Counterfeit or genuine: can you tell the difference?

'Quantitative research on the ability of the general public and cash handlers to distinguish counterfeit from genuine euro banknotes

21 December 2006

Nicole Jonker[a], Bram Scholten and Marco Wind (DNB)
Martijn van Emmerik and Marieke van der Hoeven (TNO Human Factors)[1]

Abstract

In 2005, some 25,000 counterfeit euro banknotes were identified in the Netherlands, representing a fictitious amount of two million euro. In collaboration with the TNO research institute, DNB has investigated how accurately cash handlers and consumers with no cash handler experience can distinguish counterfeit euro notes from genuine ones. Also examined was the question whether the use of DNB's educational CD-ROM entitled 'Genuine or Counterfeit?' led to improved performance and whether such aids as UV lights or IR cameras helped to identify notes correctly. The results show that the public is quite capable of recognising a counterfeit note: without practice, members of the general public correctly identified 88% of counterfeit notes they were given to examine, while after training they scored as high as 96%. Remarkable scores were recorded by cash handlers operating without aids: even without training they showed themselves expert at sifting the wheat from the chaff (98% correctly identified counterfeit notes). Recognising genuine euro notes proved slightly more challenging, but here technical aids provided useful services. Practice with the help of the CD-ROM turned out to benefit untrained consumers in particular. They soon managed to bring their performance up to the level of experienced cash handlers.

JEL code: C91, C25, E50,
Key words: banknotes, counterfeits, discrete choice model, experiment, training

[a]. Corresponding author: Nicole Jonker, e-mail: n.jonker@dnb.nl, tel:+31205242759.
[1]. We would like to thank participants of the DNB lunch seminar, Banknote 2006, and the DNB research conference 'Recent Developments in Payment Economics' for their comments, special thanks go to Ad Stokman, Joanna Stavins and Simon Lelieveldt.

Introduction

A safe and reliable payment system is a major precondition for financial stability and economic prosperity in a country. A well functioning payment system that consumers and businesses trust facilitates the exchange of goods, services and assets and is the foundation of today's real economy. One of the Dutch central bank's (De Nederlandsche Bank or DNB) major tasks in this area is to ensure the quality and the authenticity of the euro banknotes in circulation in the Netherlands so that people trust the banknotes in circulation. There are several measures DNB takes to minimise the impact of counterfeiting. Together with central banks in the Eurosystem, it develops euro banknotes and security features that are hard and costly to duplicate. This discourages the reproduction of counterfeits and enhances a quick detection of counterfeits in circulation. In addition, the Eurosystem provides information that allows one to easily check the genuineness of a euro banknote.

In 2005 about 25.000 false euro banknotes were found in the Netherlands, representing a fictitious 'value' of EUR 2 million. This corresponds with 1533 counterfeits per million inhabitants and 12 eurocents per inhabitant. These figures show that the direct economic damage of counterfeiting is limited. However, in the course of 2003 counterfeiting received a lot of negative attention in Dutch media, due to a temporary increase in counterfeited banknotes. As a result, consumers and retailers got negative feelings towards the euro banknotes and many retailers even decided to stop accepting EUR 100 banknotes (which were counterfeited relatively often). So although the economic damage of counterfeiting was rather limited, counterfeiting was becoming a huge problem from a societal point of view. Subsequently, DNB increased its efforts to inform the public and retailers on the security features of euro banknotes and on how to distinguish a genuine banknote from a false one. In 2004 DNB published the educational CD-ROM "Genuine or Counterfeit?"[2] which provides information on how to check by vision and touch whether a euro banknote is genuine or not. The CD-ROM is available to both merchants and consumers. Merchants can also use detection aids which help them to decide whether to accept a banknote or not. They can choose between so called automatic authentication devices, which determine 'by themselves' whether a banknote is genuine or not, and detection aids, which help the user to come to an informed judgement about the genuineness of a particular banknote. This left open the question about the usefulness of detection devices such as UV lights and IR cameras, technical aids which are widely used by retailers in the Netherlands. It is in particular

[2] "Genuine or Counterfeit?" can also be downloaded via www.dnb.nl under 'public', 'euro banknotes', 'counterfeits' followed by 'genuine or counterfeit'.

for this reason that the 'lab experiment' on which we report here has been initiated. The €-OK mirror light is also included in the test. A special feature of this device is that it shows simultaneously the two colours of the optical varying colour of the denomination values printed on the euro banknotes with face values of EUR 50 and higher.

This article presents the results of a 'lab-experiment' that DNB held in the summer of 2005 in co-operation with TNO[3]. In this experiment 41 consumers and 169 cashiers were tested on how well they can distinguish between genuine and counterfeit euro banknotes. The objective of this exercise is threefold. First, it analyses the capability of the general public and professional cash handlers to decide whether a euro banknote is genuine or not. Second, it tests the effectiveness of DNB's educational CD-ROM "Genuine or counterfeit?" And finally, it examines whether cash handlers who can use the UV light, the IR camera or the mirror light recognise more genuine and counterfeit banknotes as such than cashiers who use only their hands and eyes. The research results provide insight into how well the general public and the merchants are capable of distinguishing between real and counterfeit euro banknotes. This is useful since this may indicate how long a counterfeit banknote can circulate prior to detection. The better people are able to judge the genuineness of a banknote the shorter counterfeits will circulate and the less vulnerable the banknote circulation will be for counterfeits.

Important contributions of our study to the existing literature are 1) an accurate assessment of the effect of DNB's educational CD-ROM 'Genuine or Counterfeit? on how to recognise genuine and counterfeit euro banknotes and 2) an evaluation of the effectiveness of three commonly used detection devices compared to detection without aids. Little research has been conducted in the area of distinguishing between genuine banknotes and forgeries by cashiers and consumers. As far as we know there are only two previous studies: Klein *et al*. (2004) who used Canadian banknotes and Gentaz (2005) who used euro banknotes. Both also assessed the impact of different types of training, but neither of them examined the effectiveness of detection aids. Klein recruited 158 participants, 79 consumers and 79 bank tellers/commercial cash handlers. They had to classify 168 Canadian dollar banknotes of which 1/3 were counterfeit. In Klein's set up training was given between the first and the second round to a sub sample of the participants. Participants checked 84 banknotes in the first round and 84 banknotes in the second round. There were two types of training (video or leaflet). Klein reported overall performance rates of about 80% for Canadian banknotes. Consumers benefited from training, but bank tellers did not. However, they already scored very well prior to training (87% correct). Gentaz had 55

[3] TNO is a Dutch research institute that supports companies and governments with innovative, practicable knowledge, see also www.tno.nl.

students and 38 retail cashiers in his experiment. They had to test 69 banknotes of which 10 were counterfeit. Gentaz evaluated the effect of two types of training (with or without real counterfeits) with the cashiers. Before the training, the cashiers already performed very well (91% correct answers for forgeries and 89% correct answers for genuine banknotes) and after the training they performed even better (counterfeit banknotes 96% correct and genuine banknotes 98%). Gentaz showed that consumers were rather good in detecting counterfeits (percentage correct 97%), but performed worse on recognising genuine euro banknotes (percentage correct 67%). Our results are in line with the findings in these earlier studies: we also find that consumers benefit from training, but cashiers not (Klein) and that consumers are much better at recognising counterfeits than genuine banknotes (Gentaz). However, Gentaz found a significant training effect with cashiers whereas we did not. This may be the result of differences in the type of training. Gentaz' training is very intensive compared to ours. Another reason may be that Gentaz did not control adequately for learning effects during the trial. For example, he did not have a control group that did not receive any training.

The structure of this article is as follows. Section 2 discusses the selection of the banknotes used in the test, the recruitment of the participants, the training "Genuine or Counterfeit?" the set up of the actual tests and the statistical models used. Section 3 presents the outcomes of the test, distinguishing between the results in the successive rounds. It provides insights on the effectiveness of the CD-ROM training and the different detection aids on the correct recognition of genuine and counterfeit banknotes. It also compares the test scores on the different face values. Section 4 shows the results of the multivariate analyses, providing estimates of the training effect and the influence of technical aids on banknote classification. Finally, section 5 summarises and concludes.

2 Methodology

This section describes the design of the two trials held in the summer of 2005, the procedures during the trials, the banknotes used in the trial, the selection of participants (consumers and cashiers) and the characteristics of the participants.

The objective of the study was not to mimic the real life situation of consumers and cashiers as much as possible. We want to examine how well consumers and cashiers can distinguish between genuine and false banknotes if they do continuously their best under 'perfect' circumstances. The detection rates found in this study should not be considered as estimates for real life detection rates. There are several reasons for this. First, when consumers or cashiers exchange banknotes they do not spend much time checking whether a banknote is genuine or not. During the trials, participants had fifteen seconds to decide on the genuineness of a banknote. This lies between the time given to participants in other studies (Gentaz, 2005, gave 30 seconds and Klein et al., 2004 gave 7 seconds). Consequently, the real life detection rates are probably much smaller than the ones found in this study. Second, the sample of genuine and counterfeit banknotes is not representative for the banknote circulation. The quality of the counterfeits is relatively high (this causes a downward bias in our detection rates compared to real life detection rates) and there are relatively many counterfeits (ratio genuine: counterfeit is 2:1) in the sample. Third, the differences in detection rates between consumers and cash handlers will be much larger in real life than in this study: consumers hardly check the authenticity of a banknote whereas many professional cash handlers do. However, the results of this do indicate how well the general public and professional cash handlers will be in detecting counterfeits, when it is important to check banknotes, namely in case of a major counterfeiting problem.

There are several reasons why we have chosen for this composition.

- It is hard to mimic real life, you can not test how well people can distinguish between counterfeits and genuine banknotes if there are hardly any counterfeits in the sample. There are limitations on how many banknotes you can have people test: they become tired, bored and probably less accurate.
- We are interested in the effect of training and detection aids on correct identification and we see no reason why the measurement of these effects can be biased due to the relatively high share of counterfeits. We have controlled for learning effects and the participants did not know how many counterfeits were included in the test stack. Furthermore, similar training

effects were found by Gentaz who used a much smaller share of counterfeits in his experiment, supporting the view that share of counterfeits does not affect the performance of the participants in the experiment.

- The relatively high degree of variation and high 'quality' of the counterfeits enabled us to examine which types of counterfeits are hard to detect (even after training or with the use of detection aids) and which types are easily recognised as counterfeits. This can give us information when developing new banknotes and it provides useful input for new public campaigns on how to recognise counterfeits.
- We are primarily interested in whether people are able to distinguish between genuine and fake banknotes, i.e. our main focus is the quality of the euro banknote. We are less interested in how people treat banknotes in real life payment situations. We know that people may accept banknotes rather carelessly, without worrying about the authenticity.

2.1 Participants of the experiment

In total, there were 204 persons in the experiment: 40 consumers with no cash handling experience and 164 persons working as professional cash handlers[4]. The participants did not know that they were going to participate in an experiment in which they had to identify genuine and fake euro banknotes. There were 10 equally sized groups of around 10 persons in the experiment (see figure 1) varying in participants receiving training or not, using detection aids or

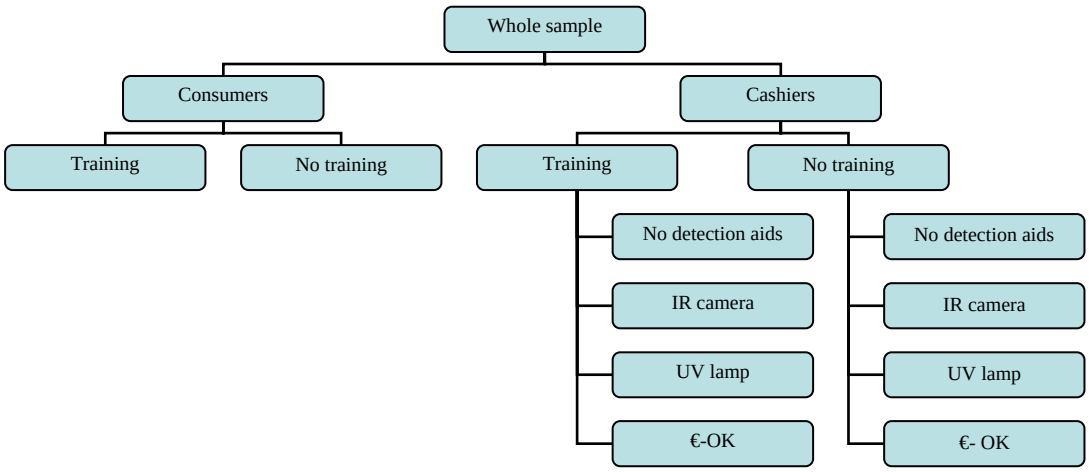


Figure 1: Set up experiment

not and being a consumer without cashier experience or being a cashier. The cashiers and the consumers were randomly assigned to get training or not. Consumers did not use any detection aids, since they also do not use them in real life. Cashiers who can use one of the three detection aids at work were assigned to a group with that particular detection aid. The consumers were randomly selected by TNO from the TNO subject database, taking into account age, gender and educational level (see table 1). Because of the modest sample size the sample is not a perfect representation of the Dutch adult population, but it represents it well enough for the purpose of this study: assessing how well consumers can distinguish counterfeits from genuine banknotes.

Table 1 Summary statistics participants experiment

(In percentages)

Consumers (n=40)		
Gender	Female	48.8
Age	20-39	29.3
	40-59	43.9
	>=60	26.8
Education	Low	7.3
	Intermediate	53.7
	High	39.0
Cashiers (n=164)		
Gender	Female	74.9
Age	30-	66.3
	30-39 years	11.2
	40-49 years	14.8
	> =50	7.7
Education	Low	23.1
	Intermediate	34.9
	High	42.0
Experience as a cashier	< 1 year	17.7
	1-5 years	42.6
	6-10 years	23.7
	>10 years	16.0

[4] We started with 210 subjects. However, we have decided to exclude the results of one consumer and of four cash handlers from the experiment.

The subjects received an allowance of € 20 per hour for participating in the test. The cash handlers were recruited by DNB. DNB recruited some cash handlers via temp agencies and via DNB employees (relatives and acquaintances of DNB employees[5] who were working as a cash handler. The DNB employees were not working at an operational cash department). The cash handlers were not informed about the subject of the experiment at the moment of recruitment. In order to prevent them for 'preparing' themselves. It is not likely that they have prepared themselves for the experiment. They got paid according to their normal standard wage.

2.2 **The trials**

This experiment consists of two trials. The first trial, involving 40 consumers, showed their spontaneous identification rate of genuine and counterfeit banknotes and the effect of the CD-ROM training on correct recognition of euro banknotes. The second trial also tested the effectiveness of three types of detection aids, i.e. the UV light, the IR camera and the mirror light. In the latter trial, 164 cashiers took part. The participants were placed in groups of four to five who undertook the test at the same time. In order to motivate the participants to do their best, they received feedback on their performance three times during the trial and the participant with most good answers within the 4-5 persons group won a small prize. For each small group of participants participating at the same time, there was an extra stimulus in the form of a small reward for the best-performing participant. On top of that cashiers also received a lump sum allowance in order to compensate for foregone income.

Before the test

Before the trial started, participants had to answer several questions on their personal background (age, work experience, education and gender) and their knowledge of the security features of euro banknotes. They were also tested on colour blindness and sharpness of sight, since we wanted to exclude people with serious sight problems from the experiment. Furthermore, the participants should have a good command of the Dutch language as half of them had to use the Dutch version of the training CD-ROM.

[5] These DNB employees are not working at an operational cash department. Relatives and acquaintances of them were excluded because they may have a higher than average knowledge about counterfeits than the average cash handler.

Training 'Genuine or counterfeit?'

After the introduction, half of the groups, that is to say 20 of the 40 consumers and 83 of the 164 cashiers, received the CD-ROM training 'Genuine or counterfeit?'. This interactive computer program informs the viewer on the security features in the euro banknotes and how (s)he can check whether a banknote is genuine or not, using his hands and eyes and the 'feel, look, and tilt' method. Participants were given genuine banknotes during this training so that they could learn how to use the security features.

Trials

After the vision test and, if appropriate, the training, participants were taken to the test room (see photo 1). Each participant had a cubicle with a PC, a box filled with banknotes and an empty box. The filled box contained the 220 banknotes. The participants received instructions from the test leader. They were asked to examine 220 banknotes. The participants knew that there were counterfeits in the sample but they did not know how many. Participants had to draw a banknote from the banknote box, examine it for fifteen seconds at most, judge its genuineness and put it in the empty box. After fifteen seconds a signal was given by the test leader. Then they had to indicate on the PC whether they thought the examined banknote was to be genuine or not. In order to make sure that the whole procedure was well understood, it was practiced four times before the trial really started (the results of these first four banknotes are not included in the analyses). During the test, participants were not allowed to talk to the other participants. After

Photo 1: test lab

checking the first 72 banknotes, the computer reported the participants their overall percentage correct answers[6] (score round 1) and the participants had a short coffee break. Then the second the new test scores (score round 2) and another short break, after which the participants had to check the final set of 72 banknotes.

Detection equipment

The effectiveness of detection equipment was tested in the trial with cashiers. One quarter of the cashiers did not use any detection equipment during the trial. They served as control group. Three quarters of the cashiers were given one piece of detection equipment per cashier: the mirror lamp (photo 2), the infrared camera (photo 3) and the UV light (photo 4), preferably the aid they would also use at their work. They could use the detection equipment during the test. Half of the cashiers in each of these four groups also received CD-ROM practice.

Photo 2: €-OK mirror light

[6] Giving feedback to the participants about their performance during the experiment may have affected the results in round 2 and 3. However, we think the magnitude of this effect is rather small: the subjects only received an overall measure of their performance and not on distinguishing between the scores on counterfeits and genuine notes separately. Subjects who did well in the first round knew they were on the right track, but those who did not, did not get any information on what they were doing wrong.

Photo 3: Infrared camera

Photo 4: UV light

2.3 **Banknotes**

In the test 1296 euro banknotes with face values between EUR 10 and EUR 200 were used of which 432 were counterfeit and 864 banknotes were genuine. This set was divided into six subsets of 216 banknotes each. These subsets were almost identical with respect to the

denomination of genuine and counterfeit banknotes, the counterfeit variants, the quality of the genuine banknotes, etc. Five subsets were used simultaneously during the trials and one served as a fall back set (in case of banknotes getting damaged during the trials). Table 2 presents the resulting number of banknotes by denomination and genuineness in each subset. Each subset included three banknotes of one counterfeit variant.

Table 2 Banknotes in a subset

Denomination	Counterfeit	Genuine	Total
EUR 10	6	12	18
EUR 20	9	18	27
EUR 50	30	60	90
EUR 100	18	36	54
EUR 200	9	18	27
Total	72	144	216

The counterfeit notes used in the test were of the types found in circulation by DNB. In composing the test sets, it was decided to use many different types of counterfeits, with a certain bias towards the 'better' forgeries. The genuine notes in the set were a mix of relatively new, moderately worn and heavily worn banknotes. Thus composed, the test set made it possible to gain an adequate understanding of the ability of the test participants to correctly identify the different types of counterfeit. When interpreting the results, however, it should be kept in mind at all times that the test set was in no way whatever a representative sample from the real banknote circulation.

The order in which different types of banknotes were received by participants was randomized in order to correct for biased results due to order, tiredness or learning effects in the experiment (see table 3). The order of the banknotes in subset A was assigned via a random number generator. Similar banknotes in the other five subsets got the same order number as in subset A, but their real order in which the participants received them differed. The reason for this is again minimising the likelihood of biased outcomes results because of order, tiredness or learning effects. For the sake of completeness, we note that the order within a group of 72 banknotes may be the opposite of the order in subset A (like in B, D and F) and also the round in which a group of banknotes is checked can be different than in A, like for C, D, E and F. For example, in A the banknotes 1-72 were checked by the participant in round 1, whereas the participant who had

Table 3 Order in which banknotes are received by participants

Subset	Round 1	Round 2	Round 3
A	1-72	73-144	145-216
B	72-1	144-73	216-145
C	145-216	1-72	73-144
D	216-145	72-1	144-73
E	73-144	145-216	1-72
F	144-73	216-145	72-1

subset C in its stack got banknotes 1-72 in the second round and a participant in group B got the same notes in round 1 in reversed order (72-1).

2.4 **Statistical models**

We have used mean comparison tests and the random effects probit model to investigate which factors significantly affect the performance of cashiers and consumers regarding correctly classifying genuine and counterfeit banknotes. Using two different tests enabled us to check the robustness of the results[7].

Random effects probit model

The random effects probit model is a statistical probability model for panel data (see also the Stata manual, 1999). It is a suitable model for analysing the performance of cashiers and consumers regarding the correct classification of individual forgeries and genuine banknotes for two reasons. First, the dependent variable only takes on two values, 1 if the classification is correct and zero when it is not. And second, the random effects probit model accounts for within-group correlation of error terms and in this study there are repeated measurements on banknote classifications per participant.

Each participant i (i=1…40 for consumers and j=1…164 for cashiers) received 216 notes, of which 72 were counterfeit (t=1…72) and 144 were genuine (s =1..144). C_{it} and G_{js} are binomial dependent variables, indicating whether the classification by participant i (j) of the t^{th} counterfeit, (s^{th} genuine banknote) was correct C_{it} =1 (G_{js}=1) or not C_{it} =0 (G_{js}=0). The values of the explanatory variables training, round, detection aids and denomination for consumer i and

[7] We have also used ANOVA variance analysis. The ANOVA results were in line with the findings from the random effects probit model. We chose to present the latter results because it accounts for the panel character of the data and because it is a statistical model for analysing events with binary outcomes.

cashier[8] j are stored in the vector x_i respectively z_j. We assume a linear effect between the explanatory variables and the outcome of the test result.

$$C_{it} = 1 \leftrightarrow x_{it}\beta + v_i + \varepsilon_{it} > 0$$
$$= 0, \text{otherwise}$$
$$G_{js} = 1 \leftrightarrow z_{jst}\gamma + w_j + \pi_{js} > 0$$
$$= 0, \text{otherwise}$$

The factors v_i and w_j denote error terms and they are participant specific, with v_i i.i.d $N(0,\sigma^2_{\varpi})$ and w_j i.i.d $N(0,\sigma^2_{\omega})$, The within group correlation of these disturbances equals $\rho_m=\sigma_m^2/(\sigma_m^2+1)$, m=v, w. It indicates the proportion of the within group variance on the total variance. When ρ_m is zero the pooled probit estimator is the same as the panel probit estimator. The error terms ε_{it} and π_{js} are both i.i.d. Gaussian distributed with mean zero and variance 1. They are independent of v_i or w_j. The probability density function and the log likelihood function of the random effects probit model can be found in appendix B.

Mean comparison tests

On top of the random effects probit model we also used two sample t-tests to test whether the average detection rates of groups of participants were significantly different from each other. The t-tests were performed for each round, for genuine and counterfeited banknotes separately and also for cashiers and consumers separately. This approach enabled us to focus on one factor at a time and to see when (which round, which banknote type, consumers or cashiers) this factor had a significant impact on the participants' test scores. We assumed unequal variances between the groups. Average scores were compared of

- Consumers and cashiers
- Participants who received CD-ROM practice and participants who did not receive it
- Cashiers using detection aids and those who did not. Each group with a detection device was tested against the other three groups (two with another type of detection aid and one group without)

[8] For cashiers, we also estimated models including demographic information on gender, age, educational level and work experience as a cash handler. We did not include demographic information in the models explaining the performance of consumers because of the small group size (see also footnote 7).

3 Exploring the data

This section explores the results of the trials. First, some general trends in the identification performance of consumers and cashiers are presented. Then we discuss learning and training effects, the effectiveness of detection equipment and denomination effects.

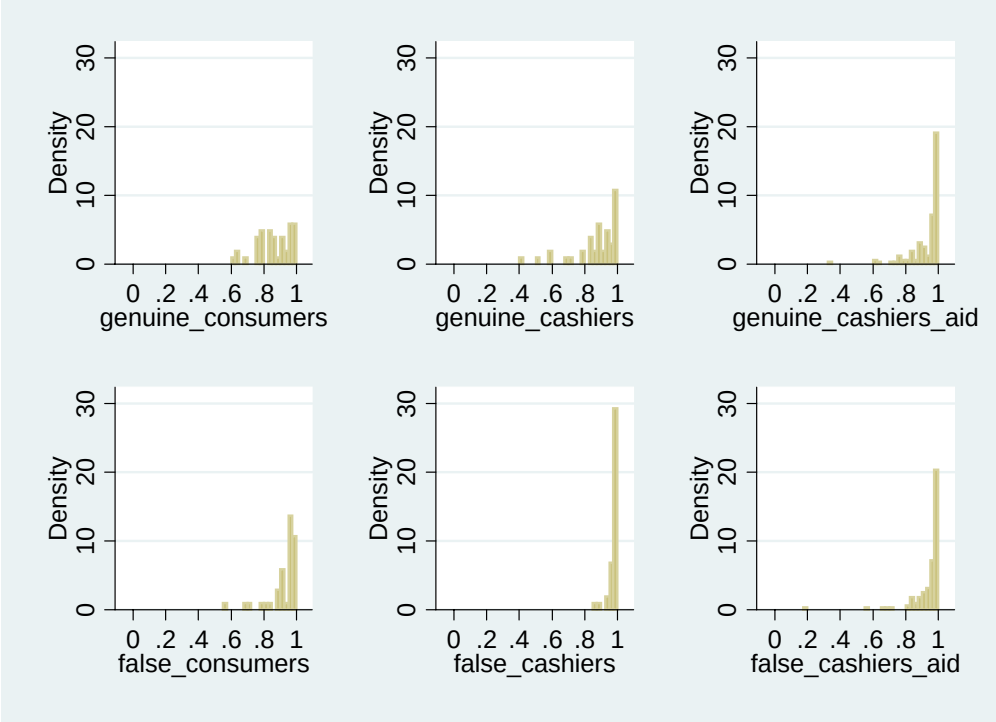
3.1 **Average and spread in test scores**

Generally, the consumers turned out to perform rather well: 88% of the banknotes were correctly identified. It was more difficult to classify a genuine banknote correctly (average percentage correct answers 86%) than a counterfeit (average percentage correct answers 92%).

Cashiers who did not use any detection aids had 91% correct answers: they recognised 98% of the counterfeits and 87% of the genuine banknotes. Cashiers using aids performed with 93% correct classifications even better. Also for them it was easier to detect a counterfeit (average score 95%) than a genuine banknote (average score 92%).

These results indicate three things: first, it is easier to recognise a counterfeit than a genuine banknote, second cashiers are better at identifying counterfeits than consumers and third aids improve cashiers performance on recognising genuine banknotes correctly but not on identifying counterfeits.

Within the group of consumers there was quite some dispersion (see graph 1). Some of them gave more than 99% correct answers whereas others had just 1 out of 3 banknotes right. The dispersion is larger for genuine banknotes (upper left graph) than for counterfeits (lower left graph). This also holds for cashiers without detection aids (two middle graphs) and cashiers who had a detection aid (right hand graphs). Furthermore the spread in scores is clearly higher for consumers than for cashiers. This is partly due to the lower number of observations for consumers than for cashiers, but it also reflects a higher degree of homogeneity regarding knowledge of banknotes among cashiers than among the Dutch population in general. Furthermore, aids seem to diminish the spread in scores on genuine banknotes, but they increase the deviation in recognition rates of counterfeits.



Graph 1: Density function average percentage correctly identified genuine and false banknotes by consumers and cashiers (in %)

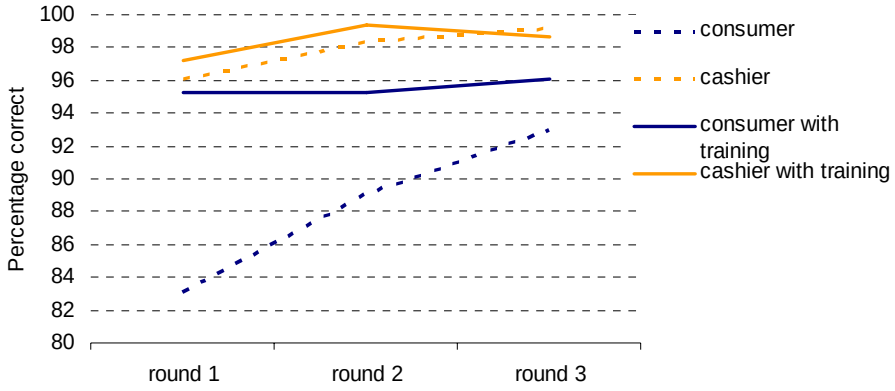
3.2 **Learning effects and training effect**

The performance of consumers and cashiers improved during the trial. This is clearly depicted in graph 2a (forgeries) and 2b (genuine banknotes) which show the development of average scores per round for trained and untrained consumers and cashiers.

Forgeries

Already in the beginning of the test consumers were quite capable at identifying forgeries and they become better at it during the test. The learning effect seems only to be present among consumers without prior CD-ROM practice. Their average performance increased by 10 % points to 93% in the 3rd round. Consumers who had had training prior to the test performed better than consumers without training. The difference was largest in the first round (83% versus 95%) and became smaller at the end (93% versus 96%). Note that the average first round score of trained consumers was only 3% points lower than the average score of untrained cash handlers.

Training only seemed to have had a moderate effect on the performance of cashiers: in the first two rounds training increased performance by 1 %-point, but in the third round untrained



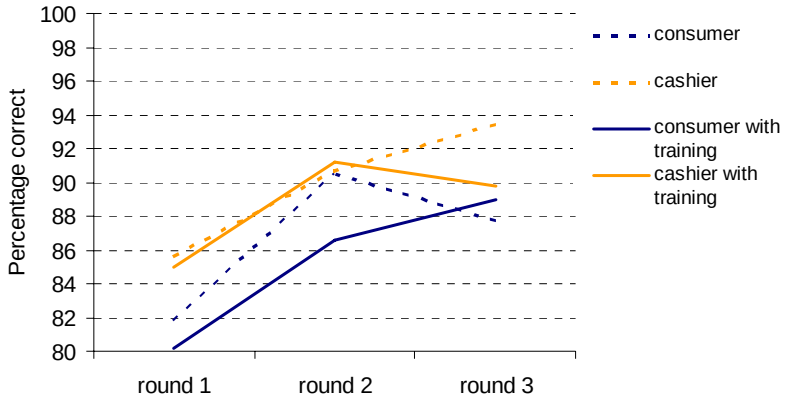
Graph 2a Scores of consumers and cashiers without detection aids on counterfeits

cashiers outperformed the trained. Learning effects were also less prominent among cashiers than among consumers, the average score of trained cashiers even declined by 1 % point to 98% between the second and the third round. This may be due to tiredness outweighing learning or the good performance in the first round that leaves little room for improvement in the remainder of the trial.

These results indicate that the CD-ROM benefits the group it is intended for. A brief practicing session will bring an average inexperienced cash user up to the level of a person with cash handler experience. Participants appeared to learn more from looking closely at genuine notes, perhaps for the first time, than from being faced with many different counterfeits. The head start that cash handlers had over untrained consumers in the first round also suggests that frequent handling of banknotes is more instructive than coming into contact with counterfeits.

Genuine banknotes

Graph 2b reveals that the educational CD-ROM did not improve consumers' and cashiers' ability to recognise genuine euro banknotes. Practicing with the CD-ROM hardly affected the performance of cashiers in the first two rounds and it seemed to have had a negative impact on the scores of the consumers (-2 % points in the first round and -4 % points in the second round). Training may have made them too critical towards genuine banknotes. Tiny differences between the genuine euro banknotes may have made them classify some genuine notes as counterfeits. Graph 2b also shows that the performance on recognising genuine banknotes of both cashiers and consumers improved considerably during the first two rounds. Their scores increased by 5½ % points (untrained cashiers) to 8 % points (untrained consumers) between the first two rounds.



Graph 2b Scores of consumers and cashiers without detection aids on genuine banknotes

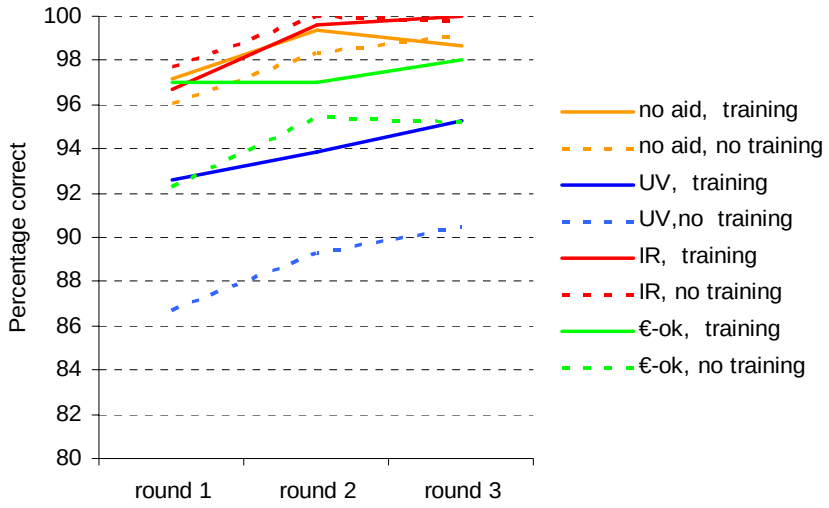
Between the second and the third round no clear learning effects were present. The declining average scores of untrained cashiers and trained consumers also show that some of the people became tired or that participants were trying too hard, inspecting the notes so meticulously that they became 'hyper selective'.

3.3 **Detection aids**

The effect of using technical aids was examined for professional cash handlers only. The question here was whether the use of, respectively, a UV light, an IR camera or a mirror light, either with or without prior practice, would lead to better results than an assessment using just the naked eye and sense of touch. Graph 3a and 3b enable us to get a first glimpse of the effectiveness of aids on distinguishing between false and genuine euro banknotes.

Forgeries

Cash handlers turned out to be at least as able to identify counterfeit notes without technical aids as with the help of such devices (see graph 3a). Cash handlers using an IR camera did slightly better than those without, with group scores in some rounds as high as 100%, but the difference was not statistically significant. Professionals who had the benefit of UV light or the mirror light but had had no prior CD-ROM practice did clearly worse than those without aids. Their 86% performance in the first round, with UV light but without practice was, in fact, 10 percentage points lower than the average score of unaided cash handlers. After practice, these two devices turned out to be used to better advantage (5 or 6 percentage points better performance in the first round). In the case of mirror light users with prior practice, results even matched those of unaided



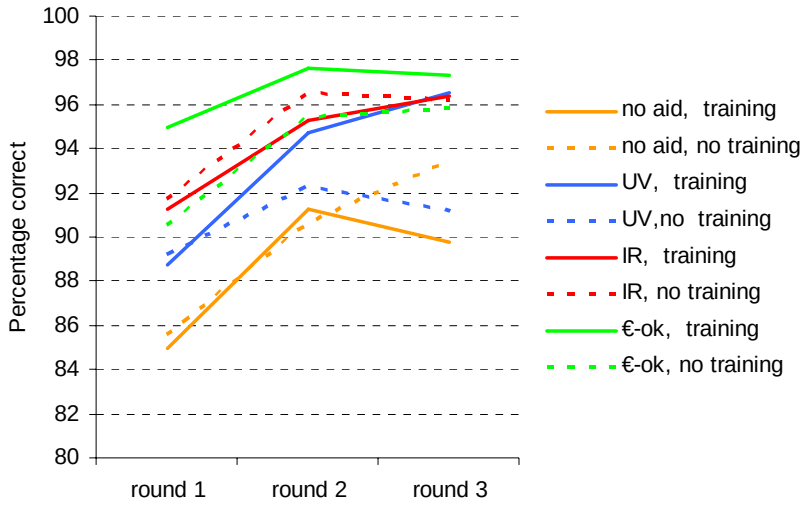
Graph 3a Scores of cashiers with and without detection aids on counterfeits

cash handlers. By implication, the group of UV light users without practice did less well than the unaided, unpractised group.

When interpreting these results, one should realise that in each of these cases the result is quite good, with 86% or more of the counterfeits correctly identified even in the first round. The outcome confirms, however, that the use of UV lights, in particular, does not contribute to the identification of counterfeit euro banknotes. Without specific instruction as to what features to look for under a UV light, the use of such a device is even less effective than an examination with just the naked eye.

Genuine notes

Remarkably, the use of the technical aids did help identify genuine banknotes correctly – (see graph 3b). Cash handlers who used an IR camera or mirror light did best of all. Where the percentage of correct identifications realised by unaided cash handlers in the last two rounds averaged 91%, the use of UV light raised the score to 94%, use of the IR camera to 96% and use of the Euro-OK to as high as 97%. Practice did little to improve the cash handlers' performance, but there was a clear learning effect between rounds one and two.



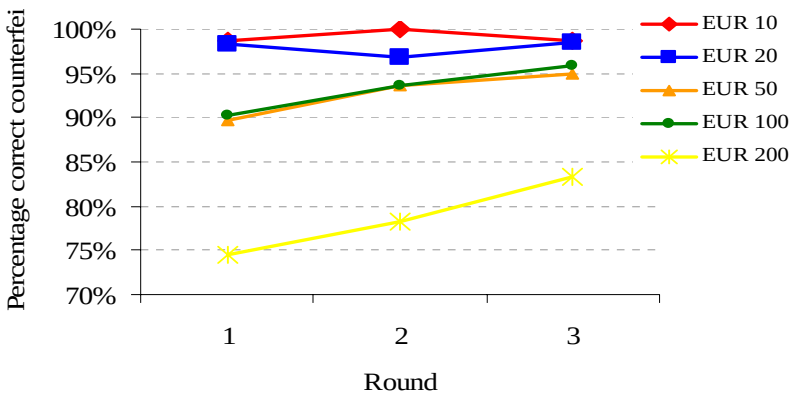
Graph 3b Scores of cashiers with and without detection aids on genuine banknotes

3.4 **Denomination**

The performances of cashiers and consumers also differ by denomination of the banknotes. In Graphs 4a and 4b the test results of consumers are shown for genuine and counterfeit banknotes, split up by denomination. Similar denomination effects have been found for cashiers. In daily life, the Dutch mainly use EUR 5-EUR 50 banknotes, which are distributed to the public via ATMs, and they rarely use banknotes above EUR 100 for retail payments.

Analogously to previous graphs, counterfeit banknotes were relatively more often correctly identified than genuine banknotes. Average correct response rates for the counterfeits varied between 75% (EUR 200, round 1) and 100% (EUR 10, round 2) and for genuine banknotes between 78% (EUR 100, round 1) and 92% (EUR 20, round 3). It should be noted here that the quality of the counterfeited EUR 200 notes was relatively high compared to the quality of the other counterfeits, whereas the quality of counterfeited EUR 10 notes was rather low. Comparing the performances of the consumers between rounds, some striking results turn up.

- The development of the performances across rounds for the EUR 10 and EUR 20 banknotes differed from those for the EUR 50, 100 and 200 banknotes. This holds for both genuine notes and counterfeits.

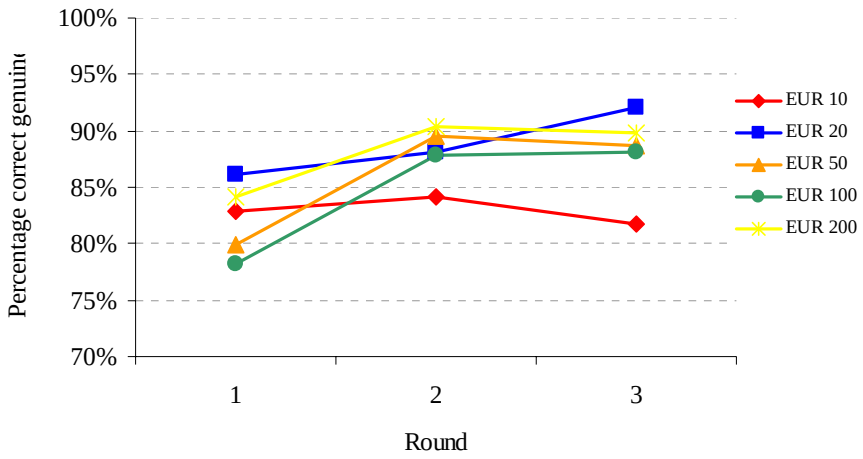


Graph 4a: Average percentage correct answers by consumers, by round and denomination (counterfeited banknotes)

- The average scores on counterfeit banknotes kept on improving between the second and the third round (except for EUR 10 banknotes), whereas the detection rates for genuine banknotes remained rather stable between the second and the third round.

- Counterfeit banknotes: Recognition rates in the first round were very high (98-99%) for the counterfeited EUR 10 and 20 banknotes, probably partly due the low quality of the counterfeits. The recognition rates in the later two rounds hardly changed whereas the recognition rates of the EUR 50, 100 and 200 counterfeited banknotes steadily increased during the second and the third round.

- Genuine banknotes: identification rates for EUR 10 and EUR 20 banknotes increased between round 1 and 2 by 1-2 %-points which is much lower than the increase in these rates for the higher denominations (6-10 %-points).



Graph 4b: Average percentage correct answers by consumers, by round and denomination (genuine banknotes)

4 Statistical analysis

Random effects probit models have been used to study the impact of learning, training, different types of detection equipment and denomination on correctly classifying genuine and counterfeit banknotes. Furthermore, we have tested whether cashiers and consumers perform differently by means of two sample t-tests. This has also been done to examine differences in test scores of cashiers using different types of aids.

4.1 **Random effects probit analysis**

The random effects probit model has been estimated to examine simultaneously the effects of several explanatory variables on the correct classification of genuine notes and counterfeits. The graphical inspections in section 3 revealed that training may interact with learning. It also showed that the effect of training may vary with the sort of detection aid. Therefore we also included some interaction terms in the set of explanatory variables. Four models have been estimated:

1) detection of counterfeits by consumers
2) detection of genuine banknotes by consumers
3) detection of counterfeits by cashiers
4) detection of genuine banknotes by cashiers

The results are reported in tables a 1-a 4 in the appendix. Generally, the random effects probit results confirm the exploratory findings in the previous sections. Furthermore, the estimated values of the ρ's lie around 0.3 and are significantly different from zero: this supports our choice of the statistical model used for analysing the data.

Consumers

The CD-ROM practice 'Genuine or counterfeit?' improved consumers' ability to detect counterfeits. This effect was only significant in the first round. Learning effects were also clearly present. In the first round consumers classified significantly less counterfeits correctly than at the end of the trial. The difference in scores between the second and the third round was not significantly different from zero. The denomination of the counterfeited banknote also mattered a lot. The lower the 'value' of the counterfeit the higher the probability that the consumers correctly identified it as a counterfeit. This may be explained by the quality of the counterfeit: low denomination counterfeits are often of a lesser quality than the high denomination counterfeits.

The CD-ROM training did not improve consumers' ability to recognise genuine banknotes. Even in the first round the training variable was not statistically significant. This finding confirms the visual observation about training in section 3.2. There was a significant learning effect between the first and the later rounds, but it was smaller than the one observed for counterfeits. Furthermore, the denomination of the banknote mattered but the pattern was less clear than with counterfeits. Compared to genuine EUR 200 notes, genuine EUR 10 and genuine EUR 100 banknotes were less often correctly identified as genuine banknotes. It can be quite interesting to learn more about this. This can yield useful information for developing and producing new banknotes.

Cashiers[9]

Training and the use of detection aids did not improve cashiers' ability to recognise counterfeits. Cashiers who used either the UV light or the mirror light even made significantly more mistakes than cashiers who did not use any of these detection aids. Users of the IR camera had higher scores than the ones without any aids, but this effect was not significant at the 5% level. The results of testing banknotes with detection aids may be ambiguous when the security feature, on which the aid focuses, is reasonably imitated. This indicates that when it comes to recognising counterfeits there may often be no better detection aid than the own hands and eyes. Training in combination with the use of a detection aid also did not really improve cashiers' performance. Just like the consumers, the performance of cash handlers improved significantly during the trial. And again, we find a negative relation between the denomination of the counterfeit and the probability that it was correctly recognised as a counterfeit.

Although the detection aids did not help cashiers with recognising counterfeits, the IR camera significantly improved cashiers' detection scores on genuine banknotes. The cashiers with the mirror lamp also performed well, but not significantly better than the cashiers without detection aids. It seems that cashiers without aids (and also consumers) tended to become too critical: genuine banknotes sometimes seem to have been classified as counterfeits because of tiny differences (due to variation in printing, paper, wear and tear effects) in appearance. The

[9] Including demographic covariates hardly altered the main results regarding the estimated impact of training, the UV light, the mirror lamp and learning effects on the recognition of forgeries. However, the effect of the IR camera did become statistically significant. Cash handlers aged 30-49 years turned out to be relatively good at recognising counterfeits compared to young cash handlers. Furthermore, educational level (reflecting intelligence) affected performance significantly. With respect to recognising genuine banknotes we found a significant gender effect: women performed significantly better than men. We also included covariates reflecting interactions of training with round and detection aids in the model, but this did not yield any significant relationships.

detection aids only focus on the security features of euro banknotes and not on other deviations in the notes. Cashiers using an aid seemed to be more willing to accept small differences in appearance, as long as the aid showed that the security feature it focuses on was present. Denomination only mildly influenced the detection rates of cashiers: compared to genuine EUR 200 banknotes only the genuine EUR 100 banknotes were significantly more often misjudged. It can be interesting to pay attention to this.

4.2 **Some additional tests**:

In addition to the random effects probit model we have used two sample t-tests to test

- whether the performances of consumers were significantly different from that of cashiers without detection aids
- whether the performances of cashiers using one of the three detection devices perform significantly different from each other

and, in addition, we also tested the effect of training once more. The results are discussed below and summarised in table 4 and 5.

Consumers versus cash handlers without detection aids

In the test we compare the performance of (un)practiced consumers with (un)trained cash handlers who could not use detection equipment. Separate tests have been done per round and for genuine notes and counterfeits. The results in table 5 show that the CD-ROM practice only improved the ability of consumers to classify counterfeits as such. The average counterfeit detection rate of trained consumers (95%) was significantly higher than the one of untrained consumers (83%) in the first round. Untrained cashiers were significantly better (5% level) at recognising a counterfeit than untrained consumers. The difference in test scores ranges from 12 %-points in round 1 to 6 %-points in round 3.

The performance of trained consumers did not differ significantly from that of untrained cash handlers. Furthermore, we found that trained consumers and trained cashiers performed differently. In the second and the third round the hypothesis of equal average test scores was rejected. In these rounds cashiers with training recognised 99% of the counterfeits against 95% by trained consumers.

Table 4 Test results consumers and cashiers

(Yes=significant difference in at least two rounds out of three)

		Detecting counterfeits		
	Consumers	Consumers with training	Cashiers	Cashiers with training
Consumers	*	No (only 1st round)	Yes	Yes
Consumers with training		*	No	Yes
Cashiers			*	No
Cashiers with training				*
		Detecting genuine banknotes		
	Consumers	Consumers with training	cashiers	Cashiers with training
Consumers	*	No	No	No
Consumers with training		*	No	No
Cashiers			*	No
Cashiers with training				*

Regarding genuine notes, the scores of the cashiers are somewhat higher (2-3 % points) than those of consumers. However, the t-tests reveal that the differences in average scores are not statistically significant.

Summarising, the test results show that the CD-ROM training improved the ability of consumers to recognise counterfeits considerably: consumers who had had training recognised counterfeits just as well as experienced cashiers. On the other hand, the educational CD-ROM did not help cashiers in identifying genuine and counterfeit banknotes.

Cashiers with versus without detection aids

Cashiers who only used touch and vision had significantly higher detection rates of counterfeits during all rounds than cashiers who used either the UV light or the mirror light. Only the cashiers with the IR camera scored equally well as the cashiers without detection aids. They also had significantly higher detection rates than the UV light and mirror light users. Furthermore, cash handlers with the mirror light outperformed those with the UV light when it came to recognising counterfeits.

However, cashiers with an aid (mirror light, IR camera) are significantly better at identifying genuine banknotes than cashiers without an aid. No statistical differences have been found between cashiers without an aid and the ones with UV. The tests also show that there were

Table 5 Test results Cashiers with or without a detection device

(Yes=significant difference in at least two rounds out of three)

		Detecting counterfeits		
	No aid	IR camera	€-OK	UV-light
No aid	*	No	Yes	Yes
IR-camera		*	Yes	Yes
€o-OK			*	Yes
UV-light				*
		Detecting genuine banknotes		
	No aid	IR camera	€ -OK	UV-light
No aid	*	Yes	Yes	No
IR-camera		*	No	No
€-OK			*	No
UV-light				*

no significant statistical differences between the detection rates of cashiers with the UV light, the IR camera or the mirror light.

5 Conclusion

In this article, the results of a study on how well consumers and cashiers can distinguish between genuine euro banknotes and counterfeits are reported. Furthermore, the effectiveness of an educational CD-ROM training 'Genuine or Counterfeit? on recognising genuine and counterfeit banknotes was tested, as well as the effectiveness of three types of detection aids (IR , UV light and the Euro-OK mirror light). This study is rather unique, especially the results on detection aids provides new insights in the usefulness of such devices.

Both cashiers and consumers were very well at correctly recognising counterfeits, many cashiers even had 100% scores. The scores on correctly classifying genuine notes were somewhat lower but still well above 85%. Cashiers performed significantly better than consumers. Training did not improve their performance. Consumers who had CD-ROM practice prior to the test were significantly better at identifying counterfeits than consumers who did not get the training. In fact, their performance was as good as that of the cashiers. These results indicate that the use of DNB's educational CD-ROM is especially useful for novice cash handlers, enabling them to quickly bring their performance in identifying counterfeit and genuine notes up to the level of more experienced peers.

The correct identification of counterfeit euro notes did not benefit by any of the three technical aids used in the test, compared to unaided identification. This shows that the knowledge the public and the cashiers have regarding banknotes and security features of the euro banknotes is sufficient to detect counterfeits by only using hands and eyes. The use of UV light even tends to harm performance. However, the use of technical aids did enable cash handlers to correctly identify genuine notes as such. This latter finding indicates that detection aids can be helpful when a cash handler doubts whether a note is real or not. There are not many counterfeits in circulation and the use of well functioning detection aids can reduce the number of 'false alarms' considerably.

Still, every retailer has to decide for himself to use detection aids or not. In any case, the present report shows that even without any kind of detection equipment at all, cash handlers in particular but also consumers are very well capable, by merely using their hands and eyes, to determine whether a particular euro banknote is genuine or not.

References

Gentaz, E. (2005), Evaluation of multi-sensory training in the detection of counterfeit banknotes for retail cashiers in Europe, Technical report WG/BC 2005 019, Université Pierre Mendès, Grenoble.

Klein, R.M., S. Gadbois, J.J. Christie (2004), Perception and Quality of Counterfeit Currency in Canada: Note Quality, Training and Security Features, Proceedings of SPIE and IS&T, vol. 5310, pp. 1-12.

Stata (1999), Stata Reference manual Su-Z (1999), Release 6, Stata Press, Texas

Appendix A: Estimation results

XT Probit results consumers

Table a 1: Counterfeits

```
Random-effects probit regression                Number of obs      =      2880
Group variable (i): ppnr                        Number of groups   =        40

Random effects u_i ~ Gaussian                   Obs per group: min =        72
                                                               avg =      72.0
                                                               max =        72

                                                Wald chi2(8)       =    143.39
Log likelihood  = -623.78442                    Prob > chi2        =    0.0000

------------------------------------------------------------------------------
answer_cor~t |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      round1 |  -.5947161   .1203318    -4.94   0.000    -.8305621   -.3588701
      round2 |  -.1843902   .1048302    -1.76   0.079    -.3898536    .0210731
    training |   .3717167   .2214734     1.68   0.093    -.0623632    .8057966
     d_r1_tr |   .4429517   .1713784     2.58   0.010     .1070563    .7788472
        d_10 |    1.85783   .2874485     6.46   0.000     1.294442    2.421219
        d_20 |   1.472855   .1878714     7.84   0.000     1.104634    1.841077
        d_50 |     .80982   .1030648     7.86   0.000     .6078166    1.011823
       d_100 |   .8767054   .1175777     7.46   0.000     .6462573    1.107153
       _cons |   .9267038   .1818755     5.10   0.000     .5702345    1.283173
-------------+----------------------------------------------------------------
    /lnsig2u |  -1.051512   .3004766                     -1.640435   -.4625887
-------------+----------------------------------------------------------------
     sigma_u |   .5911083   .0888071                      .4403358    .7935058
         rho |   .2589348   .0576577                      .1624058    .3863719
------------------------------------------------------------------------------
Likelihood-ratio test of rho=0: chibar2(01) =   149.26 Prob >= chibar2 = 0.000
```

Table a 2 Genuine banknotes

```
Random-effects probit regression                Number of obs      =      5760
Group variable (i): ppnr                        Number of groups   =        40

Random effects u_i ~ Gaussian                   Obs per group: min =       144
                                                               avg =     144.0
                                                               max =       144

                                                Wald chi2(8)       =     81.69
Log likelihood  = -2085.4443                    Prob > chi2        =    0.0000

------------------------------------------------------------------------------
answer_cor~t |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      round1 |  -.3800583   .0712934    -5.33   0.000    -.5197909   -.2403258
      round2 |   -.002048   .0574052    -0.04   0.972    -.1145603    .1104642
    training |   .0689734   .2064425     0.33   0.738    -.3356465    .4735933
     d_r1_tr |   .0012387   .0909897     0.01   0.989     -.177098    .1795753
        d_10 |  -.2464753   .0977315    -2.52   0.012    -.4380256   -.0549251
        d_20 |   .0215953   .0927022     0.23   0.816    -.1600976    .2032882
        d_50 |  -.1008071   .0735836    -1.37   0.171    -.2450284    .0434141
       d_100 |  -.1680262   .0781446    -2.15   0.032    -.3211868   -.0148655
       _cons |    1.47316   .1626116     9.06   0.000     1.154447    1.791873
-------------+----------------------------------------------------------------
    /lnsig2u |  -.9711221    .262712                     -1.486028    -.456216
-------------+----------------------------------------------------------------
     sigma_u |   .6153519   .0808302                      .475678    .7960383
         rho |   .2746569   .0523376                     .1845186    .3878839
------------------------------------------------------------------------------
Likelihood-ratio test of rho=0: chibar2(01) =   443.90 Prob >= chibar2 = 0.000
```

XT Probit results cashiers

Table a 3: Counterfeits

```
Random-effects probit regression                Number of obs      =     11808
Group variable (i): ppnr                        Number of groups   =       164

Random effects u_i ~ Gaussian                   Obs per group: min =        72
                                                               avg =      72.0
                                                               max =        72

                                                Wald chi2(14)      =    334.11
Log likelihood  = -1551.3455                    Prob > chi2        =    0.0000

------------------------------------------------------------------------------
answer_cor~t |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      round1 |   -.374439    .076225    -4.91   0.000    -.5238373   -.2250407
      round2 |  -.0403707   .0670133    -0.60   0.547    -.1717144    .0909729
    training |    .146278   .2555465     0.57   0.567     -.354584      .64714
     d_r1_tr |   .0278895   .1037703     0.27   0.788    -.1754964    .2312755
        d_ir |   .5141633   .2702261     1.90   0.057    -.0154701    1.043797
        d_uv |  -1.020308   .2214474    -4.61   0.000    -1.454337   -.5862792
        d_ok |  -.5953851   .2274453    -2.62   0.009     -1.04117   -.1496006
     d_ir_tr |  -.3788951   .3771101    -1.00   0.315    -1.118017    .3602272
     d_uv_tr |   .2102751   .3178529     0.66   0.508    -.4127052    .8332554
     d_ok_tr |   .3406003   .3335374     1.02   0.307    -.3131209    .9943216
        d_10 |   1.605007   .1737967     9.23   0.000     1.264371    1.945642
        d_20 |   1.301501   .1168545    11.14   0.000      1.07247    1.530531
        d_50 |   .8251028   .0646666    12.76   0.000     .6983586     .951847
       d_100 |   .7318003   .0707321    10.35   0.000     .5931678    .8704327
       _cons |   1.840986   .1838605    10.01   0.000     1.480626    2.201346
-------------+----------------------------------------------------------------
    /lnsig2u |  -1.073928   .1930757                     -1.45235   -.6955069
-------------+----------------------------------------------------------------
     sigma_u |     .58452   .0564283                      .4837558     .706273
         rho |   .2546567   .0366471                      .1896402    .3328091
------------------------------------------------------------------------------
```

Table a 4: Genuine banknotes

```
Random-effects probit regression                Number of obs      =     23616
Group variable (i): ppnr                        Number of groups   =       164

Random effects u_i ~ Gaussian                   Obs per group: min =       144
                                                               avg =     144.0
                                                               max =       144

                                                Wald chi2(14)      =    281.37
Log likelihood  =  -5019.792                    Prob > chi2        =    0.0000

------------------------------------------------------------------------------
answer_cor~t |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      round1 |  -.4145664   .0443082    -9.36   0.000    -.5014089   -.3277239
      round2 |  -.0454237   .0374692    -1.21   0.225     -.118862    .0280146
    training |  -.0083056   .2338191    -0.04   0.972    -.4665826    .4499714
     d_r1_tr |  -.0630878   .0572309    -1.10   0.270    -.1752582    .0490826
        d_ir |   .5581043   .2300888     2.43   0.015     .1071385     1.00907
        d_uv |   .1590192   .2277491     0.70   0.485    -.2873609    .6053992
        d_ok |   .3783455   .2336809     1.62   0.105    -.0796607    .8363518
     d_ir_tr |  -.1344676   .3292753    -0.41   0.683    -.7798354    .5109001
     d_uv_tr |   .2132217   .3218796     0.66   0.508    -.4176507    .8440941
     d_ok_tr |   .4115215   .3329961     1.24   0.217    -.2411389    1.064182
        d_10 |  -.0224435   .0629746    -0.36   0.722    -.1458714    .1009844
        d_20 |  -.0294852   .0564422    -0.52   0.601    -.1401099    .0811395
        d_50 |   .0822393   .0460321     1.79   0.074    -.0079819    .1724606
       d_100 |  -.1676867   .0477466    -3.51   0.000    -.2612682   -.0741052
       _cons |   1.693997   .1689988    10.02   0.000     1.362766    2.025229
-------------+----------------------------------------------------------------
    /lnsig2u |  -.7233366   .1393468                     -.9964513    -.450222
-------------+----------------------------------------------------------------
     sigma_u |   .6965134   .0485284                      .6076078    .7984276
         rho |   .3266587   .0306497                      .2696397     .389308
------------------------------------------------------------------------------
Likelihood-ratio test of rho=0: chibar2(01) =  1658.02 Prob >= chibar2 = 0.000
```

Appendix B: The random effects probit model

The description of the random effects probit model is taken from Stata manual release 6. We describe this model for consumers checking counterfeits. The same description holds cashiers and for genuine banknotes.

The probability function for the t^{th} check result of a counterfeit by consumer i is

$$F(x_{it}\beta + v_i) = d_{it}\Phi(x_{it}\beta + v_i) + (1 - d_{it})(1 - \Phi(x_{it}\beta + v_i))$$

with $d_{I\,t}$ a dummy variable equal to 1 when the t^{th} test result of consumer i is correct. The probability of the entire test sequence of consumer i is as follows:

$$\Pr(C_i \mid x_i) = \int_{-\infty}^{\infty} \frac{e^{-v_i^2/2\sigma_v^2}}{\sqrt{2\pi}\sigma_v} \left[\prod_{t=1}^{72} F(x_{it}\beta + v_i) \right] \partial v_i$$

This integral is approximated with the M-point Gauss-Hermite quadrature. The factors w_m^* and a_m^* denote the quadrature weights and the quadrature abscissas. The estimated log likelihood L is an approximation of the true one.

$$LogL = \sum_{i=1}^{41} w_i \log(\Pr(C_i \mid x_i)) \approx \sum_{i=1}^{41} w_i \log \frac{1}{\sqrt{\pi}} \sum_{m=1}^{M} w_m^* \prod_{t=1}^{72} F\left(x_{it}\beta + \sqrt{2\frac{\rho}{1-\rho}} a_m^* \right)$$

The approximation works best for small and moderate panel sizes (moderate means about 50 time periods). An important indication that the approximation is of poor quality is that the estimation of ρ becomes too large. In this study the number of time periods is 72 for counterfeits and 144 for genuine banknotes. The estimated values of the ρ's lie between 0.26 and 0.34.