-1993).[55]
(Rural Vs. Urban; Not Controlling for Secular Changes)

	$0 \rightarrow 1$ $(\hat{\alpha_t} - \alpha_t)$		$1 \rightarrow 2$ $(\hat{\alpha_t} - \alpha_t)$		$2 \rightarrow 3$ $(\hat{\alpha_t} - \alpha_t)$	
Time	Rural	Urban	Rural	Urban	Rural	Urban
$t = 1$	-0.05	0.76**	-0.37**	-0.02	-0.04	-0.34**
	(0.211)	(0.183)	(0.130)	(0.104)	(0.183)	(0.169)
$t = 2$	0.55**	0.39**	0.08	-0.14	-0.23*	-0.18
	(0.124)	(0.086)	(0.120)	(0.091)	(0.133)	(0.119)
$t = 3$	0.67**	0.37**	-0.15	-0.00	-0.27	-0.41**
	(0.132)	(0.090)	(0.149)	(0.118)	(0.173)	(0.148)
$t = 4$	0.67**	0.34**	-0.04	-0.36**	-0.91**	-0.49
	(0.189)	(0.123)	(0.267)	(0.153)	(0.242)	(0.189)
$t = 5$	0.22	-0.05	0.36	-0.54**	-0.52	-1.01**
	(0.226)	(0.193)	(0.385)	(0.242)	(0.588)	(0.308)
$t = 6$	0.01	-0.43	0.22	-0.05	-1.79**	-0.92**
	(0.315)	(0.288)	(0.640)	(0.294)	(0.529)	(0.348)
$t = 7$	0.14	0.02	-0.18	-0.45	–	–
	(0.345)	(0.361)	(1.001)	(0.420)		
$t = 8$	0.17	-0.90	–	–	–	–
	(0.403)	(0.421)				

impact on the hazard for first births. Urban women were significantly less likely to have a third birth.

3.5.1 Rural-Urban Differentials

So far, we have presented evidence that suggests that there were adjustments in birth timing among post-revolution marriage cohorts, without an increase in desired family size. However, can we infer that these changes were brought about by the revolution? As mentioned in the Introduction, as a result of the revolution, there was a reduction in the "price" of children. Furthermore, the revolution was largely an urban phenomenon, and the economic effects of the revolution on women's labor force participation were evident primarily in the urban formal sector (and not among rural subsistence farmers, for instance). Hence, we would expect that the impact of the revolution to be more pronounced among urban residents in our sample. Tables 9, 10, and 11 repeat the analysis of the earlier section separately for rural and urban residents. Estimates from the complementary log-log formulation of the model are reported. The logistic formulation of the model yielded similar results. First, Table 9 reports the differences in the hazard for birth for pre- and post-revolution cohorts without controlling for other determinants.

Table 9 indicates a similar trend in the hazard of a birth as observed in Table 5. It appears that post-revolution married urban residents exhibited a somewhat lower hazard of second as well as of third births when compared with those urban residents married prior to the revolution. Post-revolution married rural residents, on the other hand, began to show a significant decline only in their hazard of third birth. Table 10 reports the baseline hazard after controlling for other determinants of the hazard rate.

Table 10. Pre- and Post-Revolution Differences in α_t for Time to First, Second, and Third Birth Marriage Cohorts: Pre-Revolution (1969-1978) and Post-Revolution (1979-1993).[56]
(Rural Vs. Urban; Controlling for Secular Changes)

	$0 \rightarrow 1$ $(\hat{\alpha_t} - \alpha_t)$		$1 \rightarrow 2$ $(\hat{\alpha_t} - \alpha_t)$		$2 \rightarrow 3$ $(\hat{\alpha_t} - \alpha_t)$	
Time	Rural	Urban	Rural	Urban	Rural	Urban
$t = 1$	-0.28	0.73**	-0.44**	0.11	-0.22	-0.10
	(0.286)	(0.202)	(0.173)	(0.115)	(0.255)	(0.189)
$t = 2$	0.28*	0.31**	0.09	-0.09	-0.36*	0.06
	(0.159)	(0.097)	(0.159)	(0.104)	(0.202)	(0.143)
$t = 3$	0.66**	0.29**	-0.13	0.13	-0.59**	-0.24
	(0.167)	(0.099)	(0.189)	(0.131)	(0.266)	(0.183)
$t = 4$	0.64**	0.26**	0.10	-0.12	-1.13**	-0.23
	(0.216)	(0.134)	(0.366)	(0.170)	(0.355)	(0.224)
$t = 5$	0.21	-0.10	0.40	-0.29	-0.14	-0.81**
	(0.279)	(0.210)	(0.506)	(0.273)	(0.760)	(0.369)
$t = 6$	-0.18	-0.52*	1.39	0.33	-1.36*	-0.74*
	(0.417)	(0.307)	(0.863)	(0.330)	(0.722)	(0.421)
$t = 7$	0.29	0.13	-0.60	0.32	–	–
	(0.436)	(0.402)	(1.359)	(0.441)		
$t = 8$	-0.35	-0.88*	–	–	–	–
	(1.023)	(0.495)				

For time first birth, there is an increase in tempo for both rural and urban residents following the revolution. For time to second birth there is no significant difference between pre- and post-revolution marriage cohorts for both rural and urban residents, either for individual durations or using a joint test for all durations. For time to third birth: a joint test on all durations revealed that post-revolution marriage cohorts that were rural residents were significantly at lower risk of third birth; this was not the case for urban residents. It appears as though, upon controlling for secular changes, the post-revolution rise and compensating decline in the hazard of births occurred primarily in rural areas. There was an increase in the tempo of fertility following the revolution for urban residents, but at higher parities there appears to not have been a compensatory decline upon controlling for secular changes. This is suggestive of a longer-term impact on cohort fertility among urban residents.

Table 11 reports the β's for the independent variables in the regressions.

3.6 Conclusions

In this paper, we study fertility fluctuations in the aftermath of the revolution in Iran. Unlike previous studies, we provide evidence that suggests that, at least in part, the fluctuations in period fertility were a birth timing phenomenon: in response to the "blackout" of the revolution, couples appear to have chosen to have births sooner after marriage with a compensatory decline in later marriage years. Cohort fertility has decreased following the revolution, but not by as much as would be suggested by the TFR. These changes in birth timing are evident even after controlling for secular factors. Analysis of rural-urban differences indicates that

Table 11. Rural Vs. Urban: Hazard Rate for Time to First, Second, and Third Birth.[57]

	0 → 1		1 → 2		2 → 3	
Variable	Rural	Urban	Rural	Urban	Rural	Urban
AFM	0.02**	0.02**	-0.04**	-0.00	0.00	-0.02*
	(0.011)	(0.008)	(0.013)	(0.010)	(0.019)	(0.014)
LHHINC	0.12**	0.07**	-0.00	-0.02	-0.04	0.07*
	(0.034)	(0.022)	(0.039)	(0.026)	(0.046)	(0.039)
Mother's Education (Illiterate=0)						
Less than 5 years	-0.13	-0.04	-0.32**	-0.03	0.00	-0.22*
	(0.121)	(0.097)	(0.141)	(0.106)	(0.170)	(0.129)
Primary	-0.10	0.21**	-0.64**	-0.39**	-0.10	-0.47**
	(0.144)	(0.091)	(0.171)	(0.101)	(0.212)	(0.123)
Less than 8 years	-0.30	0.07	-0.17	-0.27*	-0.54	-0.89**
	(0.255)	(0.135)	(0.305)	(0.152)	(0.366)	(0.209)
Middle school	0.16	0.15	-0.87**	-0.46**	-0.17	-0.78**
	(0.226)	(0.107)	(0.286)	(0.151)	(0.412)	(0.170)
Less than 12 years	-0.15	0.01	-0.82*	-0.46**	0.11	-0.83**
	(0.400)	(0.132)	(0.434)	(0.151)	(0.616)	(0.228)
High school	-0.34	-0.08	-1.06**	-0.54**	-0.82*	-1.12**
	(0.274)	(0.111)	(0.333)	(0.125)	(0.471)	(0.190)
Post-secondary	-1.37*	-0.13	-2.23**	-0.84**	–	-1.15**
	(0.756)	(0.167)	(1.105)	(0.196)		(0.345)
Father's Education (Illiterate=0)						
Less than 5 years	0.37**	0.04	0.16	-0.10	-0.18	0.02
	(0.117)	(0.109)	(0.130)	(0.119)	(0.152)	(0.142)
Primary	0.16	-0.05	0.25*	-0.12	0.00	0.10
	(0.122)	(0.098)	(0.141)	(0.108)	(0.170)	(0.127)
Less than 8 years	-0.03	-0.04	0.24	-0.29	0.01	0.06
	(0.223)	(0.149)	(0.265)	(0.171)	(0.336)	(0.235)
Middle school	0.22	-0.15	0.37*	-0.16	0.08	-0.03
	(0.173)	(0.114)	(0.211)	(0.128)	(0.273)	(0.172)
Less than 12 years	0.33	0.01	0.23	-0.20	0.78	0.24
	(0.297)	(0.137)	(0.417)	(0.154)	(0.454)	(0.197)
High school	0.50**	0.02	0.43*	-0.32**	-0.31	-0.24
	(0.197)	(0.115)	(0.230)	(0.130)	(0.292)	(0.174)
Post-secondary	0.54	-0.11	0.34	-0.26*	0.61	-0.11
	(0.331)	(0.139)	(0.472)	(0.154)	(0.512)	(0.220)
MORT	-0.12	-0.42**	-0.31**	-0.33**	-0.21	0.24
	(0.092)	(0.078)	(0.104)	(0.090)	(0.125)	(0.105)
PMALE	–	–	-0.05	-0.06	0.11	-0.20**
			(0.090)	(0.057)	(0.137)	(0.099)
PTWOMALE	–	–	–	–	0.06	-0.11
					(0.164)	(0.112)
CONSTANT	-2.50**	-2.92**	-0.96**	-0.96**	-1.69**	-1.59**
	(0.228)	(0.192)	(0.154)	(0.121)	(0.215)	(0.172)
N	2736	5432	1475	3886	1202	3311

urban residents, while being at higher risk of first birth following the revolution, do not show a compensatory decline in later years. This is suggestive of a longer-term impact on cohort fertility among urban residents and merits further research.

3.7 Appendix

3.7.1 A Dynamic Model of Fertility

This model is similar to the one in Walker (1995). There are T periods in the model. A representative family begins married life at time $t = 1$ and obtains utility every period $t = 1, ..., T$ from the consumption of a composite good c_t and from the stock of children in the family n_t. The stock of children in time t is the sum of the number of births b in time $t, t-1, ..., 1$, or $n_t = \sum_{t=1}^{t} b_t$. The utility function is assumed to be intertemporally and contemporaneously strongly separable. The problem is one of maximizing

$$U = \sum_{t=1}^{T} \beta^{t-1}[u(c_t) + v(n_t)], \tag{6}$$

with respect to c_t, b_t for $t = 1, ..., T$. Here, β is the discount factor. Families face the following intertemporal budget constraint:

$$A_1 + \sum_{t=1}^{T} \frac{W_t L_t}{(1+r)^{t-1}} = \sum_{t=1}^{T} \frac{p_c c_t + p_b b_t}{(1+r)^{t-1}},$$

where A_1 includes the stock of the couple's assets at the beginning of married life as well as the present value of the husband's earning stream; W is the wage rate and is defined in time t as $W_t = \omega_t H_t$; ω_t is the return to human capital in period t. Suppose m is annual work capacity (a multiple of the minimum time required for each child), then we have $L_t = m - b_t$ for all t; H_1 is the (exogenous) stock of a woman's human capital at the time of marriage; in periods $t = 1, ..., T$ we have the return to human capital determined by:

$$H_t = H_1 + \delta \sum_{j=2}^{t} (m - b_{j-1}), \qquad \delta > 0,$$

with δ being a positive constant representing the rate at which human capital appreciates due to learning-by-doing. p_c is the price of consumption and p_b is the "price" of a birth (net present value of all expenses associated with birth including the child's consumption). Substituting (3.7.1) in the lifetime budget constraint, we have:

$$A_1 + \sum_{t=1}^{T} \frac{\omega_t H_t (m - b_t)}{(1+r)^{t-1}} = \sum_{t=1}^{T} \frac{p_c c_t + p_b b_t}{(1+r)^{t-1}}. \tag{7}$$

Maximizing (6) with respect to c_t, b_t for $t = 1, ..., T$ subject to (7) and non-negativity constraints yields the following first-order conditions:

$$\beta^{t-1} u'(x_t) = \lambda \frac{p_c}{(1+r)^{t-1}}, \tag{8}$$

where λ is the marginal utility of wealth. Similarly,

$$\sum_{i=t}^{T} \beta^{i-1} v'(n_i) = \lambda \pi_t, \tag{9}$$

where

$$\pi_t = \frac{p_b + \omega_t H_t}{(1+r)^{t-1}} + \delta \sum_{j=t+1}^{T} \frac{\omega_j (m - b_j)}{(1+r)^{j-1}}$$

is the total "price" of a birth in time t representing three components: direct cost of a child p_b, the opportunity cost in terms of foregone wages, and the third term representing the loss in future earnings due to reduced human capital accumulation. As can be seen from (8), there are cumulative flows of utility from fertility in time t – encouraging early births. The prevention of loss in human capital is a motivation to delay births. Intertemporally efficient allocations are determined by:

$$\frac{u'(c_{t+1})}{u'(c_t)} = \beta(1+r),$$

which determines optimal consumption over time, and

$$\frac{V_{t+1}}{V_t} = \frac{\pi_{t+1}}{\pi_t},$$

determines the allocation of fertility over the life cycle. Here, $V_t(n_t)$ is the marginal utility flow $\sum_{i=t}^{T} \beta^{i-1} v'(n_i)$. The right-hand side is the relative price of transferring fertility between periods. A decrease in the relative price of having children today versus tomorrow will induce both income and substitution effects. The substitution effect will tend to raise b_t at the expense of b_{t+1} and the income effect will tend to raise both b_t and b_{t+1}. Dominance of the substitution effect will yield intertemporal substitution in fertility behavior.

3.7.2 Discrete-time proportional hazards model

For expositional purposes, the hazard for time to first birth is considered. Assume an individual becomes at risk of birth at marriage time $t = 0$. After this, she is observed at discrete intervals of time $t = 1, ..., k$ where k is the final time of observation. By definition, the discrete hazard rate for time t for woman i (i.e., P_{it} with $t = 1, ..., k$] denotes the probability that woman i did not have a birth up until $t-1$ and has a birth observed at time t. If T_i is a random variable denoting the underlying (continuous) duration to first birth for woman i, then the discrete-time hazard rate at time t can be written as:

$$P_{it} = Pr(t - 1 \leq T_i < t \mid T_i \geq t - 1) \tag{10}$$

From the definition of conditional probability, this implies that:

$$P_{it} = \frac{Pr(t-1 \leq T_i < t)}{S_i(t-1)} = \frac{S_i(t-1) - S_i(t)}{S_i(t-1)} \tag{11}$$

where $S_i(t)$ is the survivor function at time t, and equals the probability that T_i is greater than or equal to t (or 1 minus the probability that a birth is observed at t). If the underlying process is assumed to occur in continuous time, then at time t the survivor function equals:

$$S_i(t) = exp\left\{-\int_0^t h(u)du\right\} \tag{12}$$

Assuming the underlying continuous-time distribution follows a proportional hazards formulation: $h_i(t) = h_0(t)exp(\beta'\mathbf{x_{it}})$ we have, from (11):

$$log[1 - P_{it}] = exp\left[-\int_{t-1}^t h_i(u)du\right] = -exp(\beta'\mathbf{x_{it}})h_0(t) \tag{13}$$

where the covariates are assumed time-varying but fixed *within* the time interval $t-1$ to t and

$$h_0(t) = \int_{t-1}^t h_0(u)du$$

is the arbitrary baseline hazard associated with the interval t, assumed to be some constant value $h_0(t)$ in the interval $t-1$ to t. Taking the logarithm of both sides of (13) yields

$$log\{-log[1 - P_{it}]\} = \alpha_t + \beta'\mathbf{x_{it}} \tag{14}$$

where the parameters α_t for $t = 1, ..., k$ are associated with the k time intervals. This is a linear model for the complementary log-log transformation of P_{it}. More generally, the discrete-time proportional hazard model at time t is:

$$P_{it} = 1 - exp\{-exp[\alpha_t + \beta'\mathbf{x_{it}}]\} \tag{15}$$

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