Update on the development of provisional external migration estimates

This report outlines the progress we've made towards producing provisional estimates of migration independent of passenger departure cards using the outcomes-based approach. It also describes the methodology we will use for this approach.

Key points

1. Stats NZ is developing a methodology that will mitigate the impact of the 17-month lag when using the outcomes-based approach to produce provisional migration estimates:
    - the outcomes-based approach will become New Zealand's official measure of migration
    - production of the outcomes-based approach mitigates the impact of the removal of the departure card.
2. To produce provisional migration estimates, the outcomes-based methodology will use a three-step process:
    - deterministic classification of border crossings
    - predictive model-based classification of border crossings
    - aggregation of results and estimation of migration.
3. Provisional migration estimates will have inherent uncertainty:
    - data in more recent provisional periods will have higher uncertainty while older provisional periods will be more certain
    - provisional estimates will be regularly revised until finalised 17 months after the reference period.
4. Provisional outcomes-based arrival and departure estimates are consistently higher than intentions-based permanent and long-term counts.
5. Provisional outcomes-based net migration estimates are sometimes higher, and sometimes lower, than intentions-based permanent and long-term counts.

Background to the outcomes-based approach

In May 2017 we introduced a new measure of migration known as the outcomes-based approach. This approach measures migrant movements by using the actual outcomes of travellers as they cross New Zealand borders. The first release of the outcomes-based migration measure was in August 2017.

Defining migrants using travel histories and the '12/16-month rule' describes the new measure of determining the contribution of international migration to changes in New Zealand's population.

Outcomes versus intentions: Measuring migration based on travel histories introduces a new measure of migration based on the travel histories of people crossing the border into and out of New Zealand.

Current measure of migration

The current measure of migration classifies border crossings by the intentions of travellers as stated on the arrival and departure cards. The intentions-based (permanent and long-term) measure has historically been a good indicator of long-term movements and the contribution of migration to New Zealand's population change. However, at different times – notably in the early 2000s – it did not fully capture long-term movements.

Since the early 2000s, we have investigated options to measure migration flows independent of the stated intentions of travellers. Initially this measure was based on aggregate or macro-level data and subsequently used individual or micro-level data (see Alternative methods for measuring permanent and long-term migration).

In recent years, two developments supported the use of an outcomes-based measure:

- availability of name, in addition to passport number and date of birth, to enable accurate linking of arrival and departure records to create individual travel histories
- technological and statistical advances that enabled more efficient linking and modelling of large datasets.

Development of outcomes-based approach

The outcomes-based approach identifies an individual's migrant status when we observe their travel history, and their cumulative time spent in/out of New Zealand after a 16-month follow-up period. This approach to measuring migration is completely independent of arrival and departure passenger cards, and therefore provides a sustainable ongoing method of classifying travellers.

The new methodology requires 16 months of travel history to deterministically classify a border crossing as a migrant movement. Because of this, it will take 17 months before final migration estimates are available.

To mitigate the impacts of such a delay and to produce a timelier statistic, we are developing a statistical model that produces provisional estimates of migration. This work aids in the removal of the departure card, which from November 2018 will no longer be filled out by passengers as they leave New Zealand.

Final call for travel departure cards on Beehive.govt.nz has more information about the demise of departure cards.

First look at provisional external migration estimates, published in August 2018, is a preview of what users can expect when the new outcomes-based approach becomes New Zealand's official measure of migration.

Provisional migration estimates and an overview of the outcomes-based approach

We do the following three steps to produce provisional migration estimates using the outcomes-based approach.

Deterministically classifying as many border crossings as possible using the logic of the 12/16-month rule

The first step uses the '12/16-month rule' to deterministically classify border crossings as either 'long-term' or 'not long-term'. Border crossings that cannot be classified deterministically by the 12/16-month rule are left as 'uncertain'. This is because there is not enough travel history for that border crossing to be classified with certainty.

Due to the way the '12/16-month rule' works, we can classify some border crossings with certainty before the required 16-month observation has passed. The longer we observe travellers following their initial crossings, the likelier we are to classify their crossings deterministically.

For example, a New Zealand resident leaves the country for a two-week holiday and then returns home. The traveller then spends the next five months in New Zealand, leaving 10 months and two weeks remaining in the observation period. Not enough time is left in the 16-month observation period for the traveller to spend outside the country for their first departure to be classified as an outbound migrant departure. As such, we can classify this departure as 'not long term' five-and-a-half months after their crossing.

Using a predictive machine learning model to assign a probability of being a migrant crossing to those that can't be classified deterministically

Border crossings that remain 'uncertain' after the first step are then passed to a predictive machine learning model that will assign a probability of the crossing being long-term or not. When all border crossings are either deterministically classified or assigned a probability of being a long-term movement we move on to the third step.

Aggregating results of the predictive model and estimating the level of migration in and out of New Zealand

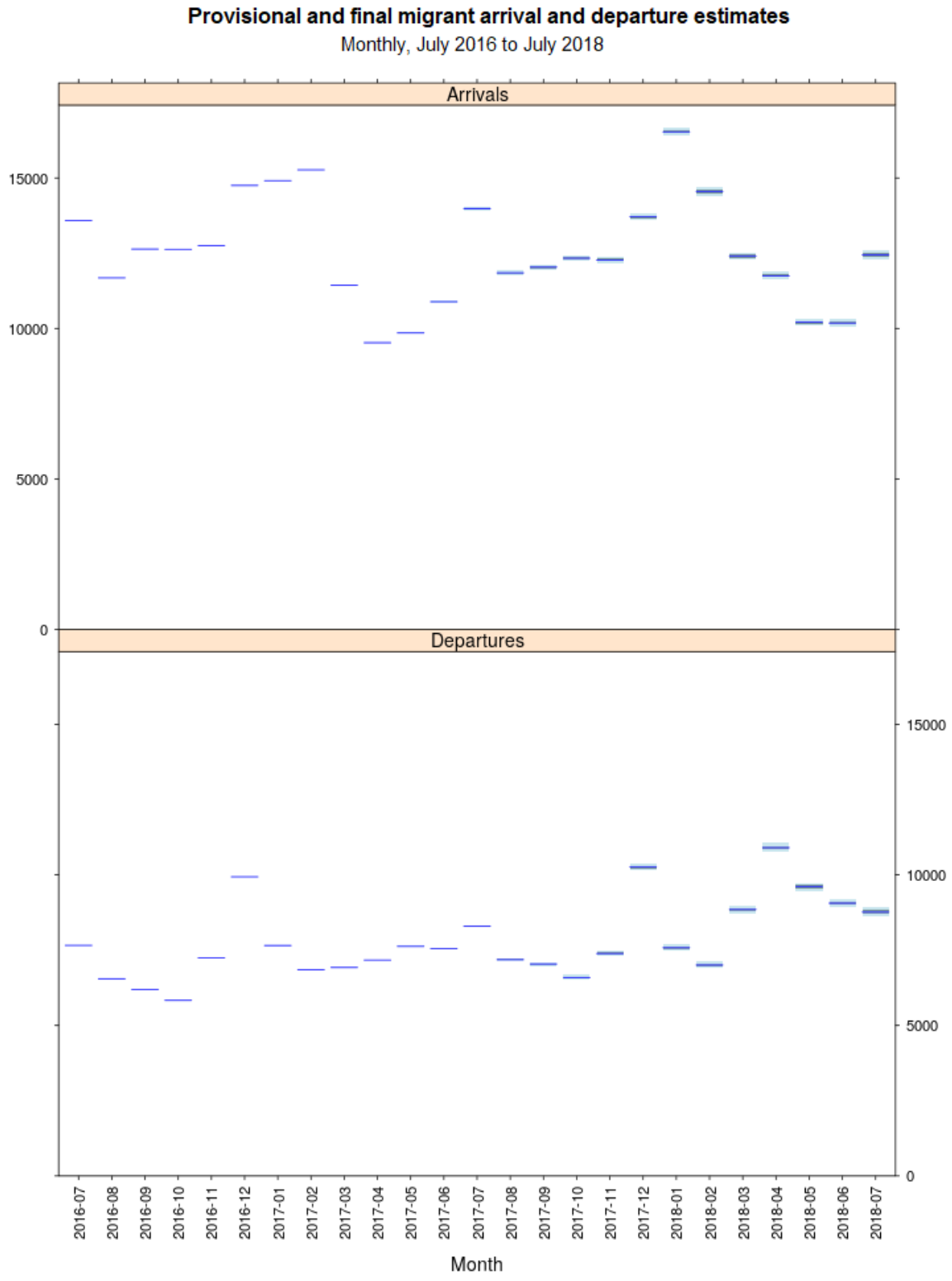
The third step aggregates all crossing classifications (deterministically classified crossings and crossings assigned a probability of being long-term) and estimates the level of migration in and out of New Zealand.

Figure 1 below shows monthly provisional migrant arrival and departure estimates as at July 2018 using this three-step methodology. Net migration estimates are presented in figure 3.

To produce these estimates, the model included data up to 15 August 2018. Specifics of the model used to produce these estimates are detailed in the technical notes. Estimates between July 2018 and April 2017 are provisional, while estimates before these dates are final.

Note that the data presented in this report is indicative only. The methodology to produce estimates is still currently under development.

Figure 1



Text alternative for Provisional and final migrant arrival and departure estimates, monthly, June 2013 to July 2018

For provisional periods, confidence bounds are present and indicate the level of uncertainty in the estimate. Uncertainty in provisional migration estimates is detailed in the next section.

Uncertainty in provisional migration estimates

Statistics produced using the new outcomes-based approach will have inherent uncertainty until 16 months have passed and enough time has elapsed to deterministically classify all crossings. At this point, migration estimates will change from provisional to final estimates.

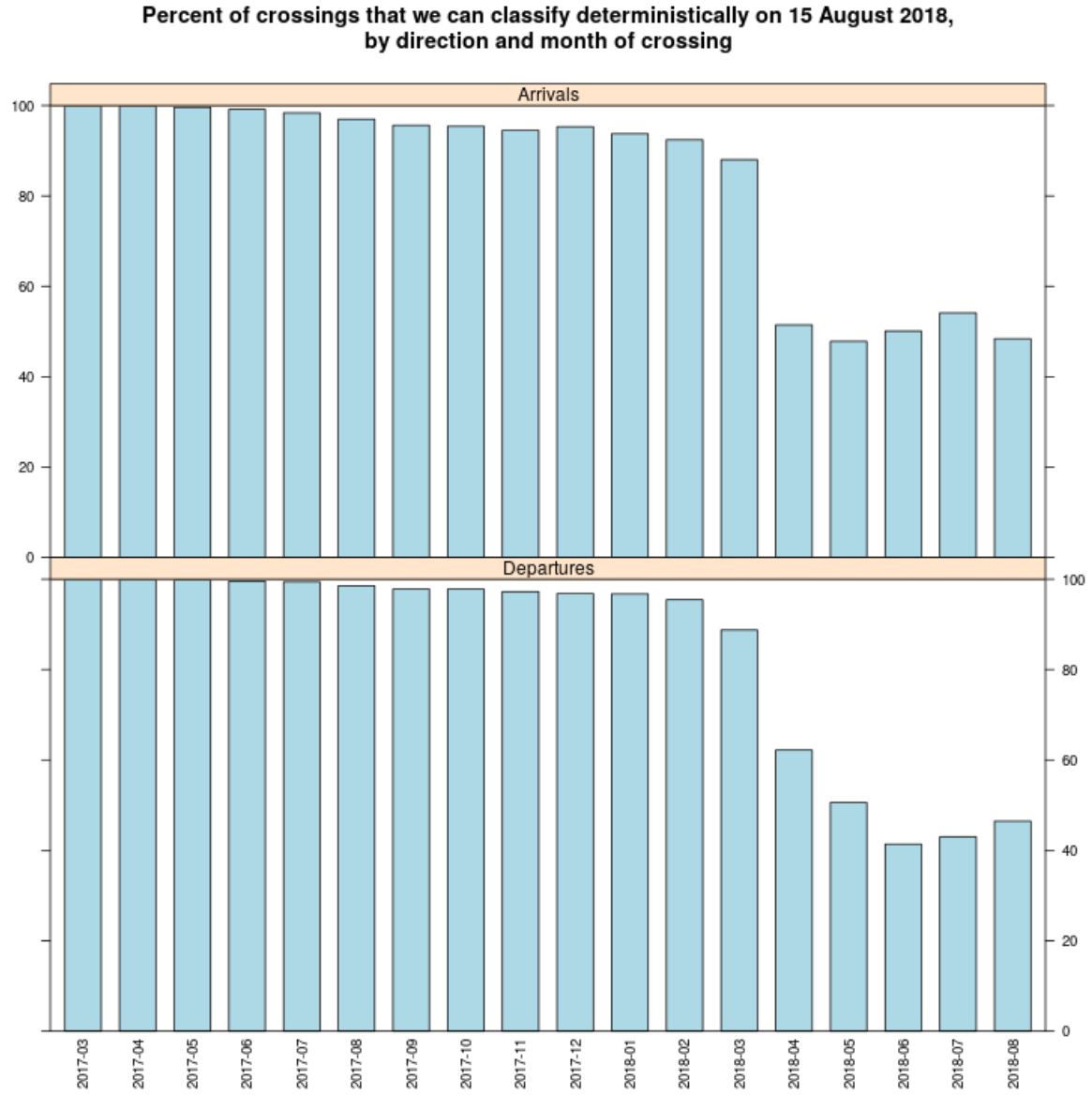
The provisional migration estimates have uncertainty due to the predictive modelling component of the method. Because 'uncertain' border crossings are assigned a probability of being a long-term movement or not, it is possible that the migration status picked from the probabilities in the aggregation and estimation step of the methodology is incorrect. The uncertainty bounds surrounding the median estimate for a month show our confidence in the predictive model's ability to correctly assign migrant statuses from the probability distribution. This means 97.5 percent uncertainty bounds indicate the range at which the correct estimate of migration will fall within 97.5 percent of the time.

Months closer to the reporting date have a higher number of 'uncertain' crossings and fewer deterministically classified crossings than months further from the reporting date. In turn, those months closer to the reporting date will have wider uncertainty bounds.

The uncertainty bounds are much narrower than indicative estimates released in August 2018 (see First look at provisional external migration estimates). This reflects the ongoing development of the model over recent months.

Figure 2 shows the number of crossings classified with certainty as of 15 of August 2018.

Figure 2



Text alternative for Percent of crossings we can classify deterministically on 15 August 2018, by direction and month of crossing

Monthly provisional migration estimates will have uncertainty, so revisions will occur each month as an estimate goes from initially provisional to final 16 months later. Future updates to this work will indicate the level of revisions data users can expect from month to month.

Comparing provisional migration estimates to intentions-based permanent and long-term figures

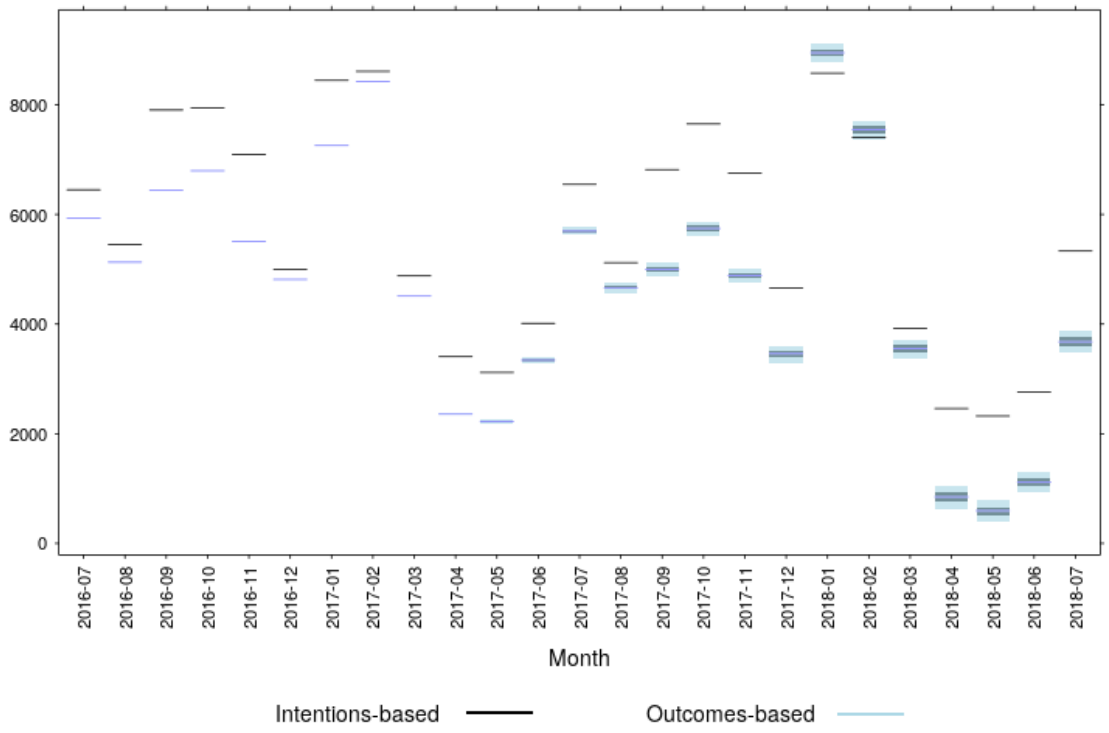
Defining migrants using travel histories and the '12/16-month rule' stated that final estimates of migrant arrivals and departures produced using the outcomes-based approach are consistently higher than the corresponding figures produced using the intentions-based approach.

Comparing provisional estimates of net migration to permanent and long-term net migration shows that provisional net migration estimates produced using the new outcomes-based approach can be both higher and lower than intentions-based net migration figures, but are more often lower.

Figure 3

Outcomes-based provisional and final net migration estimates compared to intentions-based counts

Monthly, July 2016 to July 2018



Text alternative for Outcomes-based provisional and final net migration estimates compared to intentions-based counts, monthly, July 2016 to July 2018

Differences between the outcomes-based and the intentions-based measures of migration likely reflect travellers who change their intentions after their border crossing. That is, travellers who state they intend to stay in New Zealand for less than a year but end up staying longer and the opposite case where travellers state they intend to stay for more than a year but end up leaving earlier. The outcomes-based measure of migration does not classify border crossings based on a traveller's stated intentions. Therefore, it allows us to account for travellers who change their mind after their border crossing and gives us a more accurate measure of migration.

Technical notes

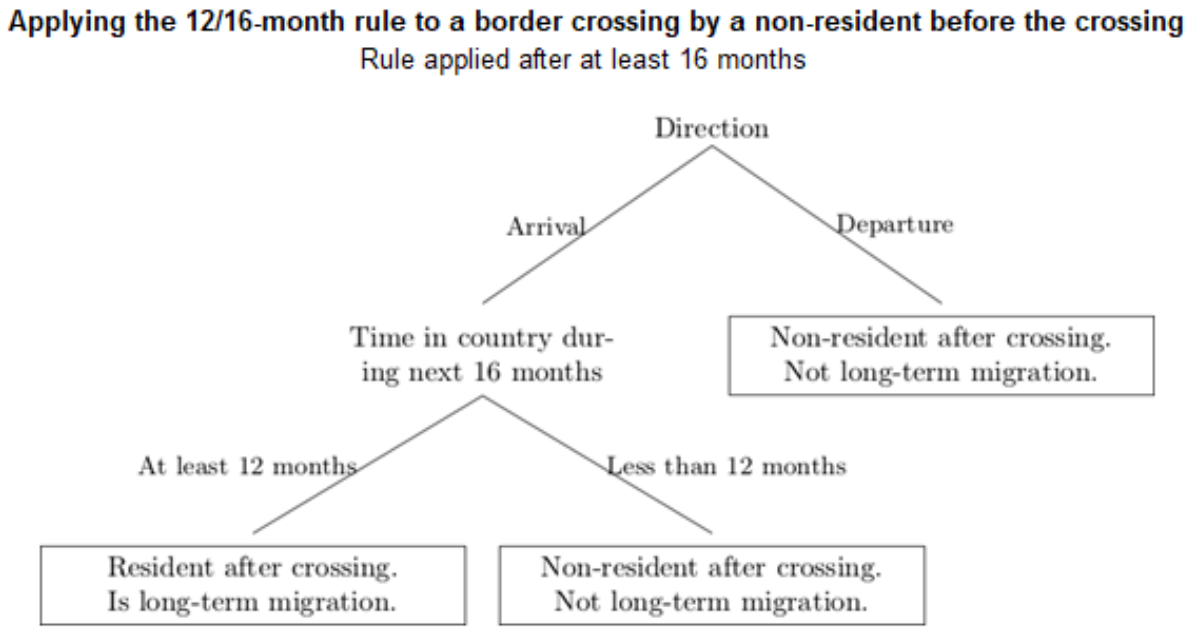
The problem of obtaining migration estimates for the past 16 months using the 12/16-month rule

Under the 12/16-month rule, a long-term migration is a border crossing that involves a change in residence status.

A border crossing counts as a long-term migration **to** New Zealand if it entails a change from non-residence to residence. A non-resident changes to resident at the time of an inward border crossing if, during the 16 months after the crossing, they spend at least 12 months inside New Zealand.

Conversely, a border crossing counts as a long-term migration **from** New Zealand if it entails a change from residence to non-residence. A resident changes to non-resident at the time of the outward border crossing if, during the 16 months after the crossing, they spend at least 12 months outside New Zealand. The 12 months spent inside or outside the country can be composed of several spells of less than 12 months.

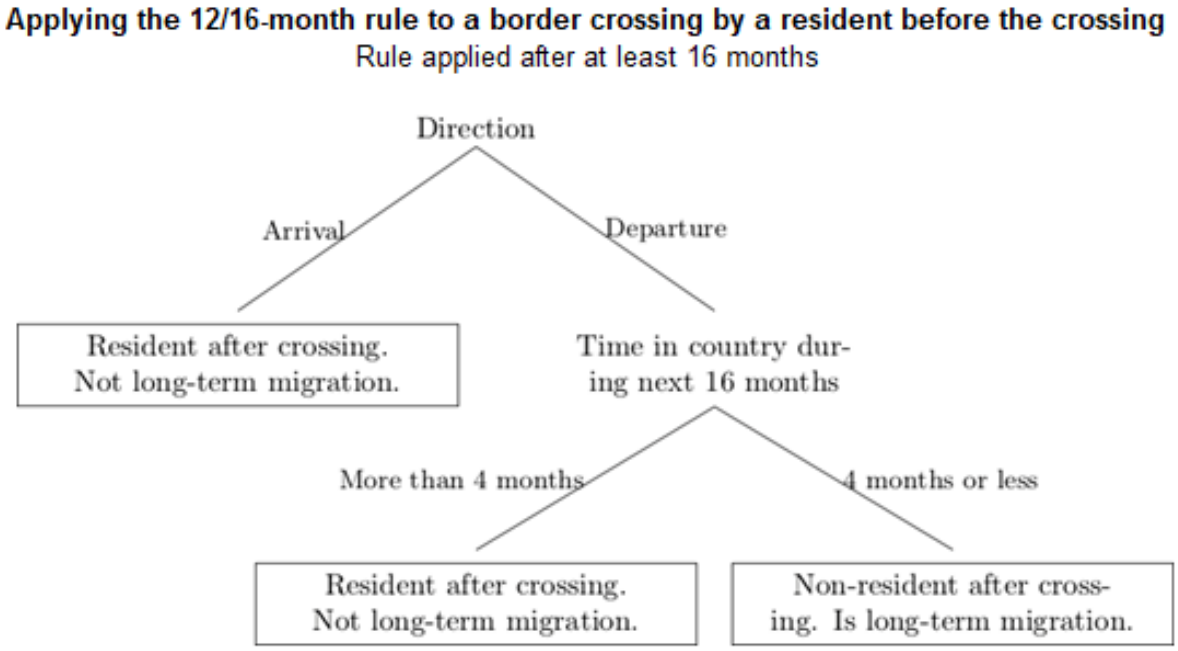
Figure 4



Text alternative for Applying the 12/16-month rule to a border crossing by a non-resident before the crossing, rule applied after at least 16 months

Figure 4 shows how the 12/16-month rule is applied to a non-resident before the border crossing, while figure 5 shows how the rule is applied to a resident. Note that in figure 5, spending four months or less inside the country is equivalent to spending 12 months or more outside the country. Both figures assume a vantage point of at least 16 months after the time of the crossing, so that full information on the person's length of stay after the crossing is available for determining migration and residence status.

Figure 5



Text alternative for Applying the 12/16-month rule to a border crossing by a resident before the crossing, rule applied after at least 16 months

Many users of migration estimates cannot wait 16 months to find out about migration levels. We publish international migration statistics with a lag of only three weeks after the conclusion of each month.

The statistical challenge is to infer migration levels from the incomplete information available about people and their border crossings at lags much less than 16 months. Any estimates derived from incomplete information will necessarily have some uncertainty. We need to minimise this uncertainty, and quantify the uncertainty that remains.

Overview of our solution

We have three solutions to the problem of estimating migration with lags of less than 16 months.

1. **Rules-based classification**. For many crossings, the partial information available within 16 months allows the crossings to be classified with complete certainty. Wherever possible, we identify these crossings and classify them accordingly.
2. **Model-based classification**. Although the remaining crossings cannot be classified with complete certainty, we do have information (from administrative data and from each person's history of arrivals and departures) that suggest what the eventual classification will be. We exploit this information by training a statistical model on historical data, and then applying it on recent unresolved cases.

3. **Estimation**. We use the output from the model to generate distributions of possible outcomes for unresolved border crossings. By combining these distributions with the information on known outcomes, we can generate estimates for any subset or breakdown of the crossings, including measures of uncertainty.

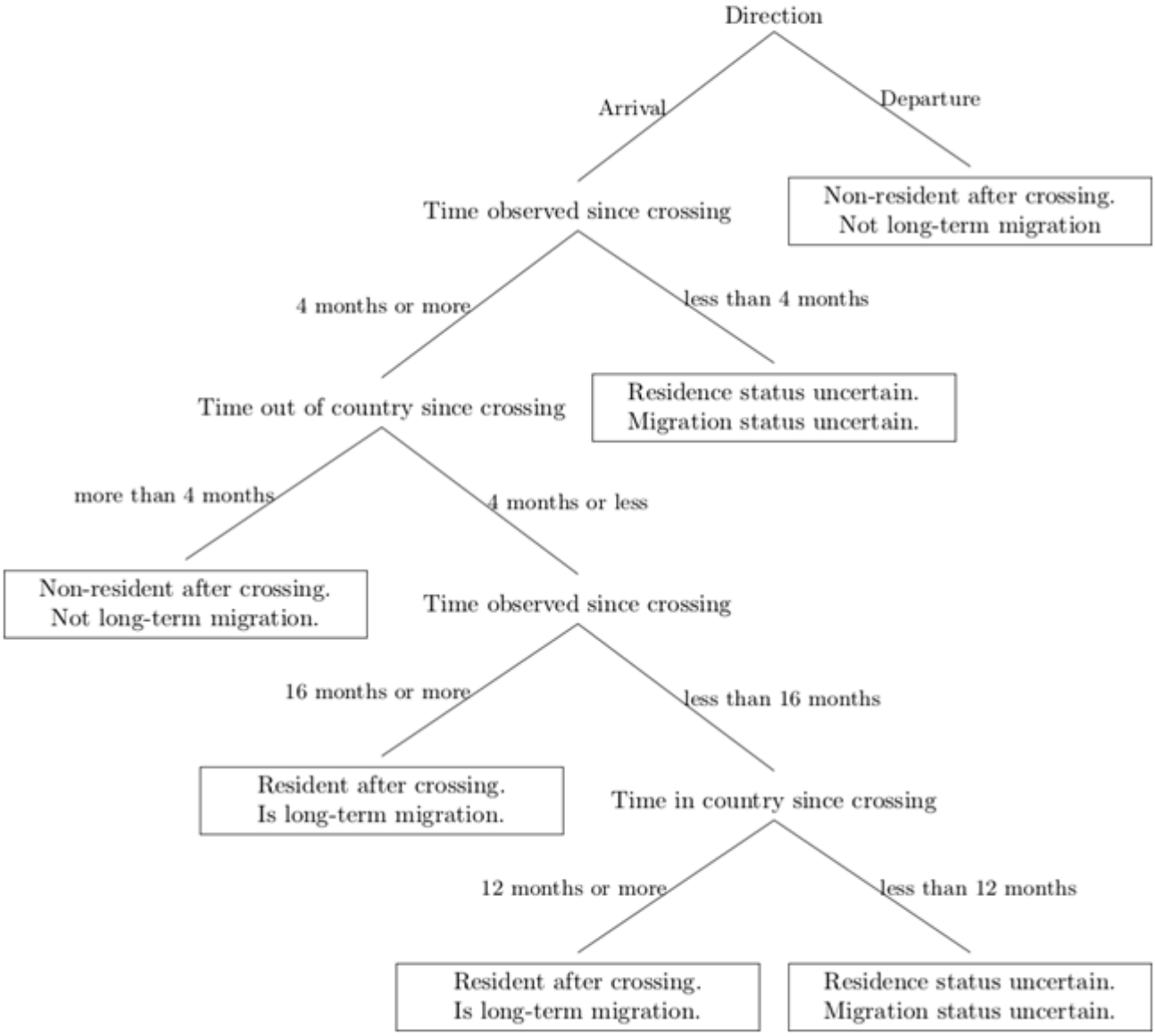
Rules-based classification

If we draw out some implications of the 12/16-month rule, we find that it allows many border crossings to be classified before the full 16 months after the crossing have elapsed. The simplest example is a resident who leaves the country and never returns. After 12 months, we already know that the person has accumulated enough time out of the country to change their residence status to non-resident. There is no need to wait an additional four months before deciding whether the departure can be classified as a long-term migration.

Similar arguments can be constructed for other combinations of residence status, direction of travel, and length of time in the country. Figure 6 presents the full set of rules in the form of a decision tree. The tree applies to crossings for a non-resident before the crossing. Figure 7 shows the equivalent tree for crossings for a resident before the crossing.

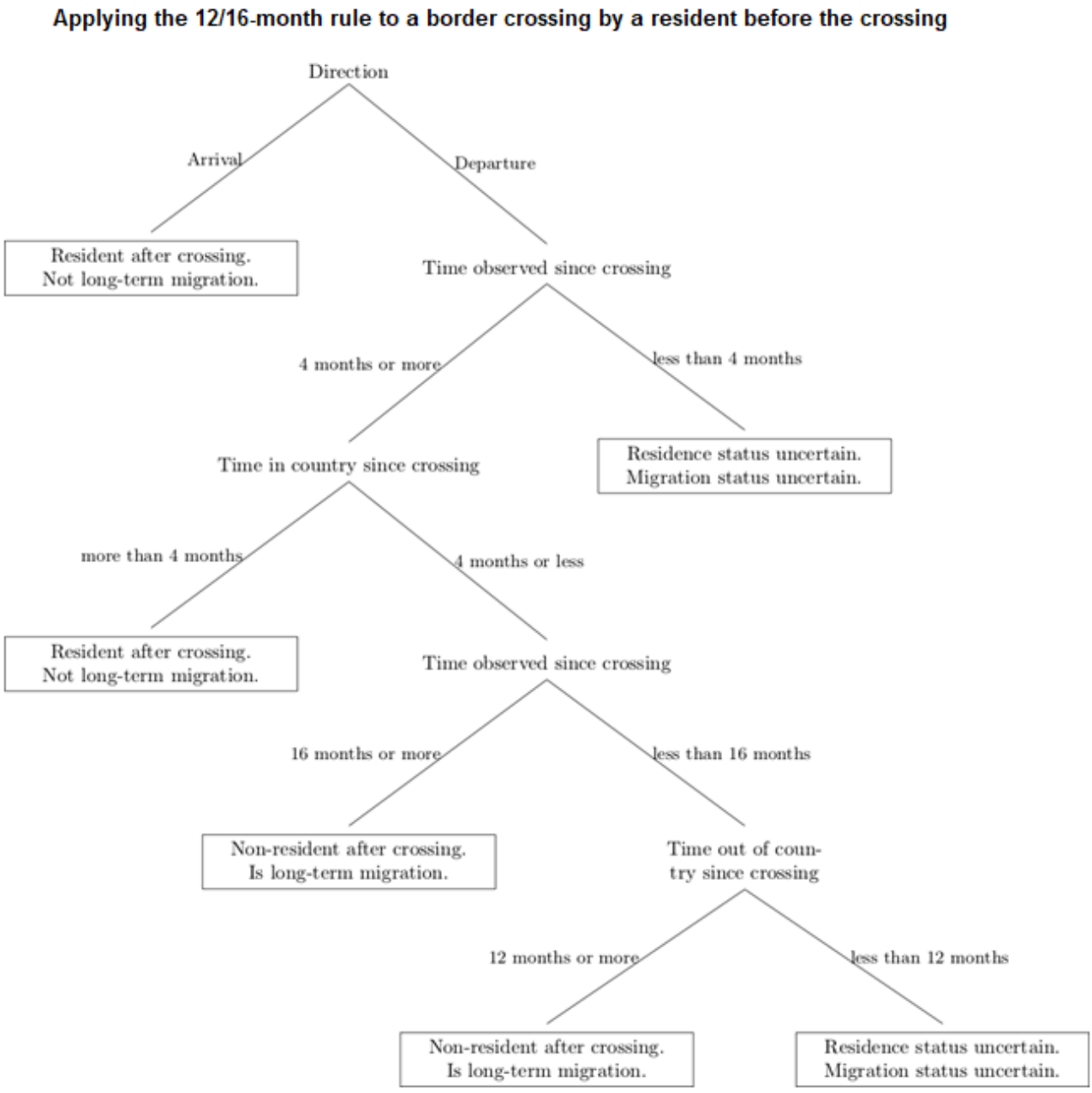
Figure 6

Applying the 12/16-month rule to a border crossing by a non-resident before the crossing



Text alternative for Applying the 12/16-month rule to a border crossing by a non-resident before the crossing

Figure 7



Text alternative for Applying the 12/16-month rule to a border crossing by a resident before the crossing

Using figures 6 and 7 we can classify a large proportion of crossings. However, both trees require the residence status to be known before the crossing. We can also make partial inferences about some crossings where the person's residence status before the crossing is unknown.

Every person who has a completely unclassified crossing must, somewhere in their history of arrivals and departures, have a partly classified crossing (a crossing where the residence status before the crossing is known but the residence status after the crossing is unknown). To make inferences about a completely unclassified crossing we need to look back to the partly classified crossing. In particular, we need to check whether the person was a resident or non-resident before that crossing.

Consider a person who arrived in New Zealand two weeks ago and is departing New Zealand today. This person's residence status before their departure is unknown, implying that the arrival is completely unclassified.

Their departure cannot be a long-term migration. To show this, we need to deal with two possibilities:

1. they remained a non-resident after their arrival two weeks ago
2. they became a resident after their arrival two weeks ago.

If case 1 is true, then their departure today is not a long-term migration, since long-term migration requires a change in residence status, and departing can never convert a person from non-resident to resident.

If case 2 is true, then the person must be spending at least 12 of the following 16 months in the country from the time of their arrival. This means that the person must be spending at least 11.5 months in the country from today.

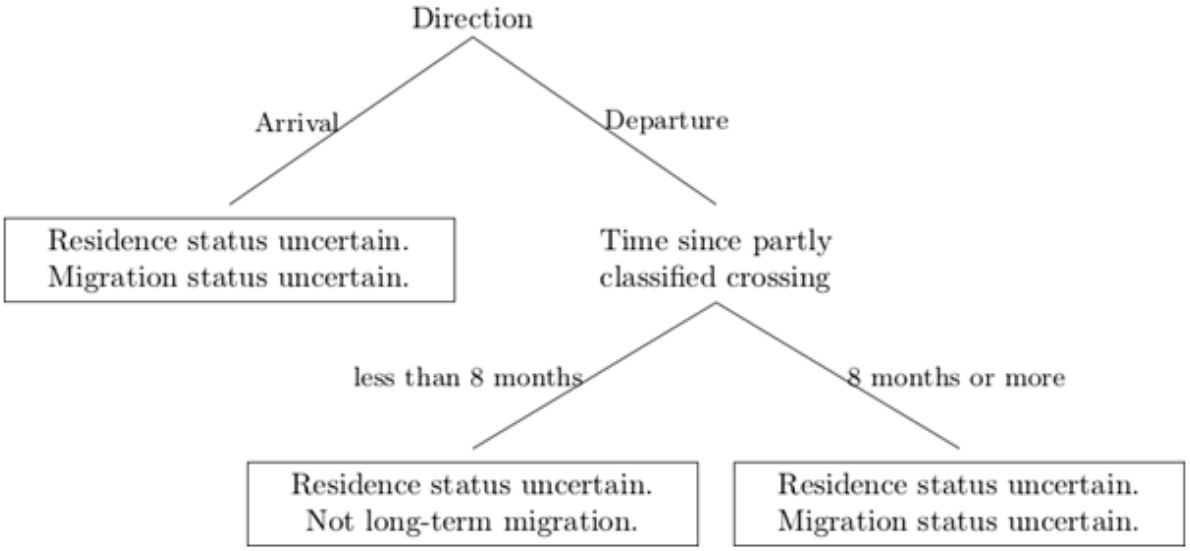
If the person is spending at least 11.5 months in the country from today, then they will remain a resident after today's departure. If they remain a resident after the departure, the departure cannot be a long-term migration.

In sum, although we do not know the person's residence status before and after the departure, we do know that the status is not affected by the departure. From this we can conclude that the crossing is not a long-term migration.

Figure 8 shows the full set of possibilities for crossings where the person was a non-resident before the partly classified crossing.

Figure 8

Applying the 12/16-month rule when current residence status is unknown and last known resident status is 'non-resident'



Text alternative for Applying the 12/16-month rule when current residence status is unknown and last known residence status is 'non-resident'

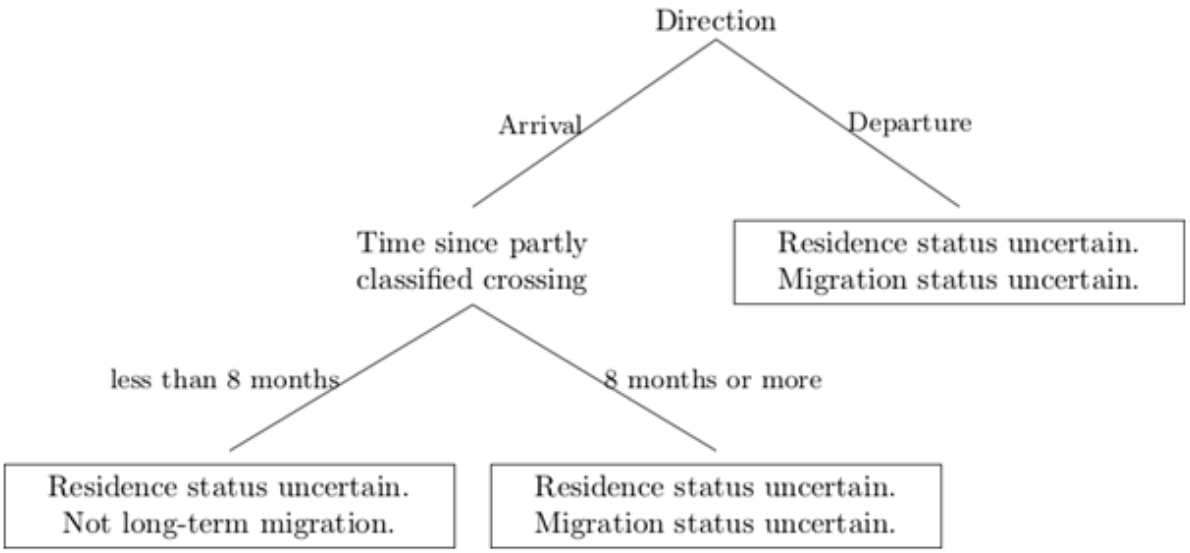
Figure 9 shows how to classify crossings where the person's current residence status is unknown and the person was a resident before the partly classified crossing.

To implement the rules from figures 6 to 9 within a statistical production system, we keep track of all crossings where the long-term migration status, or the passenger's residence status, is currently unknown. Each time we receive a new set of crossings data, we check to see whether the new data, or the passing of time, allows us to resolve any previously-unresolved crossings.

Applying these rules allows us to deduce, with complete certainty, the migration status of around half the border crossings during the last 4–5 months, and almost 100 percent of earlier crossings. In particular, the rules depicted in figures 8 and 9 allow us to classify the departures of most tourists visiting New Zealand, and the arrivals of most New Zealanders returning from short trips overseas, as soon as the crossings take place.

Figure 9

Applying the 12/16-month rule when current residence status is unknown and last known residence status is 'resident'



Text alternative for Applying the 12/16-month rule when current residence status is unknown and last known residence status is 'resident'

Model-based classification

Rule-based classification is valuable, but it leaves us with many crossings whose long-term migration status cannot yet be known with certainty. We need an alternative approach for these records. Our approach is to classify the unresolved crossings probabilistically, using a statistical model.

Dataset construction

The first task in the modelling process is to construct our datasets. We start with the original data on the time and direction of the crossings. We then add extra information on the attributes of the crossings and the people making them. Some of this extra information is obtained from passports and other administrative sources, and includes variables such as age, sex, country of citizenship, and visa type. (All linking to additional sources is done in accordance with Stats NZ's usual strict privacy standards.) Additional variables are derived from the rule-based classification, such as measures of the number of trips taken and an indicator showing whether the person is still in the country.

We divide our complete dataset into two parts: the training set and the prediction set. The prediction set consists of all crossings we are currently unable to classify deterministically. The training set consists of crossings we are able to classify deterministically at present, but would have been unable to classify deterministically in the past. Our aim is to construct a training set that resembles the current prediction set as closely as possible, except that, in the case of the training set, the eventual migration outcome is known.

Choosing a model

In addition to the data, we need a statistical model. We are experimenting with two model classes. The first is a logistic regression, and the second a more recent machine learning model called XGBoost (Chen & Guestrin, 2016). The two models have contrasting advantages and disadvantages. Linear regression copes well with smoothly varying predictors, such as numbers of days observed, and provides results that are relatively interpretable. However, it requires careful specification to perform well. XGBoost copes well with large numbers of variables, and with 'interactions' between variables, where the impact of one variable depends on the level of another variable. XGBoost also requires little human intervention. The ability to cope with complicated predictors without human intervention is potentially useful, as it would allow the model to automatically adjust to changes in the relationship between long-term migration status and the available predictors.

To carry out the model-based classification, we fit our model to the training set, and then apply the model to the prediction set to fill in the missing outcomes. We assume that the relationship between predictors and outcomes is the same in the prediction set as it is in the training set. While this assumption is never perfectly met in practice, it can be made more defensible if our model is able to capture the main predictors of migration. Our experiments so far suggest that predictors that summarise people's migration histories, such as the time spent in the country, or the number of trips taken, do a good job of predicting subsequent migration patterns.

Model performance

We can assess the performance of our models by carrying out hypothetical analyses based on historical data. We provide the models with the data that would have been available to us on, for example, 15 January 2016. We then see how well the various models would have done at estimating migration over 16 months leading up to that point. We can measure the models' performance precisely, since we now know the actual migration statuses of all border crossings over that period. Our main interest is in comparing logistic regression to XGBoost, looking at different ways of constructing the training set, and choosing which variables to include in the model. We will use these comparisons to choose the model that we will use in production.

Estimation

We obtain migration estimates by combining information on the crossings that could be determined through rule-based classification with information on the crossings that had to be determined through model-based classification. The estimates need to reflect the fact that even the best-performing classification model predicts some outcomes incorrectly. This means that we need to provide users with some indication of the uncertainty in the estimates.

Measuring the uncertainty in outcomes from machine learning models and big datasets is a difficult problem. There is, at present, no universally accepted way of doing so. The approach we have followed is known as a 'bag of little bootstraps' (Kleiner et al, 2012). This requires applying the same model repeatedly to different subsamples from the dataset and measuring how the estimates vary across the subsamples.

An advantage of the bag of bootstraps approach is that it allows us to calculate uncertainty measures for any tabulation or transformation of the migration data we wish to estimate. For

instance, it allows us to calculate uncertainty for net migration, and not just for arrivals and departures. Similarly, it allows us to calculate uncertainty for subgroups, such as migration by particular age-sex groups, migration to particular geographic areas, migrations by particular nationalities, or combinations of these variables.

References

Chen, T, & Guestrin, C (2016). Xgboost: A scalable tree boosting system. In Proceedings of the 22nd ACM SIGKDD International Conference on Knowledge Discovery and Data Mining (pp 785–794). Retrieved from https://dl.acm.org/citation.cfm?id=2939785.

Kleiner, A, Talwalkar, A, Sarkar, P, & Jordan, M (2012). The big data bootstrap. Retrieved from https://arxiv.org/abs/1206.6415.

Text alternatives for figures in this document

Figure 1 – Text alternative for Provisional and final migrant arrival and departure estimates, monthly, June 2013 to July 2018

Point estimate graph shows monthly provisional and final estimates of outcomes-based migrant arrivals and departures, from June 2013 to July 2018.

Provisional estimates produced using the new outcomes-based methodology have uncertainty bounds around the median estimate which indicate the range at which the final estimates will be within 97.5 percent of the time.

In the July 2018 month, the median estimates for arrivals, departures, and net migration were 12,500, 8,800, and 3,700, respectively.

Figure 2 – Text alternative for Percent of crossings we can classify deterministically on 15 August 2018, by direction and month of crossing

Column graph shows the number of arrival and departure border crossings that can be classified with certainty on the 15th of August 2018 using the deterministic classification step of the new outcomes-based methodology.

From April 2018 onwards, the number of crossings classified deterministically sits between 40 and 60 percent for both arrivals and departures. For months before April 2018, over 90 percent of arrival and departure border crossings were deterministically classified each month.

Figure 3 – Text alternative for Outcomes-based provisional and final net migration estimates compared to intentions-based counts, monthly, July 2016 to July 2018

Point estimate graph shows monthly provisional and final outcomes-based estimates and their respective intentions-based counts. Intentions-based counts refers to published permanent and long-term net migration figures.

Comparisons between the two measures show that provisional net migration estimates currently are lower than the intentions-based figures but can be both higher and lower. A similar trend is seen when comparing final outcomes-based estimates to the intentions-based figures.

In the July 2018 month, the median outcomes-based estimate was 31 percent lower than the intentions-based count. Conversely, in the January 2018 month, the median outcomes-based estimate was 4.3 percent higher than the intentions-based count.

Figure 4 – Text alternative for Applying the 12/16-month rule to a border crossing by a non-resident before the crossing, rule applied after at least 16 months

Decision tree shows the logic of applying the 12/16-month rule to classify the migrant status of border crossings that are at least 16-months old and that were made by a non-resident before the crossing.

For arrivals where the traveller was a non-resident before the crossing, if they spent at least 12 out of the 16 months following their initial crossing in the country then they become a resident after their crossing and their crossing is classified as a long-term migration movement. If they spent less than 12 months inside the country, they are a non-resident after their crossing and their crossing is classified as not a long-term migration movement.

For departures where the traveller was a non-resident before the crossing, they will remain a non-resident after the crossing and their crossing is classified as not a long-term migration.

Figure 5 – Text alternative for Applying the 12/16-month rule to a border crossing by a resident before the crossing, rule applied after at least 16 months

Decision tree shows the logic of applying the 12/16-month rule to classify the migrant status of border crossings that are at least 16-months old and that were made by a resident before the crossing.

For arrivals where the traveller was a resident before the crossing, they will remain a resident after the crossing and are classified as not a long-term migration.

For departures where the traveller was a resident before the crossing, if they spent more than 4 out of the 16 months following their crossing in the country then they remain a resident after their crossing and their crossing is classified as not a long-term migration movement. If they spent less than 4 months inside the country, they become a non-resident after their crossing and their crossing is classified as a long-term migration movement.

Figure 6 – Text alternative for Applying the 12/16-month rule to a border crossing by a non-resident before the crossing

Decision tree shows the logic of applying the 12/16-month rule to classify the migrant status of border crossings made by a non-resident before the crossing.

For arrivals, crossings made by travellers who were non-residents before the crossing are classified as not long-term migrations if the time observed since the crossing is 4 months or more and the time spent outside of the country since the crossing is more than 4 months. In these cases, travellers remain as non-residents after the crossing.

Arrival border crossings are classified as long-term migrations if the time spent out of the country by the traveller is 4 months or less and either (i) the time observed since the crossing is 16 months or more or (ii) the time observed since the crossing is less than 16 months and the time spent in the country since the crossing is 12 months or more.

In both these cases, the traveller becomes a resident after the crossing and is classified as a long-term migration. All other cases for arrivals result in the residence status and migration status being uncertain.

For departures where the traveller was a non-resident before the crossing, they remain a non-resident after the crossing and the border crossing is classified as not a long-term migration.

Figure 7 – Text alternative for Applying the 12/16-month rule to a border crossing by a resident before the crossing

Decision tree shows the logic of applying the 12/16-month rule to classify the migrant status of border crossings made by a resident before the crossing.

For departures, crossings made by travellers who were residents before the crossing are classified as not long-term migrations if the time observed since the crossing is 4 months or more and the time spent in the country since the crossing is more than 4 months. In these cases, travellers remain as residents after the crossing.

Departure border crossings are classified as long-term migrations if the time spent in the country by the traveller is 4 months or less and either (i) the time observed since the crossing is 16 months or more or (ii) the time observed since the crossing is less than 16 months and the time spent out of the country since the crossing is 12 months or more.

In both these cases, the traveller becomes a non-resident after the crossing and is classified as a long-term migration. All other cases for departures result in the residence status and migration status being uncertain.

For arrivals where the traveller was a resident before the crossing, they remain a resident after the crossing and the border crossing is classified as not a long-term migration.

Figure 8 – Text alternative for Applying the 12/16-month rule when current resident status is unknown and last known residence status is 'non-resident'

Decision tree shows the logic of applying the 12/16-month rule to classify the migrant status of border crossings where the current residence status is unknown, and the last known residence status is 'non-resident'.

For arrivals, the residence status and migration status are uncertain after the crossing.

For departures, if the time since the traveller's previous partly classified crossing (where the last known residence status is 'non-resident') is less than 8 months, the residence status after the current crossing is uncertain and the crossing is classified as not a long-term migration. If the time since the partly classified crossing is 8 months or more, both the residence status and migration status after the current crossing is uncertain.

Figure 9 – Text alternative for Applying the 12/16-month rule when current residence status is unknown and last known residence status is 'resident'

Decision tree shows the logic of applying the 12/16-month rule to classify the migrant status of border crossings that are at least 16-months old and that were made by a resident before the crossing.

For arrivals, if the time since the traveller's previous partly classified crossing (where the last known residence status is 'resident') is less than 8 months, the residence status after the current crossing is uncertain and the crossing is classified as not a long-term migration. If the time since the partly classified crossing is 8 months or more, both the residence status and migration status after the current crossing is uncertain.

For departures, the residence status and migration status are uncertain after the crossing.

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