Currency Design in the United States and Abroad

Handicapping Currency Design: Counterfeit Deterrence and Visual Accessibility in the United States and Abroad

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Abstract

Despite the increasing use of electronic payments, currency retains an important role in the payment system of every country. In this article, the authors compare and contrast tradeoffs among currency design features, including those primarily intended to deter counterfeiting and ones to improve usability by the visually impaired. The authors conclude that periodic changes in the design of currency are an important aspect of counterfeit deterrence, and that currency designers worldwide generally have been successful in efforts to deter counterfeiting. At the same time, currency designers have sought to be sensitive to the needs of the visually impaired. Although tradeoffs among goals sometimes have forced compromises, new technologies promise banknotes both more difficult to counterfeit and more accessible to the visually impaired. U.S. banknotes are special because, among the world's currencies, they are the banknotes most widely used outside their country of issue.

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> An efficient and sustainable payment system development process ought to be built around the current and foreseeable payment needs of the users in the economy, such as consumers, government and financial and non-financial businesses. These needs should be weighed against the current economic and technical capabilities of the economy to supply the required payment instruments and services in a cost-effective manner.
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> *Guideline 4, Committee on Payment and Settlement Systems, Bank for International Settlements (2006)*

Despite the increasing popularity of electronic payments, currency—that is, banknotes—remains an integral part of most nations' payment systems and the most familiar medium for daily face-to-face payments. In most nations, the bulk of the circulating currency is that issued by that nation's monetary authority; in a few cases, the currency of a foreign nation, such as the United States, is widely used. Regardless of the specific currencies in circulation, each nation's payment system has a large number of participants, including consumers, retail businesses, financial institutions, the central bank or other monetary authority, armored car companies and others who transport currency, and third-party currency processors. Everyone who touches currency in a nation's payment system has a stake in recognizing the authenticity of currency ("authenticating"), readily determining its denomination ("denominating"), and—subject to these constraints—minimizing the cost of its handling.

To sustain public confidence in a circulating currency, banknotes must contain features that the public can use to readily judge their authenticity and determine the notes' denominations. Currency design is driven by these considerations, subject to constraints imposed by the desire to minimize the notes' cost and maximize their ease of handling by third parties. Monetary authorities, quite naturally, prefer banknotes that are inexpensive to produce and, other things equal, have a long life in circulation. These considerations make banknote design a mixture of art, science, politics, and economics.[1]

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[1] For the economist reading this article, we note that the "currency design problem" may be framed as a constrained optimization problem in which the objective is to maximjze the contribution of circulating currency to social welfare. Absent constraints (both economic and technical), social welfare is maximized by producing banknotes that contain "all" desirable features, including those to deter illegal reproduction, those to make denomination rapid and accurate, those to make the currency easily used by the blind and visually impaired, and those (such as machine-readable features) that minimize the cost of high-volume currency handling by third-parties. Because it is reasonable to believe that the objective functions of

Generally, monetary authorities worldwide recognize that improved public understanding and awareness of the features of their currency assists them in meeting these goals. Yet, studies of public awareness of currency features suggest that often many members of the public are not aware of even a single security feature in their nation's banknotes.[2]

In this article, we compare and contrast design features in banknotes issued by monetary authorities in a number of countries, including the United States. Our focus is on two primary design issues: counterfeit deterrence and high visual accessibility (for both the normal-sighted and visually impaired).[3] We discuss both those features that are readily visible to consumers and businesses, and machine-readable features not accessible without machine assistance. Our emphasis is on design features that the public might use to determine the authenticity and denomination of a banknote. In this respect, our views coincide with those expressed by currency experts such as Brian Lang (2002), then head of currency at the Reserve Bank of New Zealand, who emphasized that building sophisticated security features into banknotes is of limited effectiveness if the public is unaware of the features, and that a highly aware public is the best defense against the circulation of counterfeit banknotes. Throughout, our analysis is based on publicly

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monetary authorities differ (for example, some might have a relatively larger fraction of their banknotes in circulation abroad, or might have a relatively more highly educated population, or might face relatively higher labor costs for currency handling), the solutions to their optimization problems—the resulting currency designs—will differ. The underlying structure of our article is such an "optimization subject to constraints" framework. In our opinion, such formalism contributes little to the public's understanding of currency design issues and hence, for accessibility to the general reader, we avoid use of such jargon in the article. Interested readers should examine Tables 1 and 2, in which the column headings approximately correspond to the constraints that would appear in a formal Kuhn-Tucker optimization statement of the currency design problem.

[2] Published studies on this topic are relatively difficult to locate. An interesting paper is de Heij et al. (2003), which, for the United States, summarizes surveys of public awareness conducted by Deloitte & Touche for the U.S. Bureau of Engraving and Printing.

[3] Throughout this manuscript, we use the term "visually impaired" to refer to persons with limited visual capacity that affects their ability to carry on their daily lives, and "normal-sighted" to describe those persons who, while perhaps having some diminished vision, are able to conduct daily major life functions, albeit in some cases with an accommodation or limitations. We recognize that these terms are imprecise and that significant disagreement remains regarding the use of such highly descriptive terms. Among other sources, a more complete discussion is available, for example, in National Research Council (1995).

available information regarding currency design considerations and features. To the extent that banknotes contain covert or secret features, these are not discussed here.

Unique in the world, U.S. currency presents special issues because of its widespread usage outside the United States. Although U.S. currency has been held abroad since before the Second World War, outflows accelerated during the 1970s. Recent estimates are that more than 50 percent of all U.S. banknotes in circulation are held outside the United States.[4] The worldwide presence increases its attractiveness to counterfeiters while, at the same time, councils caution with respect to significant design changes to deter counterfeiting that might confuse the public outside the United States. In foreign nations experiencing political or economic uncertainty, U.S. banknotes are an attractive asset; much of the recent growth in demand for U.S. banknotes has been in countries of the former Soviet Union and Latin America. Indeed, anecdotal press reports tell of Moscow taxi drivers insisting to be paid in U.S. dollars rather than rubles. Other stories tell of merchants in the most remote areas of China accepting—and giving change—in U.S. banknotes. The extensive, widespread use of U.S. banknotes benefits American taxpayers because, unlike Treasury bonds, the banknotes are a liability of the U.S. monetary authorities on which no interest is paid. The use of the banknotes also is a social and economic benefit to the residents of foreign countries who might otherwise lack a currency stable in value and widely accepted in transactions. This same popularity also encourages counterfeiting. Counterfeiters range from the casual, who produce a few notes with desktop scanners and ink jet printers or with color copiers, to professionals using sophisticated lithographic printing systems, to foreign governments that print counterfeit "supernotes" on government-owned intaglio presses.[5] Below, we consider

[4] U.S. Treasury Department (2006).

[5] Both the National Research Council (2006) and Mihm (2006) identify North Korea as a producer of "supernotes."

further the ways in which security requirements and a desire for universal acceptability around the world may limit design options for U.S. currency.[6]

We begin by exploring the characteristics of an "ideal" currency and then examine the real-world considerations that affect currency design. We conclude with a comparative analysis of currency features around the world.

WHAT ARE THE CHARACTERISTICS OF AN IDEAL CURRENCY?

There are relatively few published, analytical studies of currency design. The studies of which we are aware focus on U.S. currency and, for the most part, have been funded by the U.S. Treasury's Bureau of Engraving and Printing (BEP) and conducted by the National Research Council (NRC), including BEP (1983) and NRC (1993, 1995, 2006, 2007). The U.S. Treasury, in collaboration with other government agencies, has published three studies regarding counterfeiting and the demand for U.S. banknotes abroad (U.S. Treasury, 2000, 2003, 2006). Necessarily, our analysis draws heavily on these studies.

The U.S. Bureau of Engraving and Printing was established during the U.S. Civil War in an effort to reduce counterfeiting. Since that time, the primary focus of U.S. banknote design has been counterfeit deterrence—although features that would ease usage by both the visually impaired and normally-sighted users have not been ignored. In its 1993 report, the NRC's Committee on Next-Generation Currency Design (NRC, 1993) described the features of a "perfect" currency:

- extremely difficult to duplicate;
- easily recognized by the general public;
- durable (remains visible after considerable wear);
- can be machine-readable;
- easy to produce at low cost;

[6] Interested readers should consult U.S. Treasury (2000, 2003, 2006).

- acceptable to the public (aesthetically pleasing); and
- non-toxic and non-hazardous.

With respect to counterfeit deterrence, the committee argued that no single feature, by itself, can furnish adequate protection against even the casual counterfeiter because nearly all individual features can be simulated by a determined, well-funded counterfeiter. Instead, the committee recommended a "systems approach" that combined several features with aggressive law enforcement and detection efforts.

To introduce ideas and terminology, consider the current U.S. $50 note (see Figure 1). On the front, the note contains security features including a watermark, color-shifting ink and subtle shades of various colors; on the reverse, the note contains in the lower right corner a visual accessibility feature, the denomination in 14 mm tall numerals. In the final section of this article, we examine security and visual accessibility features of currencies from several nations.

Figure 1

Accessibility Features	*Security Features*
• Large numeral on reverse • Large portraits • Subtle over-printed colors on front	• Watermark • Color-shifting inks • Fine line printing patterns • Enlarged off-center portraits • Machine-readable feature • Security thread • Microprinting

Although the task given to the National Research Council's 1993 committee on currency design was to explore features that deter counterfeiting, the first item on its evaluation criteria was "visual and tactile recognizability," defined as "an assessment of the ease with which a U.S. citizen…could readily recognize the feature in normal ambient illumination unaided, or aided with a simple, inexpensive device." It is widely recognized that the "look and feel" of currency is important for determining whether it is genuine, both for normally sighted users and the visually impaired. The Committee concluded that U.S. currency's unique banknote paper, combined with its raised surface created by intaglio printing, were the essential ingredients for notes to have the correct "feel" of U.S. currency.[7] More recently, the National Research Council has issued two detailed technical reports on counterfeit deterrence (NRC, 2006, 2007). In broad terms, the findings and recommendations resemble the 1993 report: Currency redesign must be an ongoing process to remain ahead of the improving technology available to counterfeiters.

In 1995, the National Research Council (via its Committee on Currency Features Usable by the Visually Impaired) issued a report focused solely on visual accessibility (NRC, 1995). This study was commissioned by the Bureau of Engraving and Printing, and is, so far as we are aware, the most extensive on the topic. We review its recommendations below. In their scope and completeness, the NRC's 1993 and 1995 studies complement each other. Unfortunately, the studies are almost completely compartmentalized in their suggestions for an ideal currency. The studies omitted

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[7] Security intaglio printing refers to print produced from hand-engraved plates with a recessed image Thick paste inks and high printing pressures are used to create a raised surface on the note that cannot be reproduced by planar printing processes. Virtually all banknotes are printed, at least in part, by intaglio methods. Additional features, such as serial numbers and color, often are added via letterpress or offset printing, although color intaglio is feasible. Van Renesse (2005) and NRC (2006) provide a detailed discussions of printing techniques. Some banknote issuers cite intaglio printing as an aide to the visually impaired, but most do not. In our analysis, we have not attempted to determine which styles of intaglio may be more or less useful to currency users, but have accepted the issuers' assertions. The Bank of Japan, for example, cites intaglio high-relief numerals as an aid to the visually impaired.

comparisons between design features to deter counterfeiting and to increase visual accessibility: The 1993 report (NRC, 1993) considered "ideal" features for counterfeit deterrence, while the 1995 report (NRC, 1995) considered "ideal" visual features. The National Research Council's 1993 report, for example, in approximately 125 pages, never mentions concerns of the blind or visually impaired.[8] The National Research Council's 1995 report, for example, concluded that "features currently used by other countries …can be considered for inclusion in the forthcoming redesign of U.S. currency without compromising the security of American banknotes" (NRC, 1995, p.11). We discuss below features which have been introduced in newer currency designs.

Our analysis of notes issued worldwide suggests that security-related features (including those to deter counterfeiting) and features that enhance visual accessibility often are complementary. For U.S. banknotes, designing currency robust to counterfeiters but also as visually accessible as possible is more difficult because of the widespread use of U.S. dollars worldwide. In the past, design changes that significantly alter the appearance of U.S. banknotes have been approved with caution; yet, the Treasury's successful education campaign that surrounded introduction of the redesigned $100 note suggests that education can overcome initial resistance to design changes.[9]

CURRENCY DESIGN FEATURES TO DETER COUNTERFEITING

Technological innovations in color copying, scanning, and printing have intensified the race between increasingly sophisticated banknote counterfeiters and banknote designers. In many lines of business, the improving performance and decreasing cost of information technology have reduced "barriers to entry"—unfortunately, perhaps, the same is true in counterfeiting. The National Research Council's most recent technical report (NRC, 2007) concludes that this race eventually

[8] The 1993 report is the first report specifically linked to a pending currency redesign. Two previous reports by the NRC are discussed in the 1993 document. One of those earlier reports, in 1985, recommended the security thread and small-size intaglio-printed characters implemented in Series 1990 U.S. banknotes.

[9] See U.S. Treasury (2000, 2003, 2006) for discussions of uncertainty generated abroad by design changes and the accompanying education campaigns.

will be lost for the current generation of paper-based banknotes and explores a wide range of innovative substrates as a replacement for current banknote paper. The report's overall conclusion echoes the conclusions of previous NRC reports (NRC, 1993, 2006) that only continuous design innovation can sustain a low frequency of counterfeit notes in circulation. The report's engineering analysis of alternative substrates is fascinating but speculative. We leave details of the report to the interested reader and focus herein on current banknote designs and features.

Banknote designers worldwide have introduced a number of features to deter counterfeiting. Features of currencies for selected countries that belong to the Bank for International Settlements's Committee on Payment Systems and Services are summarized in the first column of Table 1. Such features include novel substrates such as polymer with clear windows that include embossed and printed security features[10]; embedded security threads, including ones that glow different colors under ultraviolet light[11]; high-relief raised intaglio printing; extra color features on bills; magnetic ink; and various embedded machine-readable features.[12] Counterfeit deterrence features are discussed further in the final section of this article.

United States banknotes contain a large number of security features to deter counterfeiting, including embedded security threads that glow different colors by denomination under ultraviolet light; large, complex line-drawn presidential portraits; watermarks; embedded fibers; color-shifting ink (the color of which differs by denomination); microprinting too small to be reproduced by current-generation photographic copiers and consumer-level scanners; fine-line printing; color over-printing

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[10] The Reserve Bank of Australia issued the world's first polymer note series between 1992 and 1996. The National Research Council (NRC, 2006, 2007) reviews the engineering details of such plastics and provides a list of the numerous countries now using such currency.

[11] Among others, U.S. banknotes now contain such threads.

[12] Electronic handheld note readers, of significant value to the visually impaired, perhaps can use machine readable features—but we have no knowledge of specific technical designs which, in any case, are proprietary and confidential. Although several currency issuers have told us that the machine-readable features of their banknotes might be suitable for handheld denominators, to our knowledge such machines are available only for Canadian and US banknotes. This topic is discussed further below.

in subtle shades; and embedded machine-readable features. Machine-readable features, most of which vary by denomination, include the notes' optical spectrum and image (including color-shifting inks, and a fluorescent strip that glows in denomination-specific colors under certain frequencies of light), magnetic ink, ultraviolet spectrum, and infrared ink pattern (NRC, 2006, pp. 12-13). The National Research Council notes that machine-readable features are useful both to authenticate notes and to determine notes denomination. Single-note denominators such as those installed in retail vending machines, for example, "typically use infrared, broad-wavelength optical, or magnetic sensors to detect denomination-specific features," while single-note authenticators "also detect ultraviolet and fluorescent patterns." (NRC, 2006, p. 12). The report notes that low-quality counterfeit notes most commonly are identified by low optical image quality, lack of magnetic and/or infrared ink, or incorrect paper fluorescence (discussed further below). Detection of high-quality counterfeits may require careful sensing of magnetic, infrared, or ultraviolet signatures. Magnetic ink is a difficult feature for counterfeiters to replicate, although careful procedures perhaps can maintain magnetic material in suspension long enough for printing; the NRC report notes that 90 percent of counterfeit notes found by high-speed verifiers are detected as a result of incorrect magnetic signatures (NRC, 2006, p. 12).[13]

The paper substrate of U.S. banknotes has a difficult-to-duplicate light green-yellow tint that is a major deterrent to counterfeiting (NRC, 2006). The paper is manufactured under close security by a single U.S. firm from a mixture of 75 percent cotton and 25 percent flax.[14] The color is a characteristic of the paper manufacturing process during which no clay or other whitening agents are added, and no bleach or other chemicals are used to whiten the paper. As a result, unlike most printing papers, U.S. banknote paper does not fluoresce under ultraviolet light. When combined with raised

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[13] We are not aware of comparable discussions of machine-readable features for banknotes issued by monetary authorities outside the United States, although many authorities include machine-readable features in descriptions of their banknotes.

[14] The flax provides a "stiffness" to the notes that is absent in many 100 percent cotton notes, and increases their durability.

texture provided by intaglio-printed images and numerals, U.S. banknotes have a unique "feel" which surveys have reported is the most common method of counterfeit detection by the public and bank employees. For the visually impaired, this same feel is a tactile clue that helps to determine whether an offered banknote is genuine or not; it does not, however, assist the user with identifying the denomination of the note.

To foreshadow somewhat our discussion below of visual accessibility features, we note that banknote paper's light green-yellow tint also limits the contrast ratio that can be achieved between printed denomination numerals and their background. A higher contrast ratio improves the visual clarity of numerals (ideally, near black on white). But achieving higher contrast likely would require introducing bleach or other whiteners into the papermaking process. To the extent that such a change would alter the color and "feel" of U.S. banknote paper, it would remove one of the primary features used by the public, including the visually impaired, to detect counterfeit notes. To the extent the modified paper would display fluorescence, the change would also remove a test for the legitimacy of the banknote paper. At least with respect to banknote paper, anti-counterfeiting and visual accessibility considerations interact in a complex way, illustrating the potential trade-offs in currency design.

Preserving the traditional "look and feel" of U.S. banknotes has been an important consideration in recent design changes—security features have been selected so as not to change the traditional look and feel of U.S. banknotes. The National Research Council lauds current security features as highly durable, low cost, odorless, and environmentally sound (that is, they do not depend on hazardous materials being included in the note) (NRC, 2006, p. 2). Further, many of the features are detectable unaided, by the naked eye.

All monetary authorities, on a continuing basis, monitor the effectiveness of current counterfeit deterrence features and seek to develop new ones. By all estimates,

banknote design worldwide has been successful in deterring counterfeiting.[15] In the United States, this work is coordinated by the Advanced Counterfeiting Deterrence Steering Committee which lists effective currency design first among the three elements that comprise its counterfeit deterrence program (U.S. Treasury, 2006b, p. 7).[16] Discussions that seek to measure counterfeiting must separate two concepts: (i) the fraction of outstanding banknotes that are counterfeit; and, (ii) for the volume of notes that flow through a central bank's cash offices, what fraction are determined to be counterfeit. Counterfeit notes may be detected at any point in the economy, including by retail merchants, bank tellers, or central bank cash offices. Although central bank processing centers typically own the most sophisticated equipment, in the United States the majority of notes are detected by retail and bank personnel; the National Research Council notes that an incorrect "look and feel" is the most important detection method (NRC, 2006).

The flow of notes through central bank cash offices—relative to the outstanding number of notes in circulation—differs by denomination, by country, and through time, making it difficult to accurately infer the fraction of counterfeit notes in circulation. For almost all countries, the measured frequency of counterfeit notes is regarded as "low." For U.S. banknotes in circulation both inside the United States and abroad, the Treasury estimates that fewer than 1 in 10,000 are counterfeit.[17] The Federal Reserve reports that it removed from circulation during 2005, and sent to the Secret Service, 6.4 notes per million processed, or a total of approximately 234,000 notes among the 36.5 billion

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[15] Appendix A contains a list of internet sources for counterfeiting volume statistics of major world currencies.

[16] The second and third, respectively, are law enforcement and public education programs.

[17] The Advanced Counterfeit Deterrence Steering Committee is an interagency group that includes representatives from the Department of the Treasury (including the Bureau of Engraving and Printing), the Federal Reserve System, and the Department of Homeland Security's Secret Service. (Prior to creation of the Department of Homeland Security, the Secret Service was an agency of the Treasury Department.) The Secret Service has jurisdiction over all matters related to counterfeit Federal Reserve notes. For discussion of methodologies used to estimate counterfeit currency worldwide, see the interagency reports issued by the U.S. Department of the Treasury (2000, 2003, 2006).

pieces of currency processed.[18] The incidence for the euro also is low: For 2005, the European Central Bank reports detecting and confiscating from circulation 579,000 notes during the annual processing of approximately 30 billion notes (as of December 31, 2005, there were 10.4 billion euro notes in circulation).[19] The €50 and €100 were the most frequently counterfeited notes.

Changes in currency design are an important tool to deter counterfeiting. European newspaper articles suggest that counterfeiting rates for the euro are significantly lower than for the individual country banknotes that it replaced. News reports from Canada also illustrate the necessity for updating currency designs. Published reports for 2004 cited the counterfeiting of older-design notes as being at "dangerous" levels, with a rate of 4.7 counterfeit notes per 10,000 notes examined.[20] Later published reports stated that the new-design notes with enhanced deterrence features had reduced the rate to 2.2 notes per 10,000 during the first eight months of 2006. These features of Canadian banknotes are examined below. The Reserve Bank of New Zealand and the Reserve Bank of Australia reported to us that counterfeiting of polymer notes has been negligible, with ongoing activity limited to remaining paper notes in circulation; polymer notes are described in more detail below.

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[18] During 2005, the Federal Reserve Banks processed 36.5 billion pieces of currency (Board of Governors of the Federal Reserve System, 2006). For the number of detected counterfeits, see Table 6.3, U.S. Department of the Treasury (2006). As of December 31, 2005, 24.9 billion banknotes were in circulation, excluding $2 notes (U.S. Treasury, 2006a). Of these, approximately 5.4 billion were $100 notes, a large proportion of which are likely held abroad, and approximately 8.8 billion were $1 notes, likely seldom counterfeited.

[19] See ECB (2006a, p. 102, and the biannual report of the European Central Bank regarding counterfeiting, available at www.ecb.int/press/pr/date/2006/html/pr060113_1.en.html. European newspaper articles suggest that counterfeiting decreased sharply following introduction of the euro, an example of the familiar result that design changes tend to slow counterfeiting. See also europa.eu/scadplus/leg/en/s30003.htm, a website of the European Parliament, and Europol (2006a, 2006b)

[20] More information is available from the Royal Canadian Mounted Police www.rcmp-grc.gc.ca/scams/counter_e.htm and various Canadian Broadcasting Corporation reports, including www.cbc.ca/news/background/counterfeit/ and www.cbc.ca/canada/story/2006/11/20/counterfeit-bills.html.

CURRENCY DESIGN FEATURES FOR THE VISUALLY IMPAIRED

Banknote designers worldwide are aware of the desire by the visually impaired to use currency in day-to-day transactions; hence, most banknote issuers consult regularly with advocacy organizations. The principal issue for the visually impaired (persons with some recognizable visual field, including approximately 90 percent of persons with visual impairment in the United States), is readily determining the denomination of banknotes during a transaction, say, at a distance of 16 to 24 inches.[21] The principal issue for the blind (persons with no recognizable visual field) is the presence of tactile banknote features and/or features that assist automated recognition of denomination by electronic currency readers.

Although some analysts might desire to employ economic benefit-cost analysis to select a set of features, the choice is not straightforward. Some features that assist the visually impaired, such as larger high-contrast numerals, also assist normally sighted users to denominate banknotes under low-light conditions. Such features perhaps are easily accepted on a benefit-cost basis. But these, as well as most other low-cost features that are of value for the visually impaired, typically do not greatly assist the blind. In our research, one design feature consistently appeared as the most valuable feature to the blind and severely visually impaired—note sizes that vary by denomination. (This feature also has some value to the non-impaired, especially in low-light conditions.) In a nation where the monetary authority does not issue banknotes that vary in size by denomination, implementing such a system might impose extraordinary costs on the handlers of banknotes, including financial institutions, retail merchants, high-volume banknote processors, and perhaps the non-visually impaired. Once different sizes are established in an economy, however, we have been told that *marginal* costs are minimal relative to circulating solely a single-size banknote. Among major currency issuers

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[21] In our research, we have encountered several standards for classifying persons as "visually impaired" or "blind." The text in this paragraph uses one such classification. Below, we cite another in which blind is equated to a corrected visual acuity of less than 20/200, and visually impaired as a corrected visual acuity of less than 20/40.

worldwide, only banknotes issued by Canada and the United States do not differ in size by denomination.

Advances in technology promise increased ease of use for the blind and visually impaired. Canadian banknotes and all U.S. new-design banknotes issued since 1997, for example, contain specific machine-readable features that have been designed to assist the visually impaired. In Canada, through the Canadian National Institute for the Blind, blind and visually impaired persons can obtain at no cost a handheld banknote reader that signals denomination to the user via voice, tone, or vibration. This machine is produced by Brytech (www.brytech.com), which introduced a currency reader for Canadian currency in 1989 and a reader for U S currency in 1992. The readers are not identical—the reader for Canadian notes is smaller and contains features not included in the U.S. reader. In our research, we purchased a Brytech reader for U.S. banknotes and asked approximately 20 of our colleagues to test their banknotes, both old and new designs, in a variety of condition. The note reader failed only on notes with folded corners and/or stains in the ends of the note being read. In discussions, Brytech staff noted that while some customers find the U.S. currency reader satisfactory, others find it bulky and too expensive, and that some users have reported problems using it with newer 1996-series and later currency designs. Although not inexpensive at US$280, perhaps technological advances will allow future price reductions.

When considering costly design features that assist the visually impaired, an economic analysis of the benefit-cost tradeoff depends, in part, on the number of affected persons. But, a great deal of uncertainty surrounds such estimates—it is difficult to measure accurately the number of Americans who will today and might in the future benefit from improved banknote visual accessibility. The National Research Council (1995) reports, based on one widely used classification, that as of the early 1990s approximately 9 million Americans were classified as blind or visually impaired. The NRC (1995) report cautions that traditional criteria may greatly understate the true extent of impairment because the determination is made by measuring visual acuity in laboratory settings under ideal lighting and high-contrast conditions. To read text rapidly

and accurately in practical situations such as occur at a retail cash register, might require numerals three to five times larger than the sizes suggested by laboratory visual acuity tests—such a criterion would classify millions of additional persons as visually impaired. In addition, many studies, including NRC (1995), have noted that the design of visually accessible currency is as much an *age-related* issue as a *vision-related* issue. Looking forward, the aging of the world's population portends visual problems—many conditions related to aging reduce vision, including macular degeneration, glaucoma, and retinitis pigmentosa. In addition, contrast sensitivity often diminishes with age and pupil size tends to decrease with age: At 80 years old, the eye often admits only one-quarter the light admitted for a 20-year old. Combined with other age-related factors, the result is "a severe reduction in visual performance under adverse lighting conditions for older people."[22] (The first formal study of the visual accessibility of U.S. banknotes, reviewed below, was conducted at the behest of the U.S. House of Representatives committee on aging.) The aging of the U.S. population promises to increase the importance of accessibility features for the blind and visually impaired: the National Eye Institute estimates that the number of Americans who are blind (that is, best corrected visual acuity of 20/200 or less in the better-seeing eye) and have low vision (best corrected visual acuity of 20/40 or less) due to age-related eye diseases will *double* over the next 30 years. (Of course, persons without visual impairment, might also benefit if new currency designs reduced payment errors and eased identification of denominations.)

Recognizing these technical shortcomings with respect to measuring visual impairment, the National Research Council in 1995 argued for an aggressive stance with respect to vision enhancements: Small enhancements, adequate in laboratory settings, are likely to produce designs that are inadequate in practical settings. Among their conclusions was this (NRC, 1995, p. 26):

> It is clear that a major need exists for a better means of banknote denomination for the 3.7 million Americans with visual disabilities, with the goal of giving this population the full access to currency handling available to the rest of society and to visually disabled people

[22] NRC (1995).

> in other countries. In addition, due to the increasing number of older individuals with impaired vision due to minor eye disease or the normal aging process, such features would be of great benefit to a far wider population than that represented by the current statistics on blindness and low vision. Certain new features, such as color and size, and enhanced existing features, such as larger numerals of higher contrast, would also benefit those with normal vision by making denomination more rapid and convenient for all.

Visual accessibility features of banknotes issued by several member countries of the Bank for International Settlements' Committee on Payment and Settlement Systems (including the United States) are summarized in Table 1. Features include varying note sizes by denomination, oversize numerals to indicate denomination, high-contrast numerals printed in dark inks against light backgrounds, or the reverse, different principal colors for different denominations, and, tactile features such as embossed numerals or patterns of recessed or raised dots.

In Europe, the designers of euro notes at the European Central Bank "consulted extensively" on the design of the euro banknotes with the European Blind Union and the World Blind Union, the latter a worldwide umbrella organization for advocacy groups of the blind and visually impaired. A number of their specific efforts are described on the web site of the European Blind Union (www.euroblind.org) under the "Access to Information" heading. Special features include sizes that vary by (i) denomination (ii) "striking" "clearly contrasting" colors, (iii) denominations printed in large numerals, (iv) high-relief raised intaglio printing, (v) and special tactile marks printed in intaglio along the edges of €200 and €500 banknotes. [23]

There is a similarly long history in the United States of interaction between currency designers at the Bureau of Engraving and Printing and advocacy groups for the visually impaired. The American Council of the Blind reportedly has submitted suggestions regularly to the Bureau of Engraving and Printing since at least 1972 (NRC, 1995). In 1983, the first (to our knowledge) formal study of the visual accessibility of

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[23] See www.ecb.int/bc/euro/banknotes/visually/html/index.en.html, as of January 2007. The €5, 10, 20, 50, 100, 200 and 500 notes, respectively, feature the colors gray, red, blue, orange, green, yellow, and purple.

U.S. banknotes was conducted by representatives from the American Council of the Blind, the Federal Reserve System, the Bureau of Engraving and Printing, and the U.S. Secret Service, at the request of Congressman Edward Roybal, chair of the U.S. House Committee on Aging. The subsequent report is Bureau of Engraving and Printing (1983).[24] In addition to being the first formal study, the 1983 report is important because its issues resurface in more recent discussions. In its introduction, the report says that "since the early 1970s" there has been a "significant interest" in designs for U.S. currency to assist the visually impaired—that is, since the Netherlands introduced in January 1971 innovative banknotes with raised (embossed) tactile symbols for each denomination. The report continues by citing unpublished 1976 and 1980 studies by the Bureau of Engraving and Printing regarding methods for easing the recognition of a banknote's denomination. The 1976 study, it says, examined the incorporation of Braille markings in currency, and the 1980 study examined "notching" and/or cutting the corners of banknotes.[25]

The 1983 report's original research is presented in three parts. First, the staff reviewed the currencies of 54 countries (including the United States) for characteristics that would assist denomination by the visually impaired, and asked each country to provide information on the performance of the features; five countries responded. The report's summary of the comments notes that "few countries have intentionally designed currency for this purpose" and that the comments received suggest that none are "completely satisfactory." Second, technical staff from the Bureau of Engraving and Printing evaluated "selected features" with respect to cost and usefulness to the visually impaired. Although details are not provided, the report says that the staff affirmed that commonly proposed design features—including colors that varied by denomination; large and clear numerals; note sizes that varied by denomination; cut corners or notches; and Braille-like tactile features—likely would assist denomination by the visually impaired.

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[24] This report is available from the Federal Reserve Bank of St. Louis in its FRASER archive: <fraser.stlouisfed.org>. as <http://fraser.stlouisfed.org/historicaldocs/TRESBEP/>.

[25] The outcome of such experiments in not noted in BEP (1983). With respect to notches and cut corners, the report does note that the Federal Reserve and U.S. Secret Service "expressed fundamental concerns" that problems might arise during a transition period.

Costs for implementing these features, in various combinations, ranged from $600,000 to $6 million per year, perhaps unacceptably large. Third, the staff explored the feasibility of an automated portable currency reader. Noting that such a device already was available but citing its bulk and expense, the staff recommended that funding be sought to develop a handheld electronic currency reader able to denominate currency. Such a device would assist both the visually impaired and the blind, while requiring at most only modest design changes for U.S. banknotes.

Chronologically, the next formal U.S. study of visual accessibility was commissioned by the Bureau of Engraving and Printing from the National Research Council of the National Academy of Sciences (NRC, 1995). The charge to the National Research Council was to

- assess features that could be used by people who are visually disabled to recognize, denominate, and authenticate banknotes;
- recommend features that could reasonably be incorporated into banknotes using available technology;
- suggest strategies that should be instituted to make the recommended features more effective;
- and identify research needs in particularly promising areas that could lead to attractive future approaches.

The 1995 NRC study is lengthly and complex, considering in detail both practical and technical issues. This quote summarizes the NRC's view of the state of U.S. currency design in 1995 (NRC, 1995, Chapt. 2, page 13):

> The United States is alone in issuing paper currency bills in which all denominations are of identical size and color. The numbers on the corners of the bills are small and of low contrast, making them difficult to read by people with impaired vision. For everyday transactions, U.S. paper currency possesses no nonvisual identifying features, rendering it impossible for blind people to denominate bills without assistance. The lack of distinctive visual features and the total absence of nonvisual features for the common user constitute a hindrance to commerce and daily living for millions of visually disabled people. In addition, the lack of distinctive features results in problems of denomination for a much wider population with mild visual impairments, including those impairments acquired during the normal aging process, and for anyone in a poorly lit environment.

A harsher indictment of a currency's visual features (as of 1995) is difficult to imagine.[26] The study eventually recommends four features technologically available in 1995:

- banknote sizes that vary by denomination.
- large, high-contrast numerals on a uniform background. (For large numerals, the Committee recommended numerals larger than half the note's height of approximately 65 mm.)
- different predominant colors for each of the six denominations being printed.
- embedded features to assist development of effective, low-cost devices for examining banknotes.

These recommendations are largely the same as those identified in Bureau of Engraving and Printing (1983). Consistent with that study, the NRC (1995) concludes that varying banknote sizes by denomination is the most effective feature to assist denomination by both the blind and visually impaired. The study notes, however, that this is the most expensive feature to implement. Further, the change would primarily benefit the blind, who are approximately 10 percent of all visually impaired persons in the United States. In contrast, other features—such as larger numerals and different primary colors—would benefit all banknote users by speeding identification of denomination, particularly in low-light situations. Regarding cost, the committee concluded that the costs to redesign U.S. banknotes and modify equipment to handle them (especially in varying sizes) would be high—but the Committee did not temper its recommendations with regard to these costs because a major redesign already was planned during 1996-2001. Instead, the Committee recommended that these features be incorporated during the 1996-2001 currency redesign cycle.

During the past decade, the Bureau of Engraving and Printing has introduced two new designs for U.S. banknotes, each containing features to improve accessibility for the visually impaired. These designs are frequently referred to as the Series 1996 "New

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[26] The report does not address, however, constraints placed on U.S. banknote design for widespread recognition and acceptability abroad.

Currency Design" and Series 2004 "New Color of Money" designs.[27] Series 1996-design notes were introduced beginning with the $100 note in March 1996, followed by the $50 note in October 1997, the $20 note in the fall of 1998, and the $5 and $10 notes in May 2000. Series 2004-design notes were introduced with the $20 note in October 2003, followed by the $50 note in late 2004 and the $10 in March 2006 (the $5 note is anticipated in early 2008). These new designs include a number of security and accessibility features that are visible and useful without machine assistance. For visual accessibility, the Series 1996 design, beginning with the $50 note, introduced an enlarged, 14 mm-tall denomination numeral in the lower right corner of the notes' reverse side.[28] The presidential portrait also was enlarged. A machine-readable feature to facilitate development of handheld scanning devices for the blind and visually impaired has been included in all new-design banknotes issued since 1997. The Series 2004 design introduced an additional accessibility feature, subtle background colors:

> For the first time since the Series 1905 $20 Gold Certificate, the new currency featured [sic] subtle background colors, beginning with the new $20 note on October 9, 2003. In this series, different colors are used for different denominations. This will help everyone—particularly those who are visually impaired—to tell denominations apart. The $20 note features subtle background colors of green, peach and blue, as well as symbols of freedom representing icons of Americana—in the case of the $20 note, images of the American eagle.

It is of interest to compare the features of these newer banknotes designs to recommendations made in the previous 1983 and 1995 studies. How adequate are these new features? In its most recent report, the National Research Council (NRC, 2006, p.10) concludes that these features "do not provide adequate differentiation for many visually impaired individuals and provide no method of differentiation for blind persons."

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[27] The Bureau of Engraving and Printing refers to additional series (for example, Series 1999, 2001, and 2003) to denote changes in the signatures on the notes; these were not design changes, however. See www.moneyfactory.gov/section.cfm/4/27/ .

[28] U.S. banknotes typically display denomination in numerals of between 8 mm and 12 mm tall. On $1 and $10 notes, for example, the upper front numerals are approximately 12 mm tall, while the numerals on the lower front and on the reverse are approximately 8 mm tall. The redesigned $100 note does not have the large high-contrast numeral.

This perhaps was not unexpected. Putting aside the enlarged portrait, the Series 1996 design added a single truly usable feature for the visually impaired: the enlarged 14 mm denomination numeral lower right corner of the reverse. But, the National Research Council previously noted that a numeral this size is near the visual limit for someone with 20/400 acuity when viewed at a reading distance of 16 inches (NRC, 1995): The NRC recommended a numeral more than twice as large. As an example, the NRC cites studies regarding denomination recognition of current $1 and $10 banknotes displaying 12 mm-tall numerals on their fronts, which standard acuity tests suggest should be adequate for many visually impaired—in fact, users with measured acuity less than 20/60 have difficulty recognizing such numerals at the distances of 16 to 24 inches that are common in retail cash transactions. With respect to color, the National Research Council (NRC, 1995) recommended that at least one side of each denomination's design feature a single prominent color, not subtle shades of background colors. Specifically, they wrote:

> Most other countries also use different predominant colors for each denomination. The simple detection color is faster than finding and reading printed numbers, especially for those with poor letter acuity. It should be noted, however, that many people with low vision have difficulty in discriminating subtle shades of color and that color cues are generally less obvious at low levels of illumination. Consequently, any color features should use clearly distinguishable colors.
>
> (NRC, 1995, p. 25)

We display Series 2004 notes below, and leave final judgment to the reader. Neither NRC report, however, addressed the tradeoff between improved visual accessibility and concerns for counterfeit deterrence and widespread recognition and acceptance, especially outside the United States. To date, we are aware of no study that addresses this tradeoff.

In the future, improvements in technology portend new features of value to the blind and visually impaired. The National Research Council's 2007 report (NRC, 2007), commissioned by the Bureau of Engraving and Printing, concludes that advances in currency substrates will be the only effective future deterrent to counterfeiting as improving digital technology eases image reproduction. But the report also contains fascinating glimpses of how new substrates that might permit designers to include

innovative features to assist the visually impaired denominate currency. “Shape memory” materials, for example, are ones that allow an object’s shape to change when subject to stress and return to the original shape when stress is released. Similarly, embedded piezoelectric crystals allow an object’s features to change when an electric current is applied. Conceptually, at least, such materials could allow embedded tactile denomination markings—say, similar to those in Canadian and Japanese notes—to “appear on demand” when a note is stretched or when it is energized by a battery operated device. Unlike current tactile markings, which degrade with abrasion, such markings perhaps could last the lifetime of the note. Technology also suggests the possibility of notes that change color when subject to an electric current, aiding both counterfeit deterrence and the long-sought goal of varying banknotes’ primary colors by denomination: for most users, the appearance of U.S. banknotes would be unchanged, while the visually impaired could energize special visual features as required. More analysis of such materials and features will be required before they could be implemented, and an international education program might be required if the “look and feel” of U.S. banknotes is affected by changes in substrates. But the promise intrigues.

WHAT DO OTHER COUNTRIES DO? SECURITY AND ACCESSIBILITY FEATURES

Banknote designers worldwide seek to include features both to deter counterfeiters and assist the visually impaired. Most banknotes incorporate several security features, including holograms, microprinting, serial numbers and watermarks. Most notes also include one or more visual accessibility feature, including different sizes and principal colors for different denominations, oversize high-contrast numerals, and tactile features such as embossed numerals or recessed/raised dots. In this section, we explore the features of currency issued by nine industrialized countries and the euro zone.

In their 1995 study, the National Research Council surveyed 171 currency-issuing authorities (NRC, 1995). In many countries, security and accessibility features were regarded as complementary. More than 120 countries varied note sizes by denomination,

24 featured oversized denomination numerals, and 167 used different primary color schemes for different denominations. Among larger countries, only the United States and Canada did not vary the size of their notes by denomination.

Table 1 compares and contrasts banknotes' characteristics relative those of an "ideal currency." Table 2 narrows the comparison to four visual accessibility features: colors that vary by denomination, sizes that vary by denomination, inclusion of tactile recognition symbols, and oversize denomination numerals. (The features shown in the tables are as reported by the respective monetary authorities in public documents. We have not undertaken any independent scientific investigation regarding the features of the banknotes.) In short, we find that six of the ten currencies include all four features, three currencies include three features, and one currency (the United States) includes only a single feature.

Currency images reproduced in this article are as accurate as possible with modern high-volume printing but do not necessarily match colors in the original banknotes. For some notes, to deter counterfeiters, designers select colors that cannot be accurately reproduced by office copiers, printers, and high-volume offset presses.

AUSTRALIA[29]

The Reserve Bank of Australia is responsible for printing, issuing, reissuing and canceling Australian notes. (Notes are printed by Note Printing Australia Limited, a subsidiary of the Reserve Bank.) Since 1996, all Australian banknotes have been printed on a polymer substrate.[30] The substrate is manufactured by Securency Pty Ltd., a joint venture between the Reserve Bank and Innovia Films. The substrate is created by coating a clear polypropylene film with an opacifying ink. The 'press ready' substrate is supplied to Note Printing Australia. Traditional security printing processes are used to print the notes, including offset and intaglio. As a final step, a clear overcoat is applied to the notes. It is possible to achieve the same intaglio height on polymer substrate as on paper, by depositing a greater quantity of ink.[31] When "blind embossing" polymer (using an uninked intaglio plate) a greater degree of emboss can be achieved in the substrate.

According to the Reserve Bank of Australia, the counterfeiting rate for Australian banknotes is "very low.," averaging between five and six counterfeits per million notes in circulation in recent years. Almost all counterfeits of Australian notes are printed on paper rather than polymer. Yet, even polymer notes are not immune to counterfeiting attempts; in March 2006, Interpol seized more than $5 million of such notes in Colombia, a popular location for counterfeiters.[32] Such attempts appear to be rare; so far as we are aware, no such notes were placed into circulation.

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[29] Additional information may be found at www.rba.gov.au/CurrencyNotes/

[30] Since 1998, New Zealand banknotes have been produced by the same process, in Australia.

[31] The height of the relief on polymer notes has encountered some controversy. With paper substrate, a somewhat higher initial relief may be obtained than on polymer, but advocates of polymer substrates have argued that the higher relief degrades quickly to a lower relief than on polymer notes. We take no position on this, leaving debates regarding the exotic technical details of intaglio printing on alternative substrates to others. See for example Coventry (2001), only one of many papers on this topic.

[32] See www.interpol.int/Public/FinancialCrime/CounterfeitCurrency/recentEvents.asp or the BIS-G10 Central Bank Counterfeit Deterrence Group (CBCDG) joint counterfeit deterrence task force, www.rulesforuse.org/pub/index.php?lang=en&page=pressreleases.

Although more costly than paper notes, polymer notes are more durable than paper notes (they last at least four times longer), more difficult to counterfeit, and recyclable. Australian banknotes vary in color and length according to denomination. The $5 banknote is the shortest, (130 mm by 65 mm), and the $100 banknote is the longest (158 mm by 65 mm).

Security Features

Among the security features included in the banknotes are

- clear window with "blind" embossing and a printed image
- see-through registration device
- shadow image (similar to a watermark)
- intaglio print
- background print (including screen traps)
- microprinting
- machine-readable features including UV fluorescence, infrared and magnetics/inks.

Accessibility Features

The Reserve Bank of Australia consulted with a number of bodies representing the visually impaired in designing the polymer note series. Among the accessibility features of the banknotes are

- length differentials by denomination
- strong color contrasts by denomination
- bold numerals

Raised intaglio printing of denomination numerals, portraits, and other elements is both a security and accessibility feature. In addition, Blind Citizens Australia provides, free of charge, a credit-card size device to measure note length and distinguish between denominations. So far as we are aware, no handheld reader is available that uses the included machine-readable features to assist the visually impaired.

INSERT PICTURE OF AUSTRALIAN BANKNOTES HERE

CANADA

The Bank of Canada has sole responsibility for issuing, designing, producing and distributing Canadian banknotes.[33] The Bank of Canada's first banknote series was printed on a combination of flax and cotton paper with the same nominal composition as U.S. banknote paper. Since 1983, however, Canadian banknotes have been printed on 100 percent cotton paper to conform to Quebec environmental laws on flax use.

Canadian banknotes are uniform in size but vary in color by denomination. Notes measure approximately 6 inches long by 2.75 inches wide.[34]

The production cost of Canadian banknotes is approximately 9 Canadian cents per note. The estimated life of the banknotes by denomination is as follows

- $5: 1 to 2 years
- $10: 1 to 2 years
- $20: 2 to 4 years
- $50: 4 to 6 years
- $100: 7 to 9 years

According to the Bank of Canada, Canadian counterfeit notes make up a very small percentage of notes in circulation.[35] The most recently issued banknote series—entitled the Canadian Journey series—contains both enhanced security features to deter counterfeiting and tactile features to aid the visually impaired.

The Bank of Canada consulted with the Canadian National Institute for the Blind, the Canadian Council for the Blind and the blind and visually impaired community in the design of their *Canadian Journey* and *Birds of Canada* bank note series to help the blind

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[33] Additional information may be found at www.bankofcanada.ca/en/banknotes/

[34] With the exception of the 1935 and 1937 banknote issues, which are 6 inches by 2.875 inches .

[35] The Royal Canadian Mounted Police's Bureau for Counterfeit and Document Examinations estimates that in 2005, the volume of counterfeit notes passed and seized was approximately 422,489 out of 1,501,743,000 notes in circulation, or 0.00028percent of the total notes in circulation (www.rcmp.ca/factsheets/fact_counterfeit_e.htm). The figure was even lower in 2006, according to the Bank of Canada, 313,207 counterfeit notes were passed and seized, from a total of 1,567,318,000 notes in circulation, or 0.00020 percent.

and visually impaired with recognition of bank notes by sight, touch or electronic devices. The Bank of Canada, in collaboration with the blind and visually impaired community has encouraged the development of machines to denominate Canadian notes.

Through the Canadian National Institute for the Blind, blind and visually impaired persons can obtain (at no cost) a handheld banknote reader that signals denomination to the user via voice, tone, or vibration.

The tactile denomination scheme, of Canadian invention, consists of sets of raised dots that vary in position and number according to denomination. The dot system is not Braille which, contrary to public impressions, is not known by all the blind. The basic "symbol" in the scheme is a tightly spaced rectangular block of six dots—the number and placement of such blocks indicates the denomination. The $5 note has one block, for example, while the $20 note has three such blocks separated by a smooth surface. Canadian banknotes also include intaglio printing of the denomination numerals, which doubles as a security and accessibility feature.

Security Features

- (1) Holographic stripe
- (2) Watermark portrait
- (3) Windowed color-shifting thread
- (4) See-through number when note is held to the light
- Raised ink (intaglio)
- Fine-line patterns
- Microprinting
- Fluorescence, presence of elements only visible under UV light
- Serial number
- Unique, difficult-to-reproduce colors

Accessibility Features

- Primary colors that vary by denomination
- Tactile symbols embossed and back-coated for durability
- Large high-contrast denomination numerals
- Machine readability-feature, free banknote readers

Features of Canadian Journey Series


20
CANADA
20
20
1 Holographic Stripe
2 Watermark
3 See-Through Number
4 Security Thread

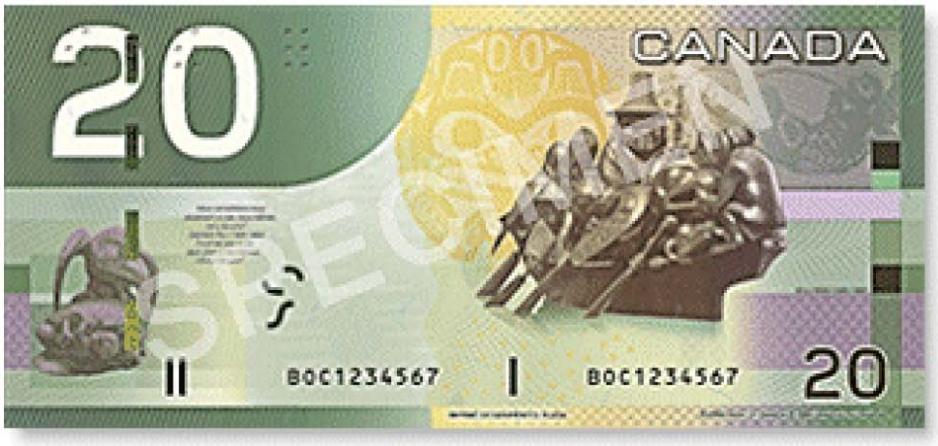
$20

2001-2004 Series, *Canadian Journey*

Front

Security features of this note

Back



EURO AREA

The euro banknotes were introduced as legal tender in the Eurosystem on January 1, 2002. [36] The European Central Bank (ECB) and the national central banks (NCBs) of the participating countries have the right to issue euro banknotes, but in practice only the NCBs issue banknotes.[37] Banknote production is pooled between the national central banks of the euro area.[38] The approximate production cost is €0.08 per banknote.

Euro banknotes are made of 100 percent cotton. Banknotes vary in height, length, and color according to denomination. The €5 banknote is the smallest in size, measuring 120 mm long by 62 mm wide; the €500 banknote is the largest, measuring 160 mm long by 82 mm wide. The estimated life of euro banknotes by denomination is as follows[39]:

- €5: 1.2 years
- €10: 1.2 years
- €20: 1.4 years
- €50: 3.3 years
- €100: 7.5 years
- €200: 10.4 years
- €500: 23.1 years

Weighted average lifetime for all denominations is 2 years.

The ECB has consulted with the European Blind Union since the beginning of the euro note design phase in 1995 to ensure notes were highly accessible to the blind and visually impaired.

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[36] The Eurosystem comprises the ECB and the NCBs of the European Union member states that have adopted the euro. Currently, 13 member states of the European Union participate in the single currency; namely, Belgium, Germany, Greece, Spain, France, Ireland, Italy, Luxembourg, the Netherlands, Austria, Portugal, Slovenia, and Finland.

[37] Additional information may be found at www.ecb.int/bc/euro/banknotes/html/index.en.html.

[38] TheNCBs commission printing works, which each print one or two of the seven denominations. Once they have printed the banknotes, the issuing central banks exchange them. This process increases efficiency and quality control. The ECB monitors the stocks of the banknotes.

[39] Data furnished by the ECB. Life span of the banknotes is calculated by dividing, for each denomination, the average circulation of banknotes during the previous 12 months, by the number of banknotes sorted to unfit during the previous 12 months.

> "Each banknote – whether €5 or €500 – had to be readily identifiable by people with residual or no sight. For example, the differences in height between the lower, more commonly used denominations were quite distinct. The €100, €200 and €500 banknotes were made the same height – to facilitate automatic handling – but repetitive embossed patterns were placed on the €200 and €500 banknotes to differentiate them.
>
> Large and bold value numerals were placed in a standard position throughout the series, on both sides, and sharply contrasting colours were used. They were derived principally from the colour wheel of the Swiss painter and art teacher Johannes Itten (1888-1967). The colours chosen for successive denominations were taken from opposing segments of the colour wheel and thus strongly contrast with each other. The same is true for denominations that have digits in common, like the red €10 and green €100 banknotes."
>
> *How the Euro became our money. A short history of the euro banknotes and coins* (www.ecb.int/pub/pdf/other/euro_became_our_moneyen.pdf).

While euro banknotes include denomination-specific machine-readable features intended to assist authentication and denomination by third parties (primarily high-volume currency processors and banknote equipment manufacturers), so far as we are aware, electronic banknote readers have not been developed to assist visual impaired individuals.

Counterfeiting of euro banknotes is reportedly low. For 2003-2006, the ECB reports detecting and confiscating from circulation approximately 600,000 notes annually (with approximately 10 billion in circulation). Figures on notes confiscated by law enforcement before entering circulation are confidential.

Security Features

- Made of pure cotton
- Intaglio print
- Tactile marks (on €200, and €500)
- Wire and multitone watermark
- Security thread

- See-through register when note is held to the light
- Perforations in the hologram foil
- Hologram foil
- Optically variable ink (€50, €100, €200, and €500)
- Iridescent stripe (€5, €10, and €200)
- Mini and microprinting
- Fluorescence, presence of elements only visible under UV-light

Accessibility Features

- Size differs by denomination
- Primary color varies by denomination: bold, striking colors, clear contrasting colors among denominations
- Oversize denomination numerals
- High-relief intaglio printing
- Tactile marks (200€ and 500€ only)

HONG KONG

The Hong Kong Monetary Authority has authorized (delegated) the issuance of Hong Kong banknotes to three commercial banks —The Hongkong and Shanghai Banking Corporation Ltd., the Standard Chartered Bank, and the Bank of China (Hong Kong) Limited— under specific terms and conditions stipulated by the Hong Kong government. The notes issued by the three banks differ somewhat in design although all banknotes are printed in Hong Kong by Hong Kong Note Printing Limited.[40] The notes illustrated here are those issued by Hong Kong and Shanghai Banking Corporation Ltd.

Under normal usage, a banknote is estimated to last for an average of about two years. Production costs are confidential.

Hong Kong banknotes vary in length and color according to denomination. Enhanced intaglio printing serves both as a security and accessibility feature.

In the design phase for the currency issued in 2003 and 2004, the Hong Kong Monetary Authority consulted with major advocacy organizations to include accessibility features for the blind and visually impaired. In addition, the three note-issuing banks and the Hong Kong Monetary Authority produce a template to aid the visually impaired in measuring a banknote's size.

Security Features

- Fluorescent machine-readable barcode
- Iridescent images
- Denomination numeral in optical variable Ink
- Holographic windowed thread
- Concealed image/ denomination
- Intaglio printing
- Invisible fluorescent fibers
- Watermarks
- Security thread
- See-through feature

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[40] Additional information may be found at www.info.gov.hk/hkma/new_hk_banknotes/eng/index.htm.

- Serial numbers

Accessibility Features

- Varying size by denomination
- Varying color by denomination
- A bold, large denomination numeral on the front of all banknotes at a common location, with deep engraving to give a pronounced tactile feel
- A bold denomination numeral in negative outline located at a common location at the back of all banknotes
- Enhanced intaglio printing to give stronger embossing effect
- Banknote size measurement template

JAPAN

The Bank of Japan is the sole issuer of Japanese banknotes. The banknotes are manufactured by the National Printing Bureau, an incorporated administrative agency.[41]

In response to the increase of Japanese counterfeit banknotes in recent years, the Bank of Japan issued a new series of banknotes in 2004 with improved security features. There are four denominations: 1,000, 2,000, 5,000, and 10,000 yen. The redesigned Japanese yen notes vary in width and color according to denomination. The 1,000 yen banknote is the shortest note, measuring 76 mm wide by 150 mm long, and the 10,000 yen banknote is the longest, measuring 76 mm wide by 160 mm long. Bank of Japan notes contain machine-readable features intended to assist mechanical note processing. So far as we are aware, no consumer-level devices to assist the blind and visually impaired.have been developed.

The average durability of the Bank of Japan notes is one to two years for the 5,000 and 1,000 yen notes and four to five years for the 10,000 Yen notes.[42]

In fiscal year 2005, the total manufacturing cost of 4.08 billion banknotes amounted to 61.7 billion yen, approximately 15.1 yen per banknote.

The current series of Bank of Japan notes contain "tactile marks" created by high-relief intaglio printing to assist the visually impaired. High-relief numerals, created by intaglio printing, both defer counterfeiting and assist the visually impaired. The Bank of Japan occasionally makes studies to improve the accessibility features for the visually impaired.

Security Features

- Hologram (10,000 yen note)
- Watermark-bar-pattern
- Latent image

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[41] Additional information may be found at www.boj.or.jp/en/type/release/zuiji/kako03/bnnew3.htm.

[42] Source: Bank of Japan.

- Pearl ink
- Ultra-fine line printing
- Intaglio printing
- Microprinting
- Luminescent ink

Accessibility Features

- Tactile marks (intaglio printing)
- Different sizes
- Different colors

New 10,000 yen note (Front and Back)

[1] Hologram: color and pattern changes as note is tilted

[2] Watermark bar pattern visible in transmitted light (shining through note)

[3] Latent image visible only from certain low angle

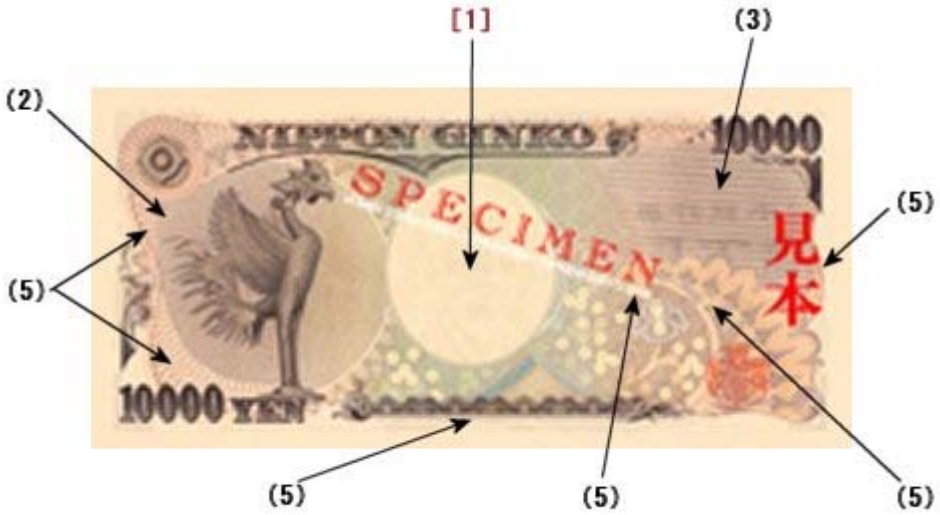
[4] Pearl ink: semi-transparent pattern appears in blank left and right margins at different angels

[5] Microprinting: very small words in background

[6] Luminescent ink: seal glows orange under ultraviolet light; some background elements fluoresce yellow-green

[7] Intaglio printing: higher relief than on previous notes

[8] Tactile marks (intaglio printing): raised symbol with rough texture for visually impaired



SINGAPORE

The Monetary Authority of Singapore (MAS) is the sole issuer of banknotes in Singapore[43]. In 1990, the MAS issued their first polymer note of S$50 denomination. Polymer notes are more durable and cost-effective. Both paper and polymer banknotes are currently in circulation. Their "Portrait Series" notes were first issued in 1999. This series has seven denominations. The banknotes vary in length, width, and color according to denomination. The smallest note is the S$2 note, measuring 126 mm in height by 63 mm in width; the largest note is the S$10,000 note and measures 180 mm in length by 90 mm in height. Singapore banknotes are machine readable.

High-relief intaglio printing of several characteristics, including the denomination numeral, serves as an accessibility and anti-counterfeiting feature. During the design phase of the Portrait-series notes, MAS consulted with the Singapore Association of the

[43] Additional information may be found at www.mas.gov.sg/masmcm/bin/pt1Singapore_Circulation_Notes.htm.

Visually Handicapped on their needs for the new series of banknotes. The Association recommended the printing of Braille codes and varying note size by denomination. The Braille codes are printed in heavy, high-relief intaglio on the top right of the front of each note.

According to the Monetary Authority of Singapore, the cost and duration of their banknotes by denomination are as follows:

$2 polymer	S$0.10	72 - 96 months (issued in Jan 2006, still monitoring the performance)
$5 paper	S$0.10	18 - 24 months
$10 paper	S$0.09	24 - 36 months
$10 polymer	S$0.12	72 - 96 months (issued in May 2004, still monitoring the performance)
$50 paper	S$0.08	24 - 36 months
$100 paper	S$0.07	48 - 60 months
$1,000 paper	S$0.09	48 - 60 months
$10,000 paper	S$0.55	48 - 60 months

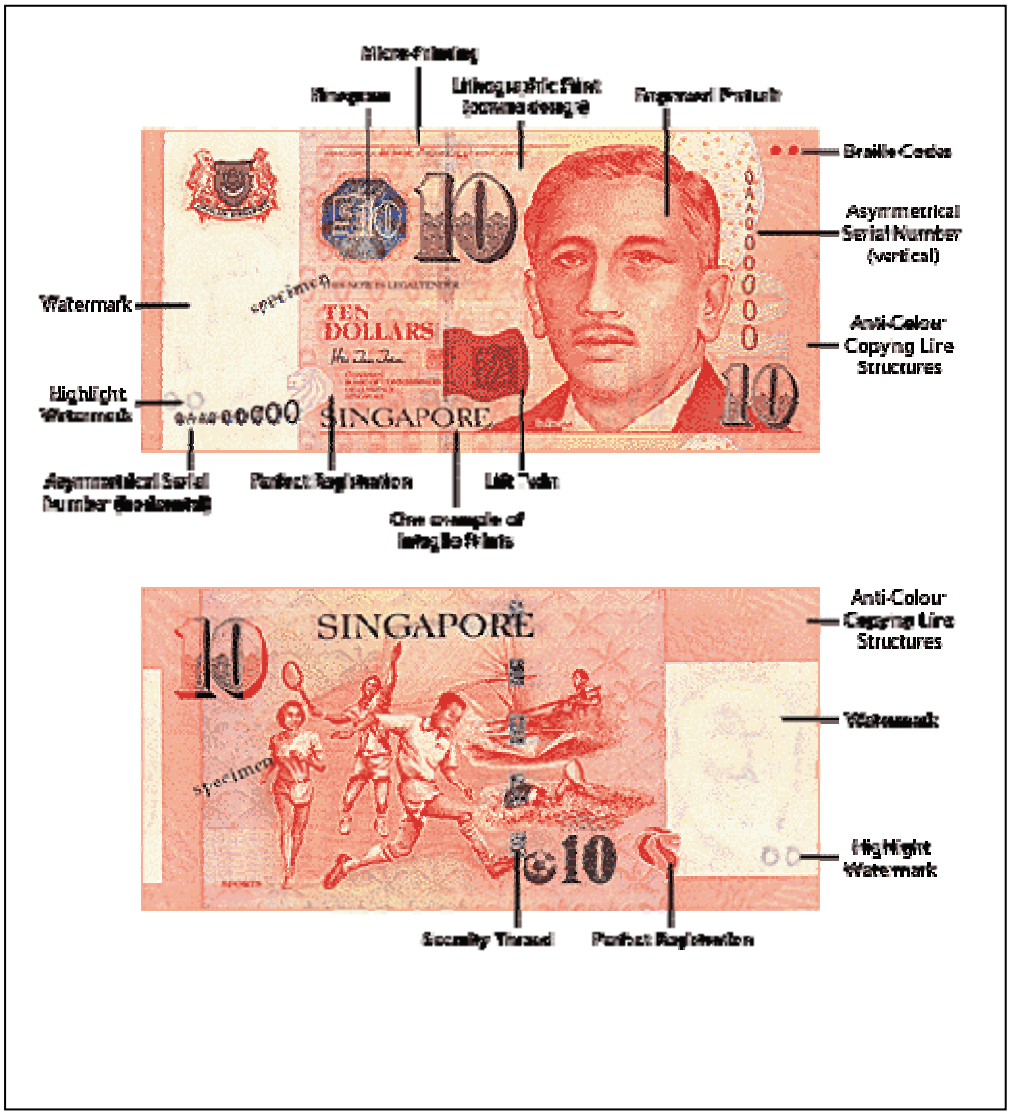
Security Features

- Microprinting
- Kinegram
- Lithographic print
- Engraved portrait
- Braille codes
- Asymmetrical serial numbers (vertical and horizontal)
- Anti-color copying line structures
- Lift twin
- Intaglio prints
- Highlight watermark
- Watermark
- Perfect registration
- Security thread
- Invisible feature: non-reflective under UV light
- See-through windows on polymer notes

Accessibility Features

- Braille codes
- Different colors

- Different sizes
- Intaglio printing



ANNEX

Design of $2 Polymer Notes

Front

Back

Key Changes in Security Features (Unique to Polymer)

				
Complex Clear Window	**Shadow Image**	**Singapore Lion Symbol with Hidden Image**	**Security Thread**	**Embossed Clear Window**
A see-through window with a multi-tonal image of the Singapore Arms	A watermark-like image of President Yusof bin Ishak is visible when viewed with transmitted light.	A stylized gold patch with the image of the Singapore Arms appearing at varying angles	A security thread in the shape of the Singapore island	A clear window with the denomination embossed in it, with repetitive patterns on the top and bottom

SWEDEN

The Sveriges Riksbank is the sole issuer of Swedish krona banknotes.[44] Swedish banknotes are 100 percent cotton. Swedish banknotes are issued in five denominations (20, 50, 100, 500, and 1000 kronor), and vary in length, width, and color according to denomination. The 20 kronor banknote is the smallest in size, measuring 67 mm in width and 120 mm in length. The 1,000 kronor banknote is the largest, measuring 82 mm in width and 160 mm in length. Banknote lifetime varies by denomination, with 20 kronor banknotes being fit for circulation for about one year, and 1000-kronor for about five years. The cost of production is about 7.5 U.S. cents per banknote. Swedish banknotes contain machine-readable features but, so far as we are aware, no handheld devices are available to assist the visually impaired. Intaglio printing of the denomination and portrait serve as both a security accessibility feature.

Security Features

- Watermark
- Security thread
- See-through picture
- Intaglio printing
- Foil strip –Hologram
- Fluorescent picture (for banknotes with a foil strip)
- Micro lettering
- Shimmering mother-of-pearl ink
- Motion (a moving image in the striped bank; included in the 1,000 krona note with a foil strip only)

Accessibility Features

- Different colors
- Different sizes
- Intaglio printing

[44] Additional information may be found at www.riksbank.com/templates/SectionStart.aspx?id=10890.

Security features: Banknotes without a foil strip

Older banknotes without a foil strip are furnished with the security features numbered 1–5 on the list below.

1. The security thread is visible as a dark line when you hold the note up to the light.

2. The watermark is visible from both sides when the banknote is held up to the light. The watermark depicts the portrait on the note.

3. Fluorescent ink lights up yellow-green under ultra-violet light, showing the banknote number, texts or patterns on the face and reverse of the note.

4. Intaglio print means that the denomination and portrait on the face of the note have a raised, rough surface. Run your thumb over it.

5. Micro letterings are inlaid in each denomination. The texts can only be read with the aid of a magnifying glass.

Security features: Banknotes with a foil strip

Banknotes with a foil strip are furnished with the security features numbered 1–8 in the list on the next page. The 1,000-krona banknote also has a feature known as motion (no. 9).

SWITZERLAND

The Swiss National Bank's (SNB) network of cash distribution services is the issuing and redeeming authority of Swiss franc banknotes.[45] The network includes the SNB's three bank offices, 16 agencies, and 234 domestic correspondents. Swiss franc notes are printed on paper made of linters and short cotton fibers. Swiss franc banknotes vary in length and color according to denomination. There are six denominations (10, 20, 50, 100, 200, and 1000 Swiss francs). All notes measure 74 mm. in width. The length varies by denomination, in 11 mm increments, with the 10-franc banknote being the shortest (126 mm) and the 1000 franc being the largest (181 mm). Some of the security elements in Swiss banknotes are machine readable.

The cost of producing Swiss franc banknotes is approximately 30 centimes per new note. The average duration of the banknotes is:

10: 2 years
20: 1.5 years
50: 1.5 years
100: 3.5 years
200: 3 years
1000: 10 years

Perforated numerals serve as both an accessibility and security feature. A tactile symbol varying by denomination is embossed at the lower end of each note as an additional accessibility feature.

Security Features

- Transparent register
- Watermark digits
- Intaglio digits
- Perforated number
- Optically variable ink
- Ultraviolet digits

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[45] Additional information may be found at www.snb.ch/en/iabout/cash.

- Metallic digits
- Tilt effect

Accessibility Features

- Different colors
- Different sizes
- Perforated number
- Intaglio digits

A. Iriodin digits: the magic number

B. Watermark digits

C. Intaglio digits: the colored number

D. The perforated number

E. Optically variable ink: the chameleon number

F. F. Ultraviolet digits

G. Metallic digits: the glittering number

H. Tilt effect

Symbol perceptible to the touch varies by denomination

UNITED KINGDOM

The Bank of England is the sole issuer of banknotes in the United Kingdom.[46] Bank of England banknotes are produced by De La Rue Currency and made from cotton fiber and linen rag. The banknotes vary by color, length, and width according to denomination, with the £5 note measuring 135 mm by 70 mm, and the £50 note measuring 156 mm by 85 mm.

The Bank of England estimates an average life of banknotes of about 1 year for the £5 note, to five or more years for the £50 note.

During the banknote design phase, advice from the Royal National Institute of the Blind, a U.K. charity, is sought and their recommendations are implemented. For the new £20 series F note, for example, the Royal National Institute of the Blind recommended that large-high contrast numerals be included and the size and color differential between denominations be retained; both were accepted by the Bank of England. In addition, a recognition symbol unique to each denomination is included on the front of the banknote to aid the visually impaired.

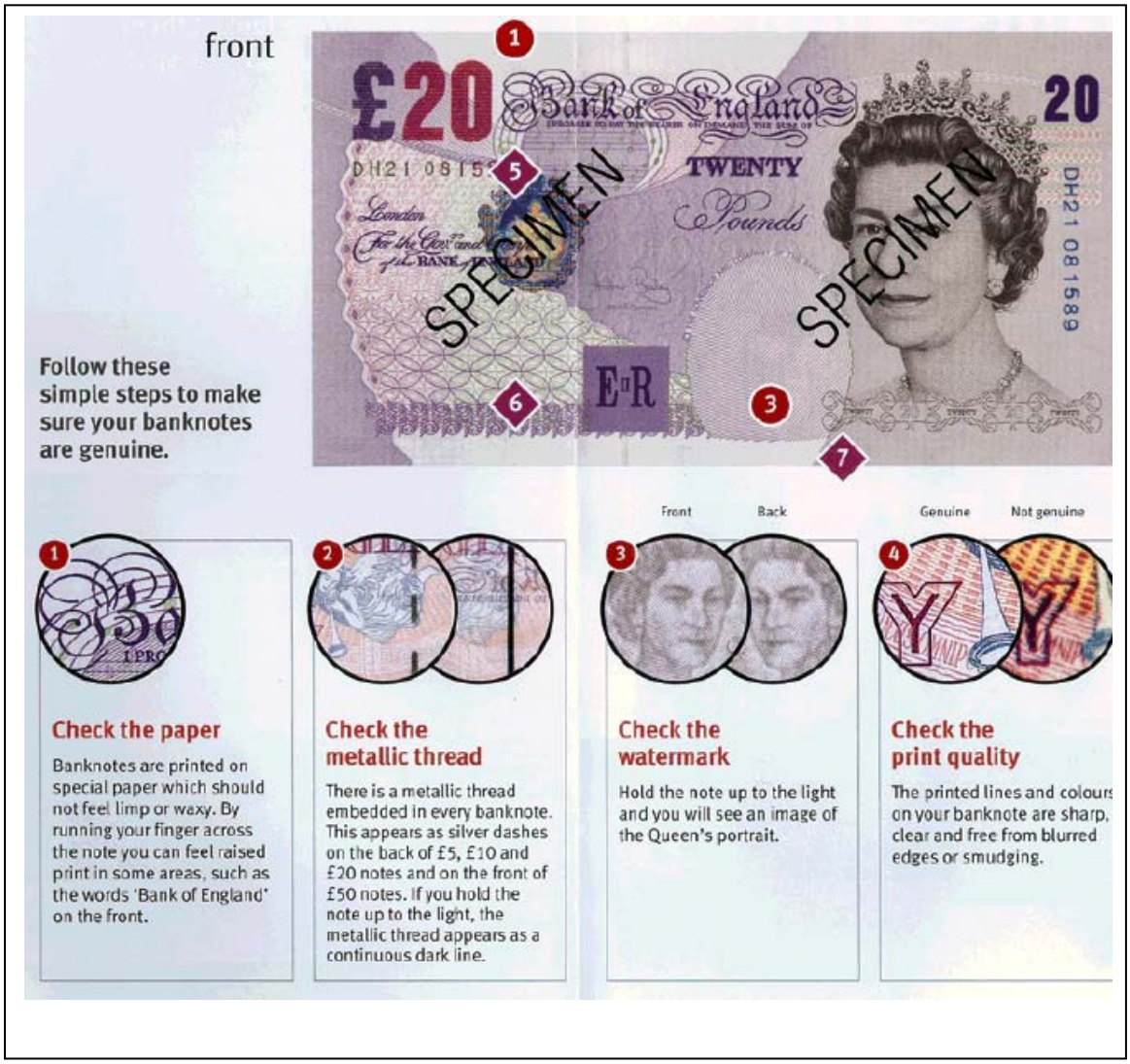
Security Features

- Made of cotton and linen paper
- Metallic thread
- Watermark
- Print quality
- Hologram
- UV-light
- Microlettering
- Foil (on £50 note)

[46] Additional information may be found at www.bankofengland.co.uk/banknotes/current/index.htm.

Accessibility Features

- Different colors
- Different sizes
- Large denomination numerals
- Recognition densely colored symbols by denomination:
    - £5: turquoise circle
    - £10: orange diamond
    - £20: purple square
    - £50: red triangle



back

Check the hologram

There is a hologram on the foil patch. If you tilt the note, the image will change between a brightly coloured picture of Britannia and the numerical value of the note.

Check with ultra-violet light

If you put a note under a good quality ultra-violet light, its value appears in bright red and green numbers while the background is dull in contrast.

Check the microlettering

Using a magnifying glass, look closely at the lettering beneath the Queen's portrait – you will see the value of the note written in small letters and numerals.

Check the foil on a £50 note

The £50 note has a foil patch on the front near the portrait of the Queen. This shows a reflective rose and medallion.

UNITED STATES

The United States Government is the sole issuer of U.S. banknotes.[47] The Bureau of Engraving and Printing, a part of the U.S. Treasury Department, produces U.S. banknotes, which are placed into circulation by the Federal Reserve Banks. Banknotes are made of paper composed of 25 percent linen and 75 percent cotton, with red and blue synthetic fibers distributed evenly throughout the paper. U.S. banknotes do not vary by size or primary color across denominations; they measure 2.61 inches wide by 6.14 inches long and 0.0043 inches thick. There are six denominations of U.S. banknotes ($1, $2, $5, $10, $20, $50, and $100). The $100 note has been the largest denomination issued since 1969.

The estimated cost of producing U.S. banknotes was 5.6 cents per banknote during fiscal year 2006[48]. The estimated average life of a U.S. banknote varies by denomination:

$ 1: 21 months
$ 5: 16 months
$ 10: 18 months
$ 20: 24 months
$ 50: 55 months
$100: 89 months

The U.S. government introduced the "New Currency Design" U.S. banknotes in 1996. This was the first major redesign of U.S. banknotes since 1928. Sophisticated security features were added to deter counterfeiting domestically as well as abroad.

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[47] The BEP prints all banknotes, based on production orders sent by the Federal Reserve Banks, and ships the notes to the Federal Reserve: at this point, they are just paper. The notes are placed into circulation by the Federal Reserve Banks, which means the Fed ships them from their vaults to a non-Fed locationAdditional information may be found at www.moneyfactory.gov/.

[48] www.federalreserve.gov/generalinfo/foia/2007newcurrency.htm

Security features include color-shifting ink, watermarks, and security threads. In 2003, The New Color of Money banknotes were introduced. These banknotes feature different subtle background colors for different denominations to assist the visually impaired. A larger numeral in the lower right corner on the back of the notes was included as an additional accessibility feature. All new Federal Reserve notes issued since 1997 include machine-readable features (such as infrared markings) that might be used by handheld currency readers for the visually impaired. To date, few such readers have been introduced and some users have reported difficulty using them with newer design banknotes (see footnote 25).

Security Features

- Watermark
- Color-shifting inks
- Fine line printing patterns (intaglio printing on both the face and back)
- Enlarged off-center portraits
- Low-vision feature
- Machine-readable feature
- Security thread
- Microprinting

Accessibility Features

- Larger denomination numeral on reverse
- Large portraits
- Subtle color patterns on face and back (Series 2004)


TEN
DOLLARS
TWENTY DOLLARS
50

Security Thread

Hold the bill up to the light and look for the security thread, or plastic strip, that is embedded in the paper and runs vertically to the right of the portrait. If you look closely, the words "USA 50" and a small flag are visible along the thread from both sides of the note. This thread glows yellow when held under an ultraviolet light.

Color-Shifting Ink

Look at the number "50" in the lower right corner on the face of the note. When you tilt the note up and down the color-shifting ink changes color from copper to green.

Watermark

Hold the bill up to the light and look for the watermark, or faint image, similar to the large portrait of President Ulysses S. Grant. The watermark is part of the paper itself and it can be seen from both sides of the note.

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Start Boxed Insert: Visual Features of Older U.S. Currency Designs

An interesting case study of visual features is to explore *older* U.S. currency.[49] Relative to one criterion—large numerals to indicate denomination—design changes during the past 80 years perhaps have made U.S. currency less visually accessible.

The $1 Note

Consider the current $1 Federal Reserve note, which perhaps because of its small denomination has been little mentioned in recent discussions of visual accessibility.[50] The current design was introduced in 1963, when $1 Federal Reserve notes replaced $1 silver certificates in circulation. The design, copied at the time from higher-denomination Federal Reserve notes, features on the front upper corners (i) 12 mm-tall numerals "1", (ii) the word "ONE" in 12 mm tall letters on the right front and (iii) smaller numerals in the lower corners. The reverse side features similar 12 mm tall numerals in all four corners plus a 17 mm tall word "ONE" in the center. The "ONE" is printed in two shades of green ink against the note's yellow-green background, for a modestly high contrast impression. Overall, the impression is of a modestly high degree of visual accessibility. The immediately previous designs—the Series 1935 and Series 1957 silver certificates—also had good accessibility features. These notes featured on the left side of

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[49] Images of older currency designs are available on a variety of web sites, and hence are not reproduced here. See for example www.friesian.com/notes.htm, www.ronsmoney.com, aes.iupui.edu/rwise/, and the Money Museum collections at the web sites of the Federal Reserve Banks of Richmond and San Francisco. We are not aware of any web site that provides a complete design history of the $1 U.S. banknote. An image of the Series 1928A silver certificate is available on the Money Museum website of the Federal Reserve Bank of Richmond. Images of Series 1934, 1935, 1957, and 1963 $1 notes are available at www.friesian.com/notes.htm (accessed January 2007).

[50] In 1929, the size of U.S. currency was reduced to its current dimension. At that time, $1 notes were silver certificates, redeemable for approximately three fourths of an ounce of silver. When silver prices rose sharply in the early 1960s, these certificates vanished from circulation and, beginning in 1964, were replaced with Series 1963 $1 Federal Reserve notes. Prior to 1963, significant design changes were made to the $1 note in 1934 and 1935. For the past decade, the Congress has prohibited the Bureau of Engraving and Printing from redesigning the $1 banknote, ostensibly due to the cost of replacing the large number of $1 notes in circulation.

the front a 15 mm tall "1" (the large "ONE" was absent). The numeral, however, was printed in a light shade against the yellow-green paper, resulting in modest contrast.

Ironically, two earlier designs of the $1 note—Series 1928 and Series 1934—had better visual accessibility. The Series 1928 design had a large 25 mm "ONE" in the right half of its front, with corner numerals the same size as the 1963 design. The Series 1934 design retained the "ONE" but overprinted it with the Treasury Department seal, reducing its visibility—but the note also added a 20 mm "1" in the left side of the front, a numeral printed in dark ink for excellent contrast.

The Series 1935 design of the $1 note must be graded as a reduction in visual accessibility—the left-side numeral was reduced in size by one-fourth and lightened (sharply reducing its visibility), plus the large right-side "ONE" was removed entirely. The Series 1957 design continued these features.

Relative to the Series 1957 silver certificate design, the Series 1963 design eliminated the large left-side numeral entirely (replacing it with the Federal Reserve district seal) but restored the word "ONE" on the right side, albeit in a smaller size.

Larger-Denomination Notes

The visual accessibility of designs for larger denomination U.S. banknotes also has varied through time. The Series 1928 and Series 1934 Federal Reserve Notes featured numerals in the upper front corners that differed by denomination, with relatively large 15 mm-tall numerals on $5 and $10 notes but numerals less than 10 mm tall on the $20 note. Accessibility was assisted on all notes by the denomination appearing as a word, approximately 20 mm tall, on the right side of the front, similar to the $1 Silver Certificate.[51] The Series 1950 design reduced the size of the word denoting the denomination to approximately 15 mm. The Series 1981 design reduced the size of the

[51] The Series 1928A identified Federal Reserve Districts by seal (name) and number (1=Boston, 8=St. Louis, etc.) on the left side; Series 1928B identified Districts by seal and letter (A=Boston, H=St. Louis, etc).

corner numerals. In turn, the Series 1996 ("New Currency Design") and Series 2004 ("New Color of Money") designs further reduced the size of the front upper corner numerals to approximately 8 mm (with the numerals internally shaded), while adding a larger 14 mm numeral to the lower right corner of the note's reverse. The Series 2004 notes improved accessibility by removing the internal shading in the upper numerals on the front and hence displaying improved contrast.[52]

--------- end of boxed insert -------

[52] As with $1 notes, we are not aware of any website that provides a complete design history of Federal Reserve Notes. An image of a Series 1928A $5 Federal Reserve Note is available in the "Money Museum" website at the Federal Reserve Bank of Richmond. Images of Series 1928, 1934, 1950 and 1981 notes are available at www.friesian.com/notes.htm (accessed January 2007). Images of some Series 1996 and Series 2004 notes are available on the websites of the Federal Reserve Banks of Richmond and San Francisco. Images of Series 2004 notes also are available at the website of the Bureau of Engraving and Printing.

	Features to Assist Authentication and Denomination (Anti-counterfeiting measures)	Features to Assist the Visually Impaired (Visual features)	Durability	Cost of production
Australia	• Clear window • Made of polymer substrate instead of paper • See-through registration device • Shadow image • Intaglio print • Background print (offset) • Microprinting • Fluorescent ink properties	• Different sizes • Different colors • Intaglio print • Large numerals	Bank of Australia estimates that polymer notes last at least four times longer than paper notes	Costs are confidential
Canada	• Holographic stripe • Watermark portrait • Windowed color-shifting thread • See-through number • Raised ink • Fine-line patterns • Microprinting • Fluorescence • Serial number • Colors	• Different colors • Tactile symbols • Large high-contrast numeral • Machine readable	*$5: 1-2 years* *$10: 1-2 years* *$20: 2-4 years* *$50: 4-6 years* *$100: 7-9 years*	Approximately CA$0.09 per note.

	Features to Assist Authentication and Denomination (Anti-counterfeiting measures)	Features to Assist the Visually Impaired (Visual features)	Durability	Cost of production
European Union*	• "Feel, look and tilt" • Made of pure cotton • Raised print • Tactile marks • Watermark • Security thread • See-through number • Perforations • Hologram patch (€50 €100, €200, €500) • Color-changing number (€50, €100, €200, and €500) • Glossy stripe • Microprinting • UV-light tests	• Different sizes • Striking colors • Large numerals • Intaglio printing • Tactile marks (200€ and 500€)	€5: 1.2 years† €10: 1.4 years €20: 1.5 years €50: 3.7 years €100: 8 years €200: 11.8 years €500: 25.6 years	€0.08 per banknote
Hong Kong SAR	• Fluorescent machine-readable barcode • Iridescent images • Denomination numeral in optical variable ink • Holographic windowed thread • Concealed image/ denomination	• Different sizes • Different colors • Large numerals • Intaglio printing	Approximately 2 years	Figures are confidential

	Features to Assist Authentication and Denomination (Anti-counterfeiting measures)	Features to Assist the Visually Impaired (Visual features)	Durability	Cost of production
	• Intaglio printing • Invisible fluorescent fibres • Watermarks • Security thread • See-through feature • Serial numbers			
Japan	• Watermark • Ultra-fine line printing • Intaglio printing • Microprinting • Luminescent ink	• Tactile marks (Intaglio printing) • Different sizes • Different colors	1,000 Yen: 1-2 years 5,000 Yen: 1-2 years 10,000 Yen: 4-5 years	15.1 yen per banknote
Singapore	• Microprinting • Kinegram • Lithographic print • Engraved portrait • Braille codes • Asymmetrical serial numbers (vertical and horizontal) • Anti-color copying line structures • Lift twin	• Braille codes • Different colors • Different sizes • Intaglio printing	$2 polymer: 72-96 months (issued in Jan 2006, still monitoring the performance) $5 paper: 18-24 months $10 paper: 24-36 months $10 polymer: 72-96 months (issued in May 2004, still monitoring the performance) $50 paper: 24-36 months	$2 polymer: S$0.10 $5 paper: S$0.10 $10 paper: S$0.09 $10 polymer: S$0.12 $50 paper

	Features to Assist Authentication and Denomination (Anti-counterfeiting measures)	Features to Assist the Visually Impaired (Visual features)	Durability	Cost of production
	• Intaglio prints • Highlight watermark • Watermark • Perfect registration • Security thread • Invisible feature: non-reflective under UV light • See-through windows on polymer notes		$100 paper: 48-60 months $1,000 paper: 48-60 months $10,000 paper: 48-60 months	S$0.08 $100 paper S$0.07 $1,000 paper S$0.09 $10,000 paper S$0.55
Sweden	• Watermark • Security thread • See-through picture • Intaglio printing • Additional features for banknotes with foil strip: • Fluorescent picture • Micro lettering • Foil Strip–Hologram • Shimmering mother-of-pearl ink • Motion	• Different colors • Different sizes • Intaglio printing	Varies by denomination. 20 krona: about 1 year 1000 krona: about 5 years	Approximately 7.5 US cents per banknote
Switzerland	• Transparent register	• Different colors	10: 2 years	About CHF 0.30

	Features to Assist Authentication and Denomination (Anti-counterfeiting measures)	Features to Assist the Visually Impaired (Visual features)	Durability	Cost of production
	• Watermark digits • Intaglio digits • Perforated number • Optically variable ink • Ultraviolet digits • Metallic digits • Tilt effect	• Different sizes • Perforated number	20: 1.5 years 50: 1.5 years 100: 3.5 years 200: 3 years 1000: 10 years	centimes per note‡
United Kingdom	• Cotton and linen paper • Metallic Thread • Watermark • Print quality • Hologram • UV-light • Microlettering • Foil (on £50 note)	• Different colors • Different sizes • Large denomination numerals • Recognition *densely colored* symbols by denomination: (£5: turquoise circle, £10: orange diamond, £20: purple square, £50: red triangle)	Ranges from around 1 year for the £5 note, to five or more years for the £50 note	Approximately £0.029 per banknote**
United	• Watermark	• Oversize	$ 1: 21 months	Approximately 3

	Features to Assist Authentication and Denomination (Anti-counterfeiting measures)	Features to Assist the Visually Impaired (Visual features)	Durability	Cost of production
States	• Color-shifting inks • Fine line printing patterns • Enlarged off-center portraits • Low-vision feature • Machine-readable feature • Security thread • Microprinting	denomination numeral on reverse • Larger portraits (than previous designs) • Subtle over-printed colors on front	$ 5: 16 months $ 10: 18 months $ 20: 24 months $ 50: 55 months $100: 89 months	cents per banknote§

Table 2

Summary of Currency Design Features Intended to Assist the Visually Impaired, Major Issuing Authorities

Issuing authority	Primary colors that differ by denomination[1]	Size that differs by denomination	Tactile recognition symbols‡	Certain oversize numerals§	Machine-readable features for banknote readers
Australia	Y	Y	Y	Y	N
Canada	Y	N	Y	Y	Y
European Union*	Y	Y	Y	Y	N
Hong Kong SAR	Y	Y	Y	Y	N
Japan**	Y	Y	Y	N	N
Singapore	Y	Y	Y	Y	N
Sweden	Y	Y	Y	Y	N
Switzerland	Y	Y	Y	Y	N
United Kingdom	Y	Y	N	Y	N
United States†	Y/N	N	N	Y	Y

1. In this table, we define the primary color of the banknote as that used for the prominent portrait (if any), borders, and the denomination numerals, or, in some cases, the dominant color of the note. Because we are not aware of any current cross-country study comparing the color design features of banknotes, judgments are those of the authors.

*For the 13 member states of the European Union participating in the single currency.

** Bank of Japan notes use less intense, near-pastel colors. Although each denomination uses a different dominant color for the portrait, background, and numerals, some readers of previous versions of this article felt that the differences are not sufficient to support our conclusion. We disagree.

† Currently issued Series 2004 U.S. banknotes in denominations of $10, $20, and $50 feature different dominant colors. The U.S. Bureau of Engraving and Printing has announced that new designs for the $5 and $100 notes also will feature differing dominant colors. All currently issued notes except the $1 note feature a large denomination numeral on the reverse. The $1 note features a prominent “ONE” in the center of the reverse..

‡ Including both embossed symbols and patterns, and special high-relief intaglio printing (if cited by issuing authority as a visual accessibility feature).

§ Included if cited by issuing authority as a visual accessibility feature.

APPENDIX

Australia:

Counterfeit volume:

www.rba.gov.au/PublicationsAndResearch/RBAAnnualReports/2005/Html/bus_serv.html

www.rba.gov.au/PublicationsAndResearch/RBAAnnualReports/2006/Html/bus_serv.html

Notes in circulation:

www.rba.gov.au/CurrencyNotes/Statistics/notes_on_issue.html

Canada

Counterfeit volume

www.rcmp.ca/factsheets/fact_counterfeit_e.htm

www.rcmp.ca/scams/counter_e.htm

Notes in circulation:

www.bankofcanada.ca/en/annual/2006/annualreport_2006.pdf

Euro Zone

Counterfeit volume:

www.ecb.int/press/pr/date/2007/html/pr070112.en.html

Notes in circulation:

www.ecb.int/bc/faqbc/figures/shared/number_of_banknotes_circulation_pdf_web.pdf?

Hong Kong

Counterfeit volume: Not available

Notes in circulation: Not available

Japan

Counterfeit volume:

www.boj.or.jp/en/type/release/teiki/ar/data/ar0605.pdf

Notes in circulation:

www.boj.or.jp/en/type/stat/dlong/fin_stat/money/cdab0010.csv

Singapore

Counterfeit volume: Not available

Notes in circulation: Not available

Sweden
Counterfeit volume:
www.riksbank.com/upload/Dokument_riksbank/Kat_publicerat/Rapporter/2007/arsred_popvers_06_eng.pdf
Notes in circulation:
www.riksbank.com/upload/Dokument_riksbank/Kat_publicerat/Rapporter/2007/arsred_popvers_06_eng.pdf

Switzerland

Counterfeit volume:

www.snb.ch/ext/link?url=%2fen%2fmmr%2freference%2fannrep_2004_accrep%2fsource

www.snb.ch/ext/link?url=%2fen%2fmmr%2freference%2fannrep_2005_accrep%2fsource

www.snb.ch/ext/link?url=%2fen%2fmmr%2freference%2fannrep_2006_komplett%2fsource

Notes in circulation:

www.snb.ch/ext/link?url=%2fen%2fmmr%2freference%2fannrep_2006_rechenschaft%2fsource

www.snb.ch/ext/link?url=%2fen%2fmmr%2freference%2fannrep_2006_komplett%2fsource

United Kingdom

Counterfeit volume:

www.bankofengland.co.uk/publications/annualreport/2005report.pdf

www.bankofengland.co.uk/publications/annualreport/2006report.pdf

March 2007 issue of *Currency News*: Sterling and the Bank of England—a study in Contradictions

Notes in circulation:

www.bankofengland.co.uk/banknotes/noteissue.pdf

United States

Counterfeit volume:

www.treas.gov/offices/domestic-finance/acd/

Notes in circulation:
www.moneyfactory.gov/document.cfm/18/106