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Modelling banknote printing costs: of cohorts, generations, and note-years

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ABSTRACT

Menzies (2004) uses a 'cohorts approach' to model banknote printing costs. This paper proposes a 'generational approach' that allows for more realistic assumptions concerning currency growth and note replacement. The paper shows that Menzies' claim that the case for polymer banknotes becomes stronger with higher currency demand is an artefact of his model. In most scenarios, the number of notes in circulation does not affect the relative cost effectiveness of paper and polymer; and when it does, the impact goes in the other direction. A second finding is that the 'note life over unit-cost rule of thumb' can be misleading.

1. Introduction

The number of central banks that have partially or fully adopted polymer banknotes is on the increase. The Bank of Canada (BoC) and the Bank of England (BoE) are recent high-profile converts. The BoC issued its first 'plastic' note in November 2011 and in the meantime five of its denominations are printed on the new substrate (Bank of Canada, 2013). The BoE in December 2013 announced its decision to migrate its two lowest denominations, the notes of UKP 5 and UKP 10, to polymer – in 2015 and 2016, respectively (Bank of England, 2013). A number of other central banks are actively considering a switch to polymer. The Reserve Bank of India, for example, is planning a pilot in five cities in the course of 2015.[1]

Apart from improved protection against counterfeiting, for central banks an important advantage of polymer banknotes lies in their higher durability and resulting lower maintenance costs. A downside is that plastic notes are more costly to produce. In a rare academic article on the topic, Menzies (2004) conducts a cost-benefit analysis of the Reserve Bank of Australia's (RBA) migration to polymer, and thus cannot avoid studying the key trade-off between higher durability and higher initial production costs. To that end, Menzies develops a model that compares the net present value (NPV) of the central bank's printing costs in a paper and in a polymer banknote regime. One of the key outcomes of the model is that "robust currency growth strengthens the case for polymer" (o.c., p. 359). That is, an increase in the demand for its notes would make it more interesting for a central bank to switch to polymer, and vice versa.

At a time when PayPal predicts not only that by 2016 UK consumers will no longer need cash to go shopping on Britain's high streets but that they will not even need a traditional leather wallet ,[2] Menzies' insight is alarming for central banks that – like the BoC, the BoE, and the RBA – have opted for polymer. PayPal's belief in mobile payments may well prove too optimistic, but a recent report by the UK Payments Council forecasts that cash payments will fall by around a third between 2012 and 2022, largely driven by increased use of contactless cards and mobile phones.[3] In many a country the use of cash is indeed decreasing, and in some the growth of currency in circulation is already slowing down. For the case of Canada a recent article in the *Bank of Canada Review* points out that the share of cash in retail payments has decreased continuously over the past 20 years (Arango et al., 2012). In the early 1990s, cash accounted for more than 80 per cent of the volume and about 50 per cent of the value of Canadian point-of-sale transactions. Estimates for 2011 put these shares at below 50 and 20 per cent, respectively (o.c., p. 32). However, in terms of currency circulation, cash has held its ground remarkably well. Arango et al. (o.c., p. 32–33) point out that "the value of bank notes in circulation has risen at an annual rate of about 5 per cent since 2000, virtually the same as the growth in aggregate personal expenditures", a phenomenon which Arango et al.

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[1] Sources: Reserve Bank of India, *Annual Report 2013-14*, August 2014, p. 136; "RBI planning to introduce plastic currency notes next year", *The Economic Times*, August 22, 2014 <https://www.paypal.co.uk/blog/paypal-predicts-the-future-of-money/>, last visited on October 23, 2014.

[2] Bishop, J., "PayPal predicts the future of money", *PayPal blog*, May 7, 2012 <https://www.paypal.fr/blog/PayPal-Predicts-the-Future-of-Money/>, last visited on December 24, 2014.

[3] Payments Council, "New report paints picture of 2022 payments", press release, December 24, 2014 <http://www.paymentscouncil.org.uk/media_centre/press_releases/2013_archive/-/page/3063/>.

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attribute to a rise in the use of cash for non-payment purposes. Still, recent figures on the *number* of banknotes in circulation – which is the more relevant metric when studying production issues – give some cause for worry. Indeed, while over 2005–2009 the number of notes of the five Canadian denominations that have been migrated to polymer increased by an average of 4.01 per cent per year, over 2010–2013 this figure is 3.01 per cent.[4] (In 2011 there was even a standstill, but this might in part be due to the introduction, in November of that year, of the new CAD 20 polymer bill.) The point is that current currency growth in Canada would seem to be lower than when the BoC gave polymer the green light. If this trend continues and if Menzies is correct in arguing that currency growth strengthens the case for polymer, the BoC might thus, in retrospect, have been too keen to adopt polymer.

Fortunately for the BoC, this paper demonstrates that Menzies' finding is, in fact, embedded in his model, which puts paper at a built-in handicap when there is positive currency growth (and vice versa when the demand for currency drops). If the evolution in the number of notes in circulation is modelled identically for both technologies, it does *not*, under Menzies' assumptions, affect the ratio of the present values of paper and polymer printing costs. This finding triggers the broader point that Menzies' 'cohorts approach' cannot adequately handle currency growth. I therefore develop a 'generational approach' and use this to gradually relax two of Menzies' key assumptions: I move from a scenario with periodical currency growth to one with yearly growth, and from a situation in which all notes of a given denomination disintegrate all at once – what we will term 'sudden decay' – to a situation in which a constant fraction needs to be replaced each year. I find that as long as paper and polymer are compared over infinite horizons, the number of notes in circulation does not affect their relative cost effectiveness, as intuition would suggest. When the horizon is finite, one has to take into account that a substantial portion of the notes in circulation will not yet have expended their full life. Given that polymer notes last longer, this drives up the cost of polymer more than it does the cost of paper. In such a setting, higher currency growth does affect the relative attractiveness of the two technologies, but the impact in fact goes in the opposite direction compared to what Menzies suggests. A second finding is that in more realistic settings the usefulness of the 'note life over unit-cost rule of thumb' is limited. Third, the proposed generational approach also provides an alternative to Bouhdaoui et al.'s (2013) single-period model. In contrast to what is suggested in Bouhdaoui et al., it is shown that discounting is not neutral, especially when the central bank's planning horizon is finite. Finally, an important preliminary remark is that the present paper only studies scenarios with non-negative currency growth. Indeed, and this is an interesting finding in itself, situations with positive and negative currency growth are not by definition symmetric. However, for the sake of brevity, scenarios with negative currency growth are studied in a companion paper (Van Hove, 2014).

The remainder of the present paper is structured as follows. Section 2 first provides a brief overview of the related literature. Section 3 then explains Menzies' approach in more detail, shows that his insight concerning currency growth results from a modelling mistake, and analyses a corrected version of his model (in which growth in the demand for paper and plastic currency is 100% identical). Section 4 introduces our generational approach and first applies it to a scenario with yearly instead of periodical currency growth, but with an infinite horizon. Sections 5 and 6 then progressively render more realistic the assumptions concerning, respectively, the time horizon and the note replacement pattern. Finally, Section 7 compares the results across scenarios as well as with the findings of the Bouhdaoui et al. model, and Section 8 concludes.

[4] Own calculations based on Bank of Canada, *Bank of Canada Banking and Financial Statistics*, February 2014, Table K1 - Bank of Canada note liabilities.

2. Prior literature

Research on banknote production issues has, not surprisingly, always largely been the preserve of central bank economists, who have mainly produced fairly topical and operations-oriented papers.[5] In a 2004 BoC working paper, Chant (2004, p. 1) notes in this respect that a search of *EconLit* using the words "counterfeit" and "currency" turned up only three academic references. More recently, Billetaria (2011, p. 44), the leading central bank publication on cash management, laments that "[t]he technical aspects of banknote production, the latest innovations, the different techniques used when putting cash into circulation, distribution systems, different ways of managing optimal banknote stocks, implementing quality policies, automated operations systems, the various anti-counterfeiting measures, are all issues on which there is a dearth of literature".

Still, in recent years the academic literature dealing with banknote production has seen substantial growth. The literature that is of relevance for the present paper can be grouped under two headings: 'counterfeiting' and 'production costs'. To start with counterfeiting, in a recent survey article Fung and Shao (2011, p. 31) highlight that "[t]here has been almost no empirical work on counterfeiting because of the limited availability of counterfeiting data and related statistics". They therefore focus their discussion on theoretical papers that model the behaviour of the economic agents involved.[6] Bouhdaoui et al. (2012, 2013), for their part, develop – just like the present paper – an analytical framework that would allow central banks to assess whether changing the manufacturing material of their notes (or coins) would be beneficial from a private cost perspective. Unlike the present paper, in Bouhdaoui et al. (2012) they also explicitly incorporate the impact of the change in technology on counterfeiting. But in the empirical part of the paper, where they simulate how the production costs and seigniorage revenue of the U.S. Federal Reserve would be impacted by the introduction of plastic banknotes, they find that the recurrent direct gains from the assumed decrease in counterfeiting are negligible (because of its low incidence).[7] However, this does not mean that central banks can be complacent when it comes to counterfeiting. As Chant (2004) points out, counterfeiting also imposes costs on other stakeholders and, in particular, there is the danger that the public at a certain point loses confidence in a specific denomination or in the currency as a whole. Chant (o.c., p. 7) stresses that the experience with the CAD 100 note suggests that "even low levels of counterfeiting can threaten the acceptance of a specific denomination".

The literature on production costs is also limited. The most interesting empirical paper is Galán and Sarmiento (2007), who examine trends in banknote printing during the period 2000–2005 for a sample of 56 central banks. With these panel data, they also estimate a cost function and a non-parametric efficient frontier model. Turning to the modelling papers, Massoud (2005) develops a banknote inventory model that solves for the central bank's optimal note order size and frequency. There is also a small but lively literature on which nominal values central banks should pick for their denominations and where they should set the so-called coin/note-boundary; see Bouhdaoui et al. (2011), Bouhdaoui and Bounie (2012), Bouhdaoui (2014), and the references therein. Finally, as could already be gleaned from the Introduction, there are only two papers that – like the present paper – try to model the choice of the central bank between two banknote production technologies. Interestingly, the two models are of a completely different inspiration. Menzies' (2004) model is multi-period, whereas Bouhdaoui et al. (2012, 2013) only consider a single – supposedly representative – year. Conversely, Bouhdaoui et al.'s model has a revenue side that is lacking in Menzies' model and can therefore, as explained, also handle the

[5] See the list of references in Bouhdaoui et al. (2012). Cowling and Howlett (2012) is a more recent example.

[6] Shao (2014) is the most recent addition to this line of research.

[7] The one-off windfall in the year of introduction is more substantial.