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DOES BROADBAND FACILITATE IMMIGRATION FLOWS? A NON-LINEAR INSTRUMENTAL VARIABLE APPROACH

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Abstract

This paper investigates whether ICT facilitates migration flows from any one OECD member country to others, and from non-OECD to OECD countries. Among various ICT tools, we primarily focus on broadband. Our instrumental-variable model derives its non-linear first stage from a logistic diffusion model, where pre-existing voice-telephony and cable-TV networks predict maximum broadband penetration. The selection of both OECD- and non-OECD-origin countries, governed by the availability of the data, is based on the magnitude of the flows, leading us to examine those with a minimum number of 100 people (threshold 0.1) who are migrating from source to host, followed by 300 (threshold 0.3) and 500 (threshold 0.5) people. By looking at the efficacy of ICT connections, we intend to fill the gap in the literature on the relationship between communication facilities and migration decisions. We find a strong and positive effect of broadband on migration flows between 1995 and 2009. This effect is more prominent for non-OECD to OECD-country pairs. The larger the threshold, the better the results.

JEL Codes: C5, F22, J61

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1. Introduction

Currently, 232 million people, who represent approximately 3.6% of the world population, are living outside their countries of origin. According to the International Organization for Migration (IOM) Report (2013), the growth in the number of immigrants between 2000 and 2010 was double that of the previous decade. This figure is slightly higher in Europe than in the US. With such great numbers of people choosing to live outside their homelands, our curiosity turns to the reasons behind one's decision to migrate.

In this regard, we intend to investigate the intra-OECD movements (hereafter OtO), as well as from the non-OECD region to the OECD one (hereafter non-OtO). The main host countries here are Austria, Belgium, the Czech Republic, Denmark, Finland, France, Germany, Hungary, Italy, Luxembourg, the Netherlands, Norway, Poland, Spain, Sweden, and the UK, and their selection by us was based on the availability of the data.

Throughout the literature, multiple economic, political, and social aspects have been pointed out as factors in individuals' decision to emigrate abroad; these are, chiefly, wages, employment and unemployment rates, inequality, GDP per capita/GDP level, population/population density, trade, immigration law, and educational attainments. We find it surprising that the levels of ICT facilities in both the origin and the host countries have not been considered as a determinant, given the dominance this assumes in the life of an immigrant abroad eager to engage in information exchange with those back home. Also and more importantly, we believe that ICT connections foster follow-up flows of migrants to the developed world by improving access to information (much of it from previous immigrants now living there) about the better life awaiting them there if they decide to move.

In this paper, we look at the role of ICT connections in encouraging migration; we also examine a number of economic aspects for possible inclusion as factors in a person's decision to move abroad. In order to do this, we will confine ourselves to the number of people aged 15-64 going from the origin to the receiving country, obtained from the OECD; controlled for the employment rate in the host country and the unemployment rate in the origin country (Eurostat); real Gross Domestic Product per capita (GDP); broadband, cable-TV and voice-telephony subscription penetration rates (International Telecommunications Union, ITU); the average wage across industries (OECD's Occupational Wages around the World, OWW) in the host country; and the distance between the origin and host countries (CEPII, Mayer and Zignago, 2011). A dummy variable to capture institutional features, FREE, is equal to 1 if an individual has free access to the host country (Eurostat, EEA). Since the data capture both time-series and cross-sectional components, a panel data analysis will be undertaken. By including ICT connections, we intend to fill the gap in the literature that would outline the relationship between communication facilities and migration decisions, and we expect to find a significant effect of such for both OtO and non-OtO flows between 1995 and 2009.

The paper proceeds as follows. Section 2 represents a literature review. Section 3 presents the data analysis and estimated model. Section 4 discusses endogenous variables, non-linear instrumental variables, the validity of instruments, certain robustness checks, and the analysis results. Finally, Section 5 presents the conclusion.

2. Literature Review

From prehistoric to modern times, human beings have always been on the move. This means that the history of migration coincides with the history of humanity. By and large, it may appear that individuals move to better and safer places, but what is a better and safer place? Is this criterion sufficient to encompass the many possible reasons behind individuals' decisions to move elsewhere? Lewis (1954) pointed out that a necessary condition for someone to migrate is the availability of adequate earnings in the host country. More generally, the direction of movement is from low-earning to high-earning countries (Massey *et al*., 1994). Chiswick (1999) claimed that the relative wage difference between the host and origin countries and both direct and indirect migration costs determine the approximate rate of return from migration, and the greater this rate, the more probability the person will migrate.

Furthermore, Greenwood (1975) surveyed the literature up to the 1970s and showed that certain aspects played into the decision to migrate, such as distance, the earnings of other immigrants there, networking, the cost of migration, and the characteristics of a typical immigrant in the target country. Greenwood (1985) conducted another survey to cover the period leading up to the 1980s and found that, in addition to the factors listed in his first survey, labor-market conditions, taxation policies, and environmental features in the host country, personal job skills, and individual circumstances, such as education, age, gender, and marital status, are essential determinants of migration.

Migration is a matter of self-selection. In this regard, the majority of labor economists follow Roy's (1951) self-selection model, which is based on the assumption that humans' decisions to participate in job markets depend on whatever ability they have, the technology to be applied, and the correlation between these factors in a community where there are only two occupations available. Although Roy's model captures a simple case, it provides a basis for decision-making problems, such as job, location, and education.

Borjas (1987, 1989), for instance, launched the first extension to Roy's model, stating that the earnings of immigrants across multiple skill groups are a main attractant to other would-be immigrants. His theory holds if the value of logged wages in the host outweighs the logged value of wages in the origin country, plus migration cost. Niedercorn and Bechdolt (1969) looked at the gravity model, using the framework of utility theory. Variables included in this theory are the population of the host nation, the finite number of journeys planned, the period of time that will be spent in the host, and the sum of money that will be needed for this journey from a single origin country to multiple host countries.

The most general form of the gravity model was given by Vanderkaup (1977): the level of immigration flows depends upon the relative populations in the origin and host countries and the distance between the two. Rodrigue *et al*. (2009) took a different approach to this model, describing it as a physical science (also known as Newton's Law) and commenting that if the importance of one location increases across any two locations, there will also be a jump in movement between those two locations. Here, the importance of the location is measured by population, GDP level, employment, unemployment, poverty, or other appropriate variables.

This gravity model departs from Niedercorn and Bechdolt's (1969) version in that the importance of a country is not defined by population only, but also captures GDP, labor-market conditions, and other relevant factors. Thus, we can state that a general assumption of the gravity model of migration is that the greater the relative importance of the origin and host countries, the more the migration. A gravity model mainly focuses on the prominence of a country within country pairs and can be adjusted to other migration theories, depending upon which aspects of decision-making are to be analyzed. Thus, this paper will use the gravity approach.

Hypothetically, a number of economic constraints, such as overall economic hardship, poverty, a low standard of living, insufficient wages, wage inequalities, failing infrastructure and dystopian social factors, such as wars, famine, drought, and other natural disasters, act as inducements for those affected to flee abroad. This paper intends to focus exclusively on the economic factors. While each man's or woman's own personal expectations motivate him or her to leave the homeland, other external realities also play a critical part in the decision: social ties, affiliations, or, simply, the dream of a better standard of living (Jong, 2010). Researchers have identified employment opportunities and a high future level of income as key incentives to move away (Daniels and Ruhr, 2003; Sorhun, 2011).

When contemplating emigration, people focus on places with a high potential of finding a job so that they can start earning money for survival soon after arrival. Widespread unemployment and a low share of GDP per capita at home are also major prods to looking elsewhere for a place to settle (Feridun, 2007). More specifically, failure to find work within a certain period of time pushes individuals to look at other locations, ones with lower unemployment rates. On the other hand, the distance between the origin and receiving countries is deemed to be a key deterrent (Mayda, 2008; Sorhun 2011); i.e., greater distance requires more cost of travel as well as more risks. As such, with the ongoing turmoil in several Middle East countries like Egypt, Libya, Yemen, and, most dramatically, Syria, multiple nationalities are streaming towards Turkey, which does not have the desired level of economic growth to put it in the same category as a developed European country but is nevertheless the destination of those fleeing neighboring states (Sirkeci and Esipova, 2013).

Severe unemployment and wide earnings differentials also figure in the decision to move to a better off region, as is borne out in not only cross-national but also interregional migration studies (Pissarides and McMaster, 1990). Furthermore, Sorhun (2011) examined the economic size of the receiving country as another magnet for migrants, as well as the association of income level with the migration decision in the case of Turkey's internal/external migration.

Zavodny (1999) investigated location choices within six states of the US and found that people desired to live in those states that they perceived as more beneficial for them. For those living in a hugely populated country, grinding poverty and "unpleasant" environments are most often cited as what prompted emigrants to head away from home (Amacher *et al*., 1998). Indeed, living under such conditions inevitably propels people outward, not necessarily to the best, but at least better, places. Deciding on a host country is also done in the hope of gaining the greatest return on human capital (Stark and Taylor, 1991). GDP per capita both in the origin and receiving countries is found to be another criterion that is weighed when deciding whether to stay or go—and where to go (Marques, 2010).

Overall, the decision to migrate depends both upon an immigrant's unique characteristics and the general labor-market conditions in the home country (Pissarides and Wadsworth, 1989). So far, the majority of the factors believed to be motivating migration have been identified. In general, we can state that a person will leave his home country if the perceived benefit in doing so outweighs any benefit of staying put.

Now that we are living in the 21st century, where telecommunications have assumed a central role in everyone's life, enabling him or her to keep in touch with family members and friends back home and exchange information between the old and new locations, telecommunications as a separate factor in triggering migration flows deserves investigation. Thus, this chapter will analyze whether there is such a relationship between migration flows and telecommunications, and, if so, fill in the gap in the migration literature.

As this paper is to adopt the Gravity Model of Migration, the related literature is followed in more detail and shown in Table 1. As is seen in the table, to the best of our knowledge, no gravity model includes telecommunications facilities as a determinant of migration. Telecommunications facilities are regarded as a tool to measure a country's wealth in relation to GDP, but not as one that improves the flow of information on host countries such that it fosters emigration from poorer places. Our gravity model will allow us to detect such mobility in flows from origin to host in relation to the availability of telecommunications facilities.

As seen in the table, in almost all cases, distance is a significant disincentive, as the greater the distance, the higher the risk and the migration cost. Better wages, high GDP per capita, and little unemployment (or a high employment rate) in the host country are found to be the main motivating factors in deciding where to migrate to. Our results in Section 3 will also demonstrate how these considerations play a leading role in choosing where to move to.

3. Data and Empirical Model

The empirical analysis employs a panel of data from a sample of inflows in thousands from origin country i to host country j at time t. The main host countries here are Austria, Belgium, the Czech Republic, Denmark, Finland, France, Germany, Hungary, Italy, Luxembourg, the Netherlands, Norway, Poland, Spain, Sweden, and the UK, covering the years between 1995 and 2009. OECD-origin countries are mainly: Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Italy, the Netherlands, Norway, Poland, Slovakia, Estonia, Sweden, Turkey, and the UK. Non-OECD-origin countries, on the other hand, are Algeria, Armenia, Bosnia-Herzegovina, Bulgaria, China, Egypt, Morocco, Nigeria, Pakistan, Romania, Russia, Tunisia, and Ukraine.

Table 1. Gravity Models Through the Literature

Author(s)	Geographical units and sample period	Methodology	Dependent variable	Significant explanatory variables
Karamera *et al*. (2000)	19 European, 16 African, 16 Asian, 2 North American, 3 Central American, 3 Caribbean, 12 South American countries to North America; 1976-1986	Panel with time- and country-pair fixed effects and origin-region dummies	Total migration inflows	(+): Population (origin), income (origin + host), unemployment (host), business credit ratings (origin), relative freedom (origin), common border, population density. (-): Distance, population (host), inflation (origin), political instability (origin), political rights (origin), civil liberty (origin), immigration policy.
Mayda (2008)	Migration to 14 OECD countries: Australia, Belgium, Canada, Denmark, France, Germany, Japan, Luxembourg, Netherlands, Norway, Sweden, Switzerland, UK, US;1980-1995	Panel OLS with individual-country dummies	Emigration rate	(+): Per worker GDP (host), young population (origin). (-): Distance.
Beine *et al.* (2006)	Migration to OECD countries; 1990 and 2000	Panel OLS with dummy for 2000	Skilled migrant inflows	(+): Distance, GDP per capita ratio, social expenditure (host), democracy index (origin), public-education expenditure (origin). (-): Linguistic proximity, education expenditures (host), openness to immigration.
Shen (1999)	Chinese provinces; 1985-1990	Panel OLS	Total migration flows	(+): Population (origin), GNP growth rate (origin + host). (-): Distance, illiteracy (host), agricultural employment (origin + host), population growth (origin), population density (origin + host).
Pedersen *et al*. (2008)	Migration to OECD countries; 1990-2000	Panel fixed effects for host, WLS and GEE with host- or country-pairs dummy	Total migration inflows	(+): Stock of immigrants, common border, common language, colony dummy, trade volume, relative population (host\origin), social expenditure (host), (-): Distance, GDP per capita (origin + host), unemployment (host), illiteracy (origin), freedom house index (origin).
Helliwell (1997)	From US to Canada, within Canada; 1991	Cross-section OLS	Total migration inflows	(+): Population (origin + host), real personal income (host). (-): Distance, real personal income (origin).
Kumo (2007)	Flows within Russian regions; 2003	Cross-section OLS	Total migration flows	(+): Population (origin + host), gender ratio, paved roads, common border, some regional dummies. (-): Distance, below-working-age ration, some regional dummies.
Ashby (2007)	Interregional flows within 48 US states; 2000	Cross-section with spatial dependency	Migration rate	(+): Relative economic freedom, relative population, relative income, relative employment growth, relative retired, relative heating days, distance squared, (-): Distance, relative precipitation, relative density, dummy for movers.
Fertig (2001)	Flows from 17 OECD countries into Germany; 1960-1994	Panel GLS with origin-country dummies	Migration rate	(+): Per capita income ratio, employment (host), free movement dummy. (-): Lagged migration rate, employment (origin).
Marques (2010)	Flows from Central and Eastern Europe to EU:15 countries; 1986-2006	Panel fixed effects for host with region dummies	Total migration flows	(+): GDP (origin + host), GDP per capita (origin), current migration stock, contiguity, common language, liberal policy reform (host), some regional dummies. (-): GDP per capita (host), unemployment (origin), political environment (host), distance, some regional dummies.
Andrienco and Guriev (2004)	Interregional migration in Russia; 1992-1999	Panel OLS with time dummies and region-pairs fixed effects	Number of people who migrate	(+): Income per capita (host), unemployment rate (origin), poverty (origin), public-goods provision (host). (-): Distance, income per capita (origin), unemployment rate (host), poverty (host), public-goods provision (origin).
Lewer and den Berg (2008)	General	Joint hypothesis of cross-section	Level of immigration	(+):population (origin) x population (host), common language, colonial link between host and origin, relative distance to income per capita in the origin, immigrants in the host. (-) distance.

As an international telecommunications channel, we expect broadband to present as the most convenient communication tool, as it is cheap and allows job applications to be submitted and job interviews to be conducted from overseas. In order to capture both ICT connections and a number of economic aspects as reasons for individuals' decision to migrate, the following gravity model will be applied:

$$\begin{aligned}\log FLOWS_{ij,t} &= \log\beta_1 ICT_i + \log\beta_2 ICT_{j,t} + \beta_3 \log DIST_{ij} + \beta_4 \log RGDP_{ij,t} \\ &+ \beta_5 \log WAGE_{j,t} + \beta_6 UNEMPR_{i,t} + \beta_7 EMPR_{j,t} + \varepsilon_{ij,t}\end{aligned} \quad (1)$$

where $FLOWS_{ij}$ is the flow of immigrants in thousands. Here, we grouped migration flows into three thresholds that are equal to and greater than 0.1, 0.3, and 0.5 (i.e., 100, 300, and 500 people or more), both for OtO country pairs and non-OtO; ICT_i, ICT_j are ICT connections in the origin and host, respectively; $DIST_{ij}$ is the distance between the origin and host country; $RGDP_{ij}$ is the relative real GDP (i.e., $\frac{RGDP_i}{RGDP_j}$ both real GDP in the origin— $RGDP_i$ — and real GDP in the host— $RGDP_j$ — are constant in US$ in the year 2000); $WAGE_j$ is the average wage across industries in the host country, all adjusted to US$ in the year 2000; $UNEMPR_i$ is the unemployment rate in the origin; $EMPR_j$ is the employment rate in the host; and ε_{ij} is the error term. Throughout the literature, technology is assumed to evolve along an exponential growth curve (Griliches, 1957; Geroski, 2000; Gruber and Verboven, 2001; Comin *et al*., 2006; Czernich *et al*., 2011); thus, ICT connections in origin and host can be written as:

$$ICT_{it} = \alpha_1 e^{\lambda_{it}} \text{ and } ICT_{jt} = \alpha_2 e^{\lambda_{jt}} \quad (2)$$

where λ_{it} *and* λ_{jt} are the growth parameters of the rate of the ICT tool in the origin and host country, respectively. In our analysis, we primarily focus on broadband as an ICT tool for the reasons we explain in Section 4. Broadband here is counted from 256kbit/s to under 2Mbit/s. Since migration occurs between specific country pairs, we focus on the relative broadband penetration rate within those country pairs. Thus, it can be written as:

$$BROAD_{ij,t} = BROAD_{it} x BROAD_{jt} \quad (3)$$

Based on equation (2), $BROAD_{ij,t}$ takes the exponential form of:

$$BROAD_{ij,t} = \alpha^{*} e^{\lambda^{*}{}_{itj}} \tag{4}$$

Here, $BROAD_{ij}$ is defined as the multiplication of the broadband penetration rates in the origin and host country at time t. There is no previous literature to guide us as to how to set up a country-pair specific variable suitable for this transaction. However, since communication is a form of information exchange, and broadband in particular is our communication variable, we decided to concentrate on such interaction variables. Given that broadband (as an example) may have been introduced into Country A (origin) two years later than into Country B (host), the resultant interaction variable will enable us to observe what happens after A and B have broadband at the same time. We cannot present them in the form of fractions since there is the possibility of either of the broadband variables being zero (e.g., broadband has not been introduced yet). Since the sample has a mix of core EU countries and later entrants (in 2004, Czech Republic, Hungary, Poland, and Slovakia), as well as more recent accession countries (in 2007, Bulgaria and Romania), we control for the legal restriction of traveling/staying and working in the host country by setting up a dummy variable $FREE_{ij}$ that is equal to 1 if there is no such restriction on moving from the origin to host country, 0 otherwise.

In order to visualize the various effects of broadband penetration across country pairs, we also control for the catching-up in broadband diffusion by including the years since broadband introduction has been introduced into country pairs, $T^{B}_{ij,t}$ (Gruber and Verboven, 2001; Czernich *et al*., 2011), where B represents the broadband penetration rate between country pairs (i.e., $BROAD_{ij}$). The calculation of $T^{B}_{ij,t}$ is made based on the broadband penetration rate, and it is the number of years that both parties in a country pair have had broadband. After the addition of time and country-pair subscriptions, the complete estimation equation will be as follows:

$$\begin{aligned} \log FLOWS_{ij,t} &= \beta_0 + \beta_1 BROAD_{ij,t} + \beta_2 \log DIST_{ijt} + \beta_3 \log RGDP_{ijt} + \beta_4 \log WAGE_{jt} \\ &+ \beta_5 UNEMPR_{i,t} + \beta_6 EMPR_{j,t} + \beta_7 FREE_{ij,t} + \beta_8 T^{B}_{ij,t} + \delta_{ij} + \theta_t + \varepsilon_{ij,t} \end{aligned} \tag{5}$$

Where δ_{ij} and θ_t are the country-pair effects and the time-fixed effect, respectively. When the independence of irrelevant alternatives fails to characterize the reasons behind individuals' thinking on migration, the benefits of migrating to certain destinations take center stage: this is called multilateral resistance to migration (Bertoli and Moraga, 2013). In the presence of this phenonomen, several studies have adopted the Common Correlated Effects (Pesaran, 2006) or have used *ad hoc* controls for the time-varying benefits of migration, or they have provided more restricted assumptions when specifying the estimated model.

In light of every gravity model's having more than one origin country as well as more than one destination country, we must limit ourselves to the relationship among specific country pairs (Anderson and Van Wincoop, 2001). In this paper, the specification of our main independent variable is in an interaction form (i.e., $BROAD_{ij,t} = BROAD_{it} x BROAD_{jt}$). By doing so, we believe we account for the relative attractiveness of the country pairs sampled. However, additional methods could be adopted for follow-up robustness checks in the future. See Table 2 below for a detailed description of the data.

Descriptive statistics for each variable are presented in Appendix B's Table 11 and Table 12, featuring OtO and non-OtO country pairs, respectively. The number of individuals leaving origin nations for host countries is around 4,058 every year. The employment rate in the host countries in the OtO group averaged around 0.69 between 1995 and 2009. In the non-OtO countries, the comparable figure was 0.65 for the same period. The unemployment rate was about 9% in origin countries as a whole.

As the broadband penetration rate is measured with the multiplication of the broadband penetration rates in origin and in host countries, the average rate for this variable is approximately 2%. The average wage (in US dollars in 2000) ranged from $944 to $27,641 per year.

Table 2. Data and Origins

Notation	Variable	Unit	Origin
$FLOWS_{ij}$	Inflows of foreign population, aged 15-64, by nationality	Thousands	OECD
$BROAD_i$	Broadband penetration rate in origin	256 kbit/s to less than 2Mbit/s Share of the population that has subscribed to broadband	ITU (International Telecommunication Union) ICT Database
$BROAD_j$	Broadband penetration rate in host	256 kbit/s to less than 2Mbit/s Share of the population that has subscribed to broadband	ITU (International Telecommunication Union) ICT Database
TEL_i	Fixed-telephone subscriptions in origin	Per 100 inhabitants	ITU (International Telecommunication Union) ICT Database
TEL_j	Fixed-telephone subscriptions in host	Per 100 inhabitants	ITU (International Telecommunication Union) ICT Database
$CABLE_i$	Cable-TV subscribers in origin	Per 100 inhabitants	ITU (International Telecommunication Union) ICT Database
$CABLE_j$	Cable-TV subscribers in host	Per 100 inhabitants	ITU (International Telecommunication Union) ICT Database
$DIST_{ij}$	Distance between origin and host	Km	CEPII
$RGDP_i$	Real GDP in origin	Constant US$ as of 2000	World Bank, World Development Indicators
$RGDP_j$	Real GDP in host	Constant US$ as of 2000	World Bank, World Development Indicators
$WAGE_j$	Average wage across industries in the host	Total wage across industries divided by number of total employees in the industries (All LCU adjusted to US$ in 2000)	OECD STAN Database, OWW Database for the UK, (ECB) European Central Bank Statistical Data Warehouse for US dollar exchange rate
$UNEMPR_i$	Unemployment rate (origin)	Total, % of total labor force, in millions	IMF
$EMPR_j$	Employment rate (host)	Percentage (total gender, aged 20-64)	Eurostat
$FREE_{ij}$	=1 if no legal restriction on living, working in host	0.1	Author calculation based on Eurostat-EEA
$T_{ij,t}^{B}$	Years since country pairs both first introduced broadband	Varies from 0 to 10 for OtO Varies from 0 to 8 for non-OtO	Author calculation based on ITU (International Telecommunication Union) ICT Database

Compared to the OtO flows, non-OtO flows could be much higher—up to 261,273 men and women per year—but, on average, it hovered around 5,700. The rate of unemployment in the non-OECD-origin countries typically goes from a low of 2.9% to a crushing high of 38.4%.

3.1 Causality of Broadband and Migration Flows

The basic gravity model may suffer from different origins of endogeneity. One concern is reverse causality: when considering the origin and host countries, we might imagine that the greater the flows of people from origin to host, the more the communications will be directed from host to origin, as migrants talk to family and friends: we will discuss this in more detail in Section 4.1.

In order to address several sources of endogeneity bias in the model, we adopted Czernich *et al.*'s (2011) instruments for the IV approach. Since broadband platforms rely on either the copper wire of voice telephony or the coaxial cable of cable TV between households and the main distribution frame, we designated the ceiling of broadband penetration as η_{ij} with voice telephony and cable TV for the year 1997, which is the year before broadband was first introduced to both countries among country pairs at the same instant:

$$\eta_{ij} = \eta_0 + \eta_1 VOICE_{ij,1997} + \eta_2 CABLE_{ij,1997} \tag{6}$$

Here we use the number of non-digital telecommunications access lines in 1997 ($VOICE_{ij,1997}$) and the number of cable-TV subscribers in 1997 ($CABLE_{ij,1997}$) to measure the spread of the traditional telecommunications and cable networks in country pairs, calculated as:

$$VOICE_{ij,1997} = VOICE_{i,1997} \times VOICE_{j,1997} \tag{7}$$

$$CABLE_{ij,1997} = CABLE_{i,1997} \times CABLE_{j,1997} \tag{8}$$

Where $VOICE_{i,1997}$ and $VOICE_{j,1997}$ are the number of non-digital telecommunications access lines per 100 inhabitants in 1997, in the origin and host countries, respectively; $CABLE_{i,1997}$ and $CABLE_{j,1997}$ are the number of cable-TV subscribers per 100 inhabitants in 1997, in the origin and host countries, respectively. These variables were obtained from the ICT Indicators Database of the International Telecommunication Union (ITO). Although $VOICE_{ij,1997}$ and $CABLE_{ij,1997}$ are time-invariant variables, Stata 13's nl (i.e., non-linear) command provides time-invariant coefficients for each of these variables. The majority of researchers have followed the logistical growth curve for a new technology, defined by Griliches (1957) (among them, Gruber and Verboven, 2001; Comin *et al*., 2006; Geroski, 2000; Czernich *et al*., 2011; Stoneman, 2002; Beck *et al*., 2005; and Michal and Tobias, 2006):

$$BROAD_{ij} = \frac{\eta_{ij}}{1 + e^{-[\beta(t-\tau)]}} \tag{9}$$

Again, $BROAD_{ij}$ is the broadband penetration rate, measured as the multiplication of the share of the population that has subscribed to broadband in the origin and the share of the population that has subscribed to broadband in the host (i.e., $BROAD_i \times BROAD_j$), whereas η_{ij} determines the maximum broadband penetration rate, β is the diffusion speed, and τ is the inflexion point. Inserting Equation 6 into Equation 9, we obtain the following non-linear first-stage equation:

$$BROAD_{ij,t} = \frac{\eta_0 + \eta_1 VOICE_{ij,1997} + \eta_2 CABLE_{j,1997}}{1 + e^{-[\beta(t-\tau)]}} \tag{10}$$

By applying such a non-linear least-squares estimation, we compute the predicted broadband penetration rate with absolute exogenous factors. In order to receive consistent estimates from the second stage of the nonlinear equation, the first-stage estimation must be specified correctly (Angrist and Imbens, 1995; Angrist and Kruger, 2001a, 2001b). To obtain the fit of the first stage of the diffusion curve of the instrumental model, we plot the graphs of actual and predicted broadband for OtO and non-OtO country pairs for each threshold. However, we only present 10 country pairs for each threshhold, as there are 366 OtO country pairs (148 + 118 + 100) and 269 non-OtO country pairs (101 + 92 + 76) in total, and it would require too much space. Figure 1 to Figure 6 present the actual and predicted broadband penetration rates (see Appendix A).

For OtO country pairs with 0.1 thresholds, Poland-UK and Germany-Austria appear to have a perfect fit of actual and predicted broadband penetration rates. On the other hand, the predicted broadband penetration rates for the Netherlands-Belgium, Sweden-Norway, and Belgium-Luxembourg country pairs seem slightly below the actual ones. The actual and predicted values for the rest of the country pairs, for the most part, apparently conform. The same pattern holds for OtO country pairs, with 0.3 and 0.5 thresholds.

When it comes to non-OtO country pairs with 0.1 thresholds, Algeria-France, Russia-Germany, Bosnia-Herzegovina-Austria, and Bulgaria-Spain appear to fit well, whereas the rest of the country pairs have predicted values coming under the actual rates. All in all, we can see a diffusion-curve shape for all country pairs, as expected, which confirms the fit of the first stage of the diffusion curve, corresponding to much of the literature on technology diffusion (Griliches, 1957; Geroski, 2000; Gruber and Verboven, 2001; Comin *et al*., 2006; Czernich *et al*., 2011). Also, we find consistent inflexion points for both OtO and non-OtO flows for each threshold. Hence, we believe that the first-stage estimation is specified adequately.

In order to establish valid fitted values for the broadband penetration rate, we attempt to use purely exogenous instrumental variables. Therefore, we use voice-telephony and cable-TV subscribers per 100 inhabitants in 1997, the year before the first emergence of broadband in the country pairs at the same time. Even though the instruments are time invariant, this produces time-variant fitted values.

The first stage of the non-linear instrumental variable is estimated by Equation 10, with a non-linear least square. Columns (I), (II), and (III) in Table 3 present 148, 118, and 101 OtO country pairs, respectively; Table 4 presents 101, 92, and 76 non-OtO country pairs, respectively, for 1995-2009.

Table 3. OECD to OECD Flows: Diffusion Curve of the Instrumental Model's First Stage

Dependent variable: Broadband penetration rate ($BROAD_{ij,t}$)	**(I)**	**(II)**	**(III)**
Voice-telephony penetration rate ($VOICE_{ij,1997}$)	0.274*** (0.006)	0.276*** (0.007)	0.277*** (0.008)
Cable-TV penetration rate ($CABLE_{ij,1997}$)	0.334*** (0.018)	0.347*** (0.018)	0.302*** (0.017)
Diffusion speed (β)	0.917*** (0.025)	0.903*** (0.027)	0.890*** (0.028)
Inflexion point (τ)	2005.662*** (0.057)	2005.668*** (0.064)	2005.720*** (0.068)
Constant	0.003** (0.001)	-0.004*** (0.001)	-0.004** (0.001)
R^2	0.97	0.97	0.97
N	1981	1580	1342
F-test (p-values in parentheses)	121.90 (0.000)	99.41 (0.000)	88.10 (0.000)

(I), (II), (III) present the first-stage results of the diffusion curve for flows with 0.1, 0.3, and 0.5 thresholds, respectively. For each threshold, we control the first-stage model with more control variables, namely distance, real GDP, the wage, the unemployment rate, and the employment rate. The results are quite significant, but the coefficients are very small, so we do not present them. They are available upon request.

Table 4. Non-OECD to OECD Flows: Diffusion Curve of the Instrumental Model's First Stage

Dependent variable: Broadband penetration rate ($BROAD_{ij,t}$)	**(I)**	**(II)**	**(III)**
Voice-telephony penetration rate ($VOICE_{ij,1997}$)	0.152*** (0.020)	0.154*** (0.021)	0.145*** (0.024)
Cable-TV penetration rate ($CABLE_{ij,1997}$)	0.107*** (0.014)	0.106*** (0.014)	0.105*** (0.017)
Diffusion speed (β)	0.997*** (0.104)	0.995*** (0.106)	0.954*** (0.113)
Inflexion point (τ)	2007.308*** (0.271)	2007.308*** (0.277)	2007.437*** (0.343)
Constant	0.005*** (0.001)	0.005*** (0.001)	0.005*** (0.001)
R^2	0.84	0.85	0.83
N	1359	1233	1015
F-test (p-values in parentheses)	44.70 (0.000)	43.23 (0.000)	28.13 (0.000)

(I), (II), (III) present the first-stage results of the diffusion curve for flows with 0.1, 0.3, and 0.5 thresholds, respectively. For each threshold, we control the first-stage model with more control variables, namely distance, real GDP, the wage, the unemployment rate, and the employment rate. The results are quite significant, but the coefficients are very small, so we do not present them. They are available upon request.

For OtO flows, Table 3 shows that the voice-telephony penetration rate, cable-TV penetration rate, diffusion speed, and inflexion point are quite significant in determining the broadband penetration rate. The inflexion point is estimated at around 2005 for OtO flows, and it does not vary much for different thresholds of flows.

For non-OtO flows, Table 4 also confirms the influence of the voice-telephony penetration rate, cable-TV penetration rate, diffusion speed, and inflexion point in determining the extent of broadband penetration. The inflexion point for non-OtO flows is estimated at 2007 and likewise does not vary much for different thresholds of flows. In view of the multiple aspects of technology adoption, it is reasonable to seek different inflexion points for OtO and non-OtO flows. Both voice-telephony penetration and cable-TV penetration appear to have positive and meaningful effects on the ceiling of the broadband penetration rate η_{ij}. The F-test of joint significance for voice telephony and cable TV suggests, according to the null hypothesis, that the estimated coefficients for both are different from zero at a 99% confidence interval.

4. Empirical Results

Based on the first stage of the diffusion curve, we calculate the predicted broadband penetration rate and plug this variable into Equation 5 from Section 3. The second-stage results are shown in Tables 5 and 6 for OtO and non-OtO migration flows, respectively. In addition, we calculate the predicted years since broadband was introduced to the country pairs at the same time and insert this into Equation 5.

Models with odd numbers are at the second stage of the instrumental-variable model with OLS, whereas models with even numbers are at the same stage but with the country-pair fixed effect. To account for the fact that the broadband penetration rate is predicted by the first stage of the non-linear model, standard errors are bootstrapped (200 repetitions) in the second stage of the non-linear models. The broadband penetration rate appears to have a positive and significant effect on both OtO and non-OtO migration flows. The significance improves greatly in fixed-effect models. The coefficient of the broadband penetration rate is much higher for the non-OtO country pairs. This suggests that broadband connections between non-OECD and OECD countries affect migration flows from origin to host countries more than among OECD member states by improving the amount of positive information about the host; this, in turn, ends up inspiring others “back home” to also make the journey. This might be explained by the inflexion point’s being around 2007 for non-OtO country pairs—approximately two years after the inflexion point for OtO country pairs. Broadband communication was seen to be more prominent between non-OECD and OECD members than among countries within the OECD between 1995 and 2009. Therefore, we can postulate that the broadband penetration rate has more sway over migration flows for non-OtO cases than for OtO ones.

Consistent with the gravity literature, distance and relative RGDP are found to be intimidating deterrents both for OtO and non-OtO migration flows for all thresholds. When it comes to wages in the host country, we observe a positive and significant relation to migration flows, as expected. It is only negative in OtO flows with 0.3 and 0.5 thresholds, and in non-OtO with 0.3 thresholds and second-stage OLS, but it is not significant. Unemployment in the origin country has a positive and important effect on migration flows for the fixed-effect models for OtO and non-OtO flows with all thresholds. To some extent, higher unemployment in the country of origin will impel individuals to seek a job elsewhere. This also confirms another finding: the employment rate in the host country is a decisive factor in facilitating migration flows in all the fixed-effect models for OtO and non-OtO migrations alike. In other words, individuals tend to move to where the employment prospects are better.

The dummy variable $FREE_{ij}$ is again found to be positive and significant in all cases. The value for the predicted years since the introduction of broadband turns out to be significant and negatively related to migration flows in the fixed-effect models. The coefficients of the predicted years since the coming of broadband appear much higher for the non-OtO country pairs. This reinforces the notion that the effect of the broadband penetration rate should be much higher for non-OtO country pairs. We also analyzed whether other telecommunications channels, such as mobile phones or fixed-landline phones, affect human movements between origin and host but found no strong correlation. Our results are available upon request.

4.1 Validity of Instruments

In order to determine whether our instruments—the voice-telephony and cable networks—might independently and directly affect migration flows or direct migration movements through channels other than broadband, we consider whether other communication technologies, such as mobile phones and the integrated-services digital network (ISDN—enabling voice and data transmission), might also affect migration flows.

In order to estimate the diffusion curves for mobile telephones and the ISDN, we apply the same ceiling, $\eta_{ij} = \eta_0 + \eta_1 TEL_{ij,1997} + \eta_2 CABLE_{ij,1997}$, based on the voice-telephony and the cable-TV penetration rates per 100 individuals for each flow-rate threshold, for both OtO and non-OtO flows. Then we follow the logistic curve ($\frac{\eta_{ij}}{1+e^{-[\beta(t-\tau)]}}$) for both mobile phones and the ISDN. The advent of broadband comes considerably later than that of voice telephony and cable TV. Since we measure the predicted broadband penetration rate according to these two variables in the year 1997—i.e., before broadband made its appearance in the country pairs sampled—it is safe to say our instruments are predetermined in terms of broadband diffusion. Yet, predetermination may be a necessary but insufficient condition for exogeneity in an econometric sense (Czernich *et al*., 2011).

Thus, first of all, we analyze whether our instruments—TEL and CABLE—have an indirect effect on migration flows or affect migration flows through channels other than broadband. They not only bring about the deployment of the broadband network but also the diffusion of other technologies that may trigger migration flows. For that, we pick one of the most common communications tools—the mobile phone—whose adoption and diffusion started as far back as the 1980s (Kalba, 2008), and the oldest telecommunications invention—the ISDN—in use since the 1970s (https://www.nfon.com/gb/solutions/resources/glossary/isdn/).

Table 5. The Effect of the Broadband Penetration Rate on OtO Migration Flows: Second-Stage Results

Dependent variable: Log of migration flows	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Predicted penetration rate ($BROAD_{ij,t} - hat$)	0.007 (0.017)	0.048*** (0.012)	0.034** (0.017)	0.044*** (0.012)	0.044** (0.018)	0.045** (0.014)
Log of distance ($\log DIST_{ij}$)	-0.540*** (0.046)		-0.367*** (0.047)		-0.172*** (0.048)	
Log of relative real GDP ($\log RGDP_{ij,t}$)	-0.249*** (0.018)	-0.869** (0.407)	-0.257*** (0.017)	-1.585*** (0.419)	-0.212*** (0.018)	-1.663*** (0.450)
Log of wage in the host country ($\log wage_{j,t}$)	0.114** (0.037)	0.056** (0.024)	-0.033 (0.033)	0.046* (0.025)	-0.020 (0.031)	0.045* (0.025)
Unemployment rate in the origin ($Unempr_{i,t}$)	0.032 (0.009)	0.002** (0.009)	0.039 (0.009)	0.001*** (0.010)	0.034 (0.009)	0.002*** (0.010)
Employment rate in the host ($Empr_{i,t}$)	-0.011 (0.003)	0.024* (0.014)	-0.007 (0.003)	0.025** (0.013)	0.001 (0.003)	0.029** (0.014)
Dummy = 1 if no restriction ($FREE_{ij,t}$)	0.614*** (0.088)	0.707*** (0.138)	0.349*** (0.092)	0.992*** (0.158)	0.450*** (0.094)	1.024*** (0.166)
Predicted years ($T_{ij,t}^{\beta}\_hat$)	0.061 (0.024)	-0.003* (0.015)	0.048 (0.023)	-0.006* (0.013)	0.030 (0.024)	-0.014* (0.014)
Constant	3.034*** (4.478)	-1.063 (0.983)	3.452*** (0.462)	-1.010 (0.883)	1.665 (0.478)	-1.143 (0.979)
R^2	0.17	0.27	0.15	0.37	0.12	0.36
N	2064	2064	1644	1644	1409	1409
Country pairs	148	148	118	118	100	100

Table 6. The Effect of the Broadband Penetration Rate on non-OtO Migration Flows: Second-stage Results

Dependent variable: Log of migration flows	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Predicted penetration rate ($BROAD_{ij,t} - hat$)	0.078*** (0.012)	0.103*** (0.021)	0.089*** (0.012)	0.101*** (0.023)	0.072*** (0.012)	0.109** (0.030)
Log of distance ($\log DIST_{ij}$)	-0.071 (0.066)		-0.179** (0.063)		-0.466*** (0.054)	
Log of relative real GDP ($\log RGDP_{ij,t}$)	-0.287*** (0.021)	-0.923** (0.371)	-0.249*** (0.021)	-0.950** (0.382)	-0.196*** (0.019)	-0.928** (0.440)
Log of wage in the host country ($\log wage_{j,t}$)	0.080** (0.041)	0.062* (0.037)	0.053 (0.041)	0.082** (0.036)	0.200*** (0.038)	0.089** (0.037)
Unemployment rate in the origin ($Unempr_{i,t}$)	-0.062 (0.007)	0.016* (0.013)	-0.058 (0.007)	0.015* (0.014)	-0.060 (0.006)	0.013* (0.015)
Employment rate in the host ($Empr_{j,t}$)	0.030* (0.003)	0.039* (0.002)	0.022* (0.003)	0.042* (0.023)	0.022 (0.003)	0.049* (0.033)
Dummy = 1 if no restriction ($FREE_{ij,t}$)	0.062 (0.299)	0.709*** (0.153)	0.158 (0.298)	0.725*** (0.161)	0.961*** (0.264)	0.739*** (0.199)
Predicted years ($T_{ij,t}^{\beta}\_hat$)	0.030 (0.073)	-0.025* (0.048)	-0.088 (0.072)	-0.032* (0.050)	-0.219 (0.081)	-0.062* (0.061)
Constant	3.289*** (0.609)	-3.470** (1.695)	4.152*** (0.562)	-3.607 (1.747)	5.475*** (0.496)	-3.732 (2.398)
R^2	0.20	0.34	0.19	0.36	0.28	0.36
N	1397	1397	1277	1277	1049	1049
Country pairs	101	101	92	92	76	76

Models (1)-(3)-(5) and Models (2)-(4)-(6) of Table 5 and Table 6 present the second stages of the instrumental variable with country-pair and time-fixed effect, respectively. Models (1)-(2), Models (3)-(4), and Models (5)-(6) are for the 0.1, 0.3, and 0.5 rate thresholds for the OtO and non-OtO migration flows, respectively. Bootstrapped standard errors are in parentheses.

To test our claim, we estimate diffusion curves with the same ceiling (see Equation 9) for MOB and ISDN. The related results are in Tables 13-18 in Appendix C; clearly, no significant effect has been found. Thus, we find no evidence of penetration of the traditional networks—TEL and CABLE—on the diffusion of MOB and ISDN. We conclude that these instruments only determine broadband diffusion and not that of other potential telecommunications modalities that might have an impact on migration flows, thus underlining the validity of our instruments.

TEL and CABLE could also have a direct impact on migration flows, which we test by inserting them into the same model as was used for broadband—but to no avail (see Tables 19 and 20 in Appendix D). As is seen in these tables, we observe no noticeable effect of voice telephony and cable TV on either of the alternative communications channels—mobile and ISDN—at a conventional level. This confirms the validity of our instruments. Here, we obtained information from the ITU's ICT database on both mobile-telephone subscribers per 100 inhabitants and ISDN subscribers per 100 inhabitants. The F-test of joint significance for voice telephony and cable TV suggests that, based on the null hypothesis, the estimated coefficients for both are different from zero at a 99% confidence interval.

4.2 Robustness Checks

Our first-stage results are based on the voice-telephony penetration rate and the cable-TV penetration rate per 100 inhabitants in the population. This is done to arrive at the predicted broadband penetration rate per 100 inhabitants in the population. However, such a measurement may lead to a correlation in the first-stage result, as both the endogenous and instrumental variables have a common denominator. Thus, we estimate the first-stage diffusion curve with the voice-telephony penetration rate per 100 inhabitants and the cable-TV penetration rate per 100 inhabitants to determine the broadband penetration rate at household level ($BROADHH_{ij}$), as in Table 7 for OtO migration flows with 0.1, 0.3, and 0.5 thresholds and Table 8 for non-OtO migration flows with 0.1, 0.3, and 0.5 rate thresholds.

The levels of both instruments—the voice-telephony penetration rate per 100 inhabitants and the cable-TV penetration rate per 100 inhabitants—remain positive and significant for both OtO and non-OtO cases. In fact, the coefficients are much higher, suggesting that both instrumental variables determine broadband penetration to be higher if measured at the household level. The inflexion point remains around 2005 for OtO flows, 2007 for non-OtO flows.

Table 7. Diffusion Curve: First Stage of the Instrumental Variables for OtO Flows

Dependent variable: $BROADHH_{ij}$	**(1)**	**(2)**	**(3)**
Voice-telephony penetration rate ($VOICE_{ij,1997}$)	1.251*** (0.047)	1.236*** (0.052)	1.221*** (0.056)
Cable-TV penetration rate ($CABLE_{ij,1997}$)	0.926*** (0.144)	1.059*** (0.143)	0.835*** (0.184)
Diffusion speed (β)	0.905*** (0.030)	0.893*** (0.033)	0.891*** (0.035)
Inflexion point (τ)	2005.783*** (0.070)	2005.785*** (0.080)	2005.840*** (0.087)
Constant	0.084*** (0.008)	0.081*** (0.000)	0.088*** (0.009)
R^2	0.96	0.96	0.96
N	1981	1580	1342
F-test (p-values in parentheses)	459.54 (0.000)	375.74 (0.000)	312.76 (0.000)

$BROADHH_{ij}$ is measured as the multiplication of broadband subscribers per household in the population in origin and host.

Table 8. Diffusion Curve: First Stage of the Instrumental Variables for Non-OtO Flows

Dependent variable: $BROADHH_{ij}$	**(1)**	**(2)**	**(3)**
Voice-telephony penetration rate ($VOICE_{ij,1997}$)	0.709*** (0.141)	0.662*** (0.113)	0.006*** (0.002)
Cable-TV penetration rate ($CABLE_{ij,1997}$)	0.708*** (0.265)	0.684*** (0.154)	0.671*** (0.100)
Diffusion speed (β)	0.961*** (0.103)	0.962*** (0.106)	0.918*** (0.112)
Inflexion point (τ)	2007.347*** (0.298)	2007.348*** (0.306)	2007.477*** (0.381)
Constant	0.065*** (0.010)	0.063*** (0.010)	0.069*** (0.012)
R^2	0.80	0.80	0.78
N	1359	0.85	1015
F-test (p-values in parentheses)	35.26 (0.000)	34.10 (0.000)	22.82 (0.000)

$BROADHH_{ij}$ is defined above in Table 7.

Following the first-stage results based on the household level of broadband subscription, the second stage of the estimation results is presented in Table 9 for OtO flows with 0.1, 0.3, and 0.5 rate thresholds, and in Table 10 for non-OtO flows with 0.1, 0.3, and 0.5 rate thresholds. As can be seen in both tables, the significance and the sign of the coefficients remain the same. The pattern of how coefficients change across different thresholds also remains the same. The F-test of joint significance for voice telephony and cable TV suggests that, based on the null hypothesis, the estimated coefficients for both are different from zero at a 99% confidence interval, for both OtO and non-OtO country pairs.

Table 9. Second Stage of the Instrumental Variables Model for OtO Flows

Dependent variable: Log of migration flows	**(1)**	**(2)**	**(3)**
Predicted penetration rate ($BROAD_{ij,t}\_hat$)	0.052 (0.018)	0.056** (0.017)	0.049** (0.018)
Log of distance ($\log DIST_{ij}$)	-0.543*** (0.047)	-0.371*** (0.047)	-0.175*** (0.049)
Log of relative real GDP ($\log RGDP_{ij,t}$)	-0.251*** (0.018)	-0.257*** (0.017)	-0.212*** (0.018)
Log of wage in the host country ($\log wage_{j,t}$)	0.098** (0.037)	-0.043 (0.033)	-0.024 (0.031)
Unemployment rate in the origin ($Unempr_{i,t}$)	0.028** (0.009)	0.037*** (0.009)	0.034*** (0.009)
Employment rate in the host ($Empr_{j,t}$)	-0.009 (0.003)	-0.006 (0.003)	0.002 (0.003)
Dummy = 1 if no restriction ($FREE_{ij,t}$)	0.634*** (0.087)	0.353*** (0.093)	0.451*** (0.095)
Predicted years ($T^{\beta}_{ij,t}\_hat$)	-0.033 (0.023)	0.004 (0.021)	0.019 (0.022)
Constant	3.392 (0.476)	3.587*** (0.455)	1.628** (0.470)
R^2	0.16	0.15	0.12
N	2064	1644	1409

(I), (II), (III) present the OLS estimation of the second-stage results of instrumental variables for OtO flows with 0.1, 0.3 ,and 0.5 rate thresholds, respectively. We also obtained a fixed-effect estimation of the second-stage results but do not present it here, as the time-invariant variable is dropped from the model. The sign and significance of the coefficients remain the same in the fixed-effect model. They are available upon request.

Table 10. Second Stage of the Instrumental Variables Model for Non-OtO Flows

Dependent variable: Log of migration flows	**(1)**	**(2)**	**(3)**
Predicted penetration rate ($BROAD_{ij,t}\_hat$)	0.082*** (0.013)	0.094** (0.013)	0.077*** (0.012)
Log of distance ($\log DIST_{ij}$)	-0.080 (0.066)	-0.187** (0.062)	-0.452*** (0.054)
Log of relative real GDP ($\log RGDP_{ij,t}$)	-0.286*** (0.021)	-0.247*** (0.021)	-0.195*** (0.019)
Log of wage in the host country ($\log wage_{j,t}$)	0.078* (0.041)	0.049 (0.041)	0.196* (0.038)
Unemployment rate in the origin ($Unempr_{i,t}$)	-0.062 (0.007)	-0.058 (0.007)	-0.060 (0.006)
Employment rate in the host ($Empr_{j,t}$)	0.029 (0.003)	0.022 (0.003)	0.022 (0.003)
Dummy = 1 if no restriction ($FREE_{ij,t}$)	0.064 (0.230)	0.159 (0.298)	0.961*** (0.264)
Predicted years ($T^{\beta}_{ij,t}\_hat$)	0.032 (0.073)	-0.090 (0.071)	-0.221** (0.081)
Constant	3.208*** (0.606)	4.080*** (0.558)	5.414*** (0.491)
R^2	0.20	0.20	0.28
N	1397	1277	1015

(I), (II), (III) present the OLS estimation of the second-stage results of instrumental variables for non-OtO flows with 0.1, 0.3, and 0.5 rate thresholds, respectively. We also obtained a fixed-effect estimation of the second-stage results but do not present it here, as the time-invariant variable is dropped from the model. The sign and significance of the coefficients remain the same in the fixed-effect model. They are available upon request.

Additional robustness checks are listed in Tables 19-20 in Appendix D. One can argue that, apart from broadband, phone traffic between the origin and host countries might have an effect on migration flows. In order to check this, we control the second-stage results with an extra variable of phone traffic between origin and host, and we calculate this variable:

$$phntraffic_{ij} = phntraffic_i \times phntraffic_j \quad (11)$$

Where $phntraffic_i$ stands for international incoming phone traffic to the origin, and $phntraffic_j$ is international outgoing phone traffic from the host country. This variable will give the approximate international phone traffic between country i and country j at time t. Tables 21-22 in Appendix E present the results for OtO and non-OtO countries with 0.1, 0.3, and 0.5 rate thresholds under Models (I), (II), and (III), respectively. Indeed, phone traffic within country pairs has a positive and significant effect on OtO migration flows, whereas there is little evidence that this holds true for non-OtO flows. All in all, the broadband penetration rate is still positive and significant; the sign of the remainder of the control variables also remains the same.

We apply additional robustness checks and see that the broadband penetration rate holds positive as a significant determinant of migration. These tests are available upon request.

5. Conclusion

Our non-linear instrumental approach to broadband penetration rates found a positive and strong effect on migration flows. This effect appears to be even stronger for non-OtO flows in comparison to OtO flows.

Our results are robust to a number of different specifications. For instance, measuring broadband penetration at the household level while keeping our instrumental variables—voice telephony and cable TV penetration—at the per-100-inhabitant level did not affect the second-stage results as far as the sign of the coefficients or the significance went; in fact, the significance improved. Additionally, we checked whether landline-phone traffic between country pairs or international calling-in or calling-out phone traffic also had a similar effect to broadband, controlling for them in all the models. The broadband penetration rate remains the main determinant of migration decisions, while the sign of the other variables does not change at all for all three thresholds.

The effect of broadband penetration is higher in non-OtO migration flows. This may be so not only for information-exchange reasons but also for job applications and interviews, which are more likely to take place online; job-related travel, on the other hand, can be undertaken more easily between geographically closer countries. In other words, migrants in non-OtO flows make more use of broadband to ensure a place to work or stay, while those in OtO flows can interact with contacts in the host country not only through broadband but also in person.

We had different thresholds, namely 0.1, 0.3, and 0.5 rates (10, 30, and 50 per 1,000 population), as we wanted to capture the relationship between the broadband penetration rate and migration flows at various levels. The lowest rate we focused on was 0.1 (10 per 1,000), due to our belief that the flows should be at a countable level if we were to analyze the effect of broadband penetration on migration flows. To give even more accountability, we chose the other thresholds as 0.3 and 0.5. The results for each threshold, particularly 0.3 and 0.5, were quite similar, and they were all consistent. The results improved above the larger (that is, the 0.5) constraint. We believed a higher frequency—while capturing fewer country pairs—would produce more accurate results. Moreover, we argue that a group of flows whose threshold is 0.1 can capture more country pairs but may yield less accurate results, since the 0.1 threshold will pick up country pairs in which even a single migrant will be treated as a migration flow: this segment surely does not justify an investigation into the relationship between migration and broadband penetration.

The different thresholds for OtO flows gave consistent results with one another, with the results improving from the 0.1 to the 0.5 rate thresholds. This was the same for non-OtO flows, where the significance of the right-hand-side variables went from the 0.1 to the 0.5 rate threshold. We found the inflexion points for OtO and non-OtO flows as 2005 and 2007, respectively. The possible explanation for this may lie in the way more developed countries (OECD ones) adopt technology versus their developing or undeveloped counterparts (non-OECD ones). The inflexion point of 2007 for non-OECD countries suggests that they adopt technology and reach saturation point approximately two years later.

What is more, having no legal restriction was always found to be positively and significantly correlated with migration flows, both OtO and non-OtO; this relationship was stronger for the latter. In this regard, if we consider legal restrictions as a migration cost, people comprising the flows from more distant countries will take these barriers more into account before setting out. That is also consistent with the result for distance, which was consistent with the gravity models across the literature (as one of the essential demotivating factors in deciding where to move).

Overall, we found that the broadband penetration rate had a significant and positive effect on migration flows. This effect was stronger for non-OtO migration flows. Broadband appeared to be preferred over landline phones by potential migrants between 1995 and 2009. Further research is needed to investigate whether the new and more sophisticated smart phones stimulate migration flows, which we believe to be true: they also provide cheaper and easier communications to individuals overseas, and so may be preferred by those contemplating emigrating. However, we were unable to investigate the existence of such an effect due to lack of data. The ITU's ICT indicators consist of only a few years of records of smart-phone subscriptions, but more data will become available in the foreseeable future, enabling other researchers to delve into this area for more detail.

APPENDIX A

Figure 1. Actual and Predicted Broadband Penetration Rates for Country Pairs, OtO Flows at a 0.1 Rate (10 per 1,000)

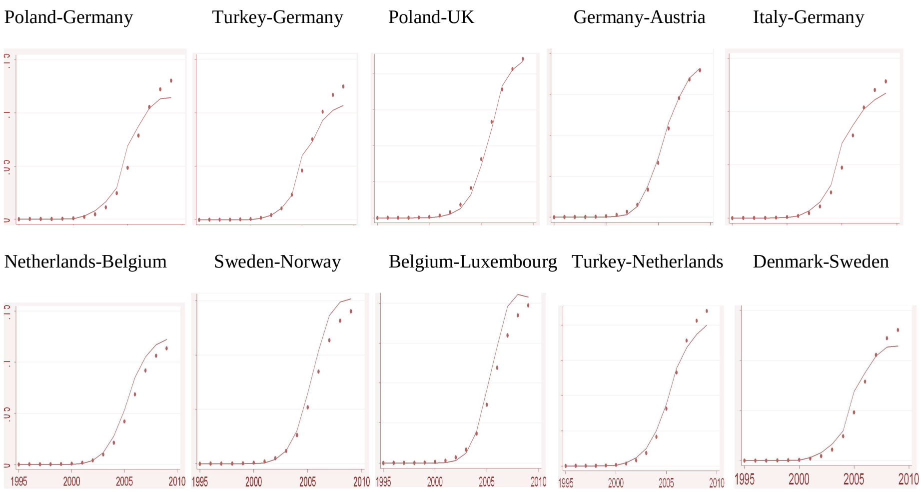


Figure 2. Actual and Predicted Penetration Rates for Country Pairs, OtO Flows at a 0.3 Rate (30 per 1,000)

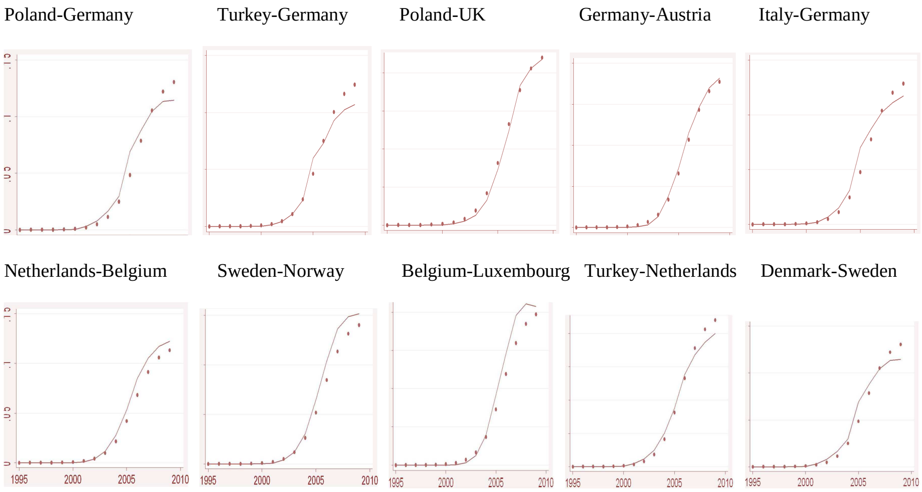


Figure 3. Actual and Predicted Broadband Penetration Rates for Country Pairs, OtO Flows at a 0.5 Rate (50 per 1,000)

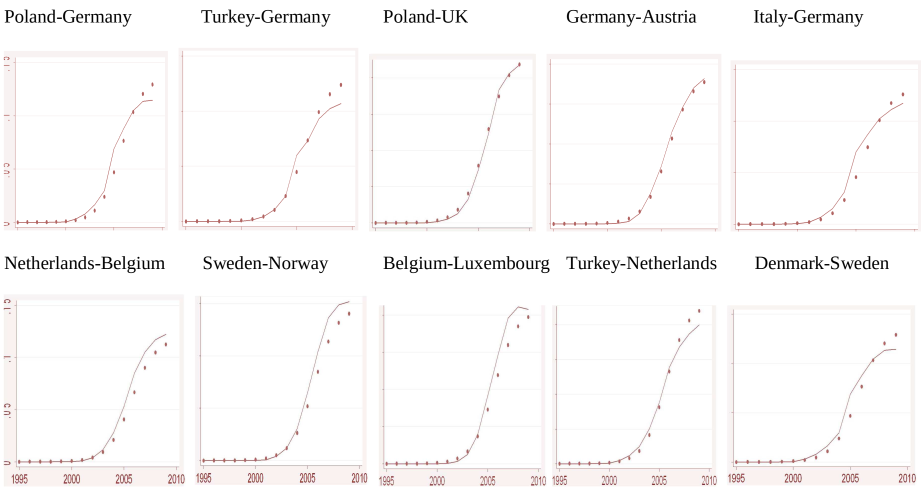


Figure 4. Actual and Predicted Broadband Penetration Rates for Country Pairs, Non-OtO Flows at a 0.1 Rate (10 per 1,000)

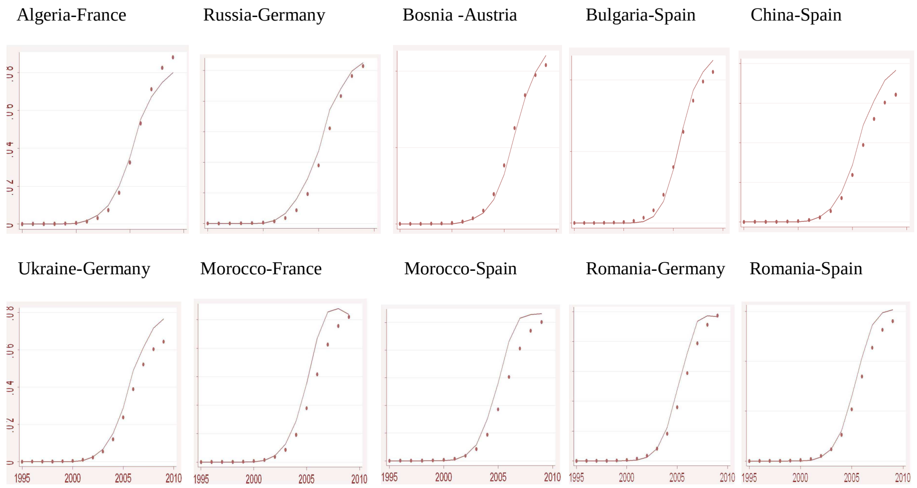


Figure 5. Actual and Predicted Broadband Penetration Rates for Country Pairs, Non-OtO Flows at a 0.3 Rate (30 per 1,000)

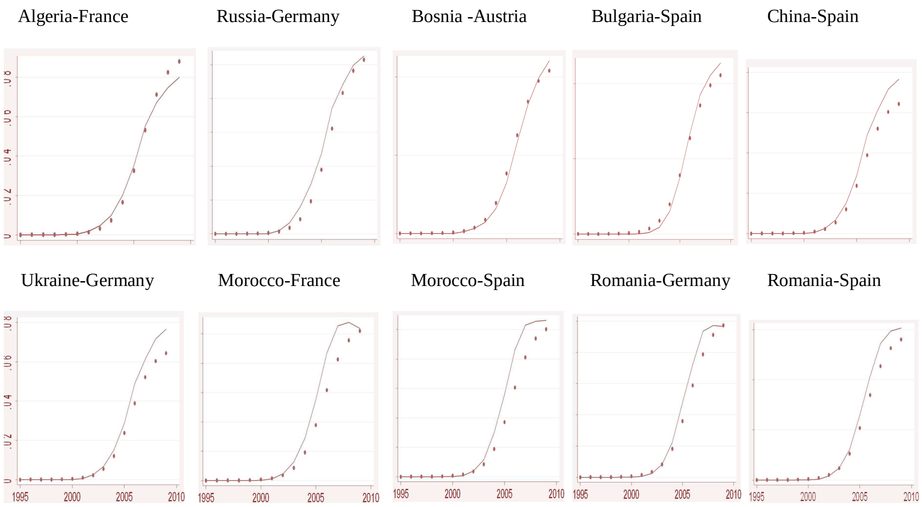
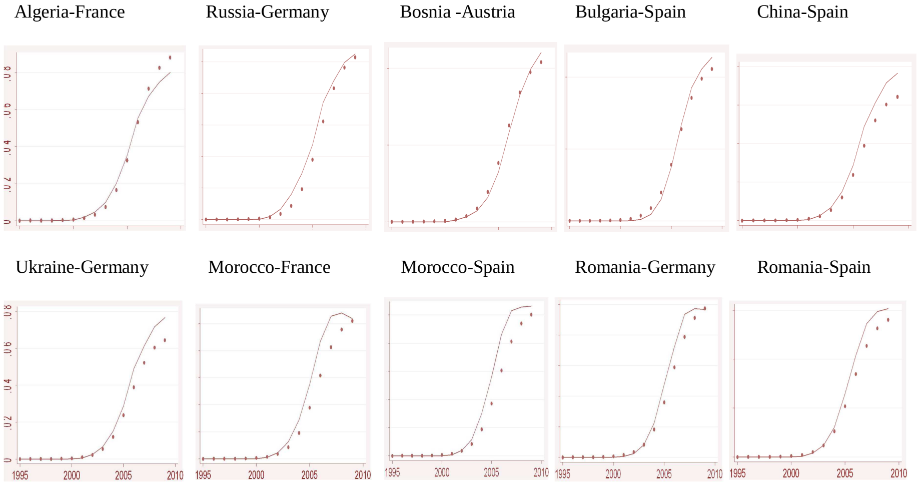


Figure 6. Actual and Predicted Broadband Penetration Rates for Country Pairs, Non-OtO Flows at a 0.5 Rate (50 per 1,000)



APPENDIX B

Table 11. Descriptive Statistics for OtO Country Pairs

Variable	Obs	Mean	Std. Dev.	Min	Max
Flowsij	2067	4.058166	10.9581	0	151.743
Unempri	2220	8.878677	3.949635	2.513	22.9
Emprj	2220	68.60214	9.911995	27.6	81.8
Freeij	2220	.740991	.4381893	0	1
Broadijt	2220	.0176976	.027628	8.89e-07	.1304825
Distij	2220	1162.671	686.4299	160.9283	3027.229
Rgdpij	2220	5.193729	11.65273	.0029073	104.3875
Awagej	2220	2524.594	3036.444	.9440161	27641

Table 12. Descriptive Statistics for Non-OtO Country Pairs

Variable	Obs	Mean	Std. Dev.	Min	Max
Flowsij	1401	5.683184	14.66967	0	261.273
Unempri	1515	11.56115	7.882959	2.9	38.4
Emprj	1515	65.39724	12.90079	27.6	81.8
Freeij	1515	.0356436	.1854611	0	1
Broadijt	1515	.0026988	.0058787	2.35e-08	.0504853
Distij	1515	3283.739	2426.287	485.1447	9592.113
Rgdpij	1515	1.711511	6.159809	.0008763	86.71633
Awagej	1515	2456.605	3249.689	.9440161	27641

APPENDIX C

Table 13. Diffusion Curve for First Stage of Instrumental Variable Model: OtO Flows at a 0.1 Rate (10 per 1,000)

	Dependent variable: MOB_{ij}	**Dependent variable:** $ISDN_{ij}$
Voice-telephony penetration rate ($VOICE_{ij,1997}$)	0.235* (0.122)	0.032* (0.002)
Cable-TV penetration rate ($CABLE_{ij,1997}$)	-0.534 (0.326)	0.010 (0.008)
Diffusion speed (β)	0.403** (0.195)	0.117*** (0.010)
Inflexion point (τ)	2003.572*** (2.845)	1995.204*** (0.232)
Constant	-0.132 (0.780)	6.087*** (0.221)
R^2	0.11	0.19
N	2078	1794
F-test (p-values in parentheses)	122.12 (0.000)	117.83 (0.000)

Table 14. Diffusion Curve for First Stage of Instrumental Variable Model: OtO flows at a 0.3 Rate (30 per 1,000)

	Dependent variable: MOB_{ij}	**Dependent variable:** $ISDN_{ij}$
Voice-telephony penetration rate ($VOICE_{ij,1997}$)	0.265* (0.149)	0.034* (0.002)
Cable-TV penetration rate ($CABLE_{ij,1997}$)	-0.627 (0.401)	0.004 (0.008)
Diffusion speed (β)	0.415* (0.238)	0.122*** (0.010)
Inflexion point (τ)	2003.440*** (3.172)	1995.082*** (0.231)
Constant	-0.403 (0.914)	5.917*** (0.215)
R^2	0.11	0.19
N	1475	1275
F-test (p-values in parentheses)	99.16 (0.000)	98.12 (0.000)

Table 15. Diffusion Curve for First Stage of Instrumental Variable Model: OtO Flows at a 0.5 Rate (50 per 1,000)

	Dependent variable: MOB_{ij}	**Dependent variable:** $ISDN_{ij}$
Voice-telephony penetration rate ($VOICE_{ij,1997}$)	0.069 (0.036)	0.033* (0.003)
Cable-TV penetration rate ($CABLE_{ij,1997}$)	-0.183 (0.086)	0.015 (0.010)
Diffusion speed (β)	0.396* (0.104)	0.117*** (0.012)
Inflexion point (τ)	2003.343*** (1.745)	1995.064*** (0.280)
Constant	2.008* (0.734)	5.999*** (0.262)
R^2	0.30	0.19
N	1177	1014
F-test (p-values in parentheses)	91.08 (0.000)	87.11 (0.000)

In Tables13-15, MOB_{ij} is calculated as $MOB_i \times MOB_j$ where MOB_i is the mobile-phone subscribers per 100 inhabitants in the origin and MOB_j is the mobile-phone subscribers per 100 inhabitants in the host. $ISDN_{ij}$ is calculated as $ISDN_i \times ISDN_j$ where $ISDN_i$ is the integrated-services digital network subscribers per 100 in the origin and $ISDN_j$ is the integrated-services digital network subscribers per 100 in the host.

Table 16. Diffusion Curve for First Stage of Instrumental Variable Model: Non-OtO Flows at a 0.1 rate (10 per 1,000)

	Dependent variable: MOB_{ij}	Dependent variable: $ISDN_{ij}$
Voice-telephony penetration rate ($VOICE_{ij,1997}$)	0.191*(0.074)	0.000 (0.011)
Cable-TV penetration rate ($CABLE_{ij,1997}$)	-0.353*(0.167)	0.125* (0.055)
Diffusion speed (β)	0.785**(0.296)	-9.193 (5.081)
Inflexion point (τ)	2005.563***(0.980)	2008.178*** (9.872)
Constant	0.815**(0.239)	6.419*** (0.065)
R^2	0.29	0.14
N	1425	1163
F-test (p-values in parentheses)	7.33 (0.000)	6.11 (0.000)

Table 17. Diffusion Curve for First Stage of Instrumental Variable Model: Non-OtO Flows at a 0.3 Rate (30 per 1,000)

	Dependent variable: MOB_{ij}	Dependent variable: $ISDN_{ij}$
Voice-telephony penetration rate ($VOICE_{ij,1997}$)	0.201* (0.082)	0.000 (0.010)
Cable-TV penetration rate ($CABLE_{ij,1997}$)	-0.300 (0.170)	0.072 (0.055)
Diffusion speed (β)	0.789**(0.336)	-7.866 (4.708)
Inflexion point (τ)	2005.558***(1.098)	2008.355*** (21.283)
Constant	0.635**(0.203)	6.112***(0.066)
R^2	0.29	0.15
N	1275	1047
F-test (p-values in parentheses)	6.15 (0.000)	5.39 (0.000)

Table 18. Diffusion Curve for First Stage of Instrumental Variable Model: Non-OtO Flows at a 0.5 Rate (50 per 1,000)

	Dependent variable: MOB_{ij}	Dependent variable: $ISDN_{ij}$
Voice-telephony penetration rate ($VOICE_{ij,1997}$)	0.247 (0.108)	0.008 (0.012)
Cable-TV penetration rate ($CABLE_{ij,1997}$)	-0.320 (0.195)	0.233 (0.062)
Diffusion speed (β)	0.836* (0.446)	-7.791 (7.523)
Inflexion point (τ)	2005.527*** (1.243)	2008.398*** (38.495)
Constant	0.373** (0.185)	5.351*** (0.075)
R^2	0.28	0.15
N	1035	855
F-test (p-values in parentheses)	5.12 (0.000)	4.27 (0.000)

In Tables16-18, MOB_{ij} is calculated as $MOB_i \times MOB_j$ where MOB_i is the mobile-phone subscribers per 100 inhabitants in the origin and MOB_j is the mobile-phone subscribers per 100 inhabitants in the host. $ISDN_{ij}$ is calculated as $ISDN_i \times ISDN_j$ where $ISDN_i$ is the integrated-services digital network subscribers per 100 in the origin and $ISDN_j$ is the integrated-services digital network subscribers per 100 in the host.

APPENDIX D

Table 19. Additional Robustness Checks for OtO Flows

Dependent variable: Log of migration flows	**(1)**	**(2)**	**(3)**
Predicted penetration rate ($BROAD_{ij,t}\_hat$)	0.0447*** (0.0130)	0.0359*** (0.0124)	0.0370*** (0.0138)
Log of distance ($\log DIST_{ij}$)	-0.689*** (0.208)	-0.744*** (0.222)	-0.489** (0.224)
Log of relative real GDP ($\log RGDP_{ij,t}$)	-0.327*** (0.0742)	-0.439*** (0.0734)	-0.390*** (0.0778)
Log of wage in the host country ($\log wage_{j,t}$)	0.0442* (0.0254)	0.0342 (0.0232)	0.0323 (0.0253)
Unemployment rate in the origin ($Unempr_{i,t}$)	0.003 (0.00964)	0.00517 (0.00949)	0.00712 (0.0112)
Employment rate in the host ($Empr_{j,t}$)	-0.0193 (0.0128)	0.0224** (0.0111)	0.0273** (0.0119)
Dummy = 1 if no restriction ($FREE_{ij,t}$)	0.675*** (0.148)	0.912*** (0.151)	0.929*** (0.177)
Predicted years ($T^{\beta}_{ij,t}\_hat$)	0.009 (0.017)	0.007 (0.015)	-0.002 (0.016)
TEL_{ij}	0.577 (0.581)	0.836 (0.587)	0.650 (0.707)
$CABLE_{ij}$	-0.748 (0.522)	-1.665 (0.541)	-1.354* (0.692)
Constant	3.697** (1.605)	4.042** (1.601)	2.136 (1.560)
R^2	0.26	0.34	0.34
Country pairs	148	118	100

Table 20. Additional Robustness Checks for Non-OtO Flows

Dependent variable: Log of migration flows	**(1)**	**(2)**	**(3)**
Predicted penetration rate ($BROAD_{ij,t}\_hat$)	0.086*** (0.016)	0.086*** (0.015)	0.091*** (0.018)
Log of distance ($\log DIST_{ij}$)	-0.073 (0.29)	-0.172 (0.252)	-0.395* (0.240)
Log of relative real GDP ($\log RGDP_{ij,t}$)	-0.312*** (0.100)	-0.260*** (0.094)	-0.183** (0.092)
Log of wage in the host country ($\log wage_{j,t}$)	0.071* (0.043)	0.089** (0.037)	0.100*** (0.036)
Unemployment rate in the origin ($Unempr_{i,t}$)	0.002 (0.012)	0.001 (0.013)	0.005 (0.014)
Employment rate in the host ($Empr_{j,t}$)	0.015 (0.017)	0.018 (0.016)	0.012 (0.017)
Dummy = 1 if no restriction ($FREE_{ij,t}$)	0.785*** (0.157)	0.807*** (0.163)	0.847*** (0.209)
Predicted years ($T^{\beta}_{ij,t}\_hat$)	-0.052 (0.0526)	-0.065 (0.0496)	-0.096 (0.065)
TEL_{ij}	-0.578 (0.395)	-0.874* (0.392)	-0.768* (0.395)
$CABLE_{ij}$	0.195 (0.279)	0.498 (0.242)	0.274 (0.257)
Constant	-1.233 (2.500)	0.941 (2.293)	3.540* (2.029)
R^2	0.32	0.35	0.33
Country pairs	101	92	76

APPENDIX E

Table 21. Robustness Check with Additional Control Variables: OtO for 0.1, 0.3, 0.5 Rate Flows

Dependent variable: Log of migration flows	(1)	(2)	(3)
Predicted penetration rate ($BROAD_{ij,t}\_hat$)	0.022*(0.016)	0.026*(0.016)	0.038**(0.017)
Log of distance ($\log DIST_{ij}$)	-0.745**(0.045)	-0.528**(0.045)	-0.329**(0.047)
Log of relative real GDP ($\log RGDP_{ij,t}$)	-0.694**(0.024)	-0.605**(0.027)	-0.529**(0.028)
Log of wage in the host country ($\log wage_{j,t}$)	0.001*(0.000)	0.002*(0.000)	0.002*(0.000)
Unemployment rate in the origin ($Unempr_{i,t}$)	0.058*(0.008)	0.056*(0.009)	0.053*(0.009)
Employment rate in the host ($Empr_{j,t}$)	0.007**(0.003)	0.004 (0.003)	0.011(0.003)
Dummy = 1 if no restriction ($FREE_{ij,t}$)	0.039(0.090)	-0.085 (0.096)	0.062 (0.096)
Predicted years ($T^{\beta}_{ij,t}\_hat$)	0.066*(0.023)	0.060 (0.022)	0.046 (0.023)
$\log\_phntraffic_{ij}$	0.872*(0.034)	0.659*(0.037)	0.587*(0.037)
Constant	-	-	-
R^2	0.35	0.29	0.25
N	1906	1517	1300
Country pairs	148	118	100

Models (I), (II), (III) present the results for OtO flows with 0.1, 0.3, and 0.5 rate thresholds, respectively. Here, $\log\_phntraffic_{ij}$ is calculated as international incoming fixed-telephone traffic $\log\_trafficin_i$ in the origin times international outgoing fixed-telephone traffic $\log\_trafficout_j$ in the host in minutes, respectively.

Table 22. Robustness Check with Additional Control Variables: non-OtO for 0.1, 0.3, 0.5 Rate Flows

Dependent variable: Log of migration flows	(1)	(2)	(3)
Predicted penetration rate ($BROAD_{ij,t}\_hat$)	0.077***(0.013)	0.087***(0.013)	0.106***(0.013)
Log of distance ($\log DIST_{ij}$)	-0.125*(0.070)	-0.237**(0.065)	-0.429**(0.058)
Log of relative real GDP ($\log RGDP_{ij,t}$)	-0.556**(0.033)	-0.491**(0.034)	-0.380**(0.031)
Log of wage in the host country ($\log wage_{j,t}$)	0.010 (0.007)	0.011*(0.006)	0.011*(0.008)
Unemployment rate in the origin ($Unempr_{i,t}$)	-0.053 (0.007)	-0.051(0.007)	-0.052 (0.007)
Employment rate in the host ($Empr_{j,t}$)	-0.023(0.003)	-0.016 (0.003)	-0.015 (0.003)
Dummy = 1 if no restriction ($FREE_{ij,t}$)	0.162 (0.297)	0.246 (0.295)	0.793*(0.273)
Predicted years ($T^{\beta}_{ij,t}\_hat$)	0.039 (0.081)	-0.076 (0.080)	-0.191*(0.086)
$\log\_phntraffic_{ij}$	0.670 (0.070)	0.623 (0.069)	0.429*(0.062)
Constant	-	-	-2.155 (1.364)
R^2	0.30	0.28	0.33
N	1243	1132	923
Country pairs	101	92	76

Models (I), (II), (III) present the results for non-OtO flows with 0.1, 0.3, and 0.5 rate thresholds, respectively. Here, $\log\_phntraffic_{ij}$ is calculated as international incoming fixed-telephone traffic $\log\_trafficin_i$ in the origin multiplied by international outgoing fixed-telephone traffic $\log\_trafficout_j$ in the host in minutes, respectively.

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