Reexamining the regional income convergence in Canada

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Abstract

Sigma, beta, stochastic (weak) and club convergence in Canadian provinces have been examined for a variety of periods. Our empirical results show that sigma convergence exists since the standard deviation of real personal disposable income declined from 1926 to 2020. Moreover, beta convergence occurs for the whole period 1926-2020 and the subperiod 1950-2020 but not for the more recent datasets, i.e., 1981-2020 and 1996-2020. In contrast, the unit root tests show a complete lack of stochastic convergence while the cointegration tests indicate stochastic convergence for the period 1949-2020. Strong stochastic cointegration doesn't happen too. However, the data doesn't support convergence since beta and stochastic convergence (weak) don't occur simultaneously, apart from the period 1949/50-2020 where convergence indeed happens. Furthermore, robustness analysis, shows that it is important to be a distinction between measures of real personal/household income since in some cases, the different measures can lead to different conclusions, especially in terms of disposable and non-disposable income. Finally, the definition of convergence, namely strong or weak can really change our results. However, this paper doesn't support in any case one unique steady state among provinces after 1981.

Keywords: Sigma convergence, beta convergence, stochastic convergence, household disposable income, Canada

"No one who achieves success does so without acknowledging the help of others. The wise and confident acknowledge this help with gratitude."

– Alfred North Whitehead–

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1. Introduction

In recent years, one of the intriguing topics in economics concerning the per capita (pc) income convergence. Overtaking the convergence among countries, without ignoring or reducing its importance, we focus on regional convergence. It is crucial to take into consideration differences in the distribution of income in one country's regions. However, what do we mean by term "convergence"? Convergence can be defined in different ways.

The *first* concept is known as *σ-convergence* which is, also, known as cross-sectional dispersion (Barro and Sala i Martin, 1992) and it is the oldest method as Genc et al. (2011) mention (see Kuznets, 1955; Easterlin, 1960; Williamson, 1965). In sigma convergence, researchers study the cross-sectional dispersion of per capita income usually comparing changes in some measure of regional dispersion as the standard deviation, the variance, or the coefficient of variation of the logarithm of per capita income across points in time (Millers and Genc, 2004; Genc et al., 2011; Rey and Montouri, 1999). We have to refer that β convergence (see next paragraph) is a necessary but not a sufficient condition for σ convergence or differently a β convergence does not require the existence of a σ convergence (Barro and Sala i Martin, 1990; Barro and Sala i Martin, 1992; Pintera, 2021; Coutinho and Turrini, 2019)[1].

A *second* perspective of convergence is called *β-convergence* which is related to the neoclassical growth model (Solow, 1956). Convergence occurs when growth rates are negatively correlated with initial levels of regional per capita income (Barro and Sala-i-Martin, 1990). There are two types of β-convergence, *absolute* or *unconditional* convergence and *conditional* convergence. Unconditional convergence there is under the assumption of

[1] Coutinho and Turrini (2019) mention that the speed of convergence depends on the degree of dispersion in per capita income:

$$\sigma_t^2 = e_t^{2\lambda}\sigma_{t-1}^2 + \sigma_u^2$$

where, $\beta = -\left(1 - e_t^{\lambda}\right) < 0$.

So, this equation can be rewritten as

$$\sigma_t^2 = (1+\beta)^2\sigma_{t-1}^2 + \sigma_u^2 \,.$$

the same growth dynamics for all countries, namely the same steady state. If assumptions about common steady-state are untenable researchers study conditional convergence. In conditional convergence the steady state differs depending on individuals' characteristics, so each economy has a particular steady-state equilibrium. Economies with same characteristics, i.e. savings rate, human factors, population growth, etc. are approached to the same steady state independently for initial conditions (Barro and Sala-i-Martin, 1992; Galor, 1996). Nonetheless, we consider the absolute version of the beta convergence in this article.

It is important to be mentioned that beta convergence has received analytical and methodological criticisms (Arvanitopoulos et al., 2019). Studies of absolute and conditional convergence, usually, use a *cross-section* regression to examine the relationship between the growth rate of (regional) income per capita and the initial level of (regional) income per capita. In the case of conditional, some structural factors are added in regression to account for compensating income differentials (Miller and Genc, 2004). However, Caselli et al. (1996), like Lee et al. (1997), claim that cross-section regressions have some problems. First, the OLS estimate of the convergence's coefficient is downward bias. The second disadvantage is endogeneity. If we assume homogeneity of long-run and short-run parameters we will risk leading to inconsistent results. Caselli et al. (1996) criticize, also, panel regressions. They refer that panel data can solve some problems, namely the endogeneity but they can't solve other problems, such as the omitted-variables bias and the correlated country effects. Briefly, we can cite this conclusion by Caselli et al. (1996)[2]:

> "*In particular, the above overview of the literature leads us to argue that almost all existing cross-country regressions, either based on cross-section, or panel-data techniques, have been estimated inconsistently*."

Furthermore, a *third* type of convergence is called *club* convergence. If economies are grouped by common characteristics and their initial growth conditions are above or

[2] Caselli et al. (1996), "Reopening the convergence debate: a new look at cross-country growth empirics", page 369.

below a specific threshold value (the initial conditions are important) we have club convergence (Baumol, 1986; Galor, 1996). Specifically, each group has its own steady state where region reaches its own group equilibrium since long-run per capita income depends on its initial conditions and therefore countries with similar conditions and characteristics have similar long-run per capita incomes. Thus, they form a convergence club or differently, economies converge to their steady state that is associated with the initial conditions (Johnson and Papageorgiou, 2020). Moreover, Christopoulos et al. (2022) and Seo and Shin (2016) use panel threshold models taking into account the endogeneity, where the sample is divided into groups according to a threshold variable, i.e. human capital. Thus, there are two or more regimes, namely clubs. In this way they examine club convergence. Obviously, this threshold will affect indirectly all others coefficients and directly the coefficient of threshold variable if it is included in regression. Rey and Montouri (1999), also, mention that club convergence requires an economical "leader" with the highest income throughout the study period. Novac and Moroianu-Dumitrescu (2020a[3]) give the following dynamical definition for a convergence club:

> *"A group of economies belonging to the same geopolitical, economic, and social environment and having similar initial characteristics form a convergence club if and only if the dynamics of their evolution drive them to the same steady state, meaning that the property of absolute convergence holds for a club".*

According to Johnson and Papageorgiou (2020) the dispersions in long-run per capita incomes are transitory, if the initial conditions aren't important and that implies that these differences shall reduce if convergence is taking place.

Finally, there is the *stochastic* or *pair-wise* convergence. According to Genc et al. (2011) first called stochastic convergence by Campbell and Mankiw (1989). However, its

[3] Novac and Moroianu-Dumitrescu (2020a), "Dynamic model of regional convergence", page 51.

estimation method became known as a pairwise approach by Pesaran (2007). Carlino and Mills (1993) refer that there is stochastic convergence if shocks to relative regional per-capita incomes are transitory. Similarly, Rey and Montouri (1999) mention that convergence is violated if shocks persist into infinite time since the stochastic convergence requires the long-run expected differences in income levels between two economies to tend to be 0. Furthermore, Arvanitopoulos et al. (2019), referring to Pesaran (2007), argue, implying that stochastic convergence occurs when there is a common growth path across regions and the shocks which lead to deviations from this path are temporary. They add that this approach of convergence has some advantages in comparison to beta convergence. For instance, i) it isn't affected from the start and end dates, and mean reversal, ii) it allows two economies with different steady states to converge under some conditions, and iii) it, also, allows for divergence under some assumptions. In addition, iv) through the same model specification can let club convergence occurs.

This notion of convergence, usually, is estimated with time series methods. Unit root tests are used to determine whether random shocks to a regional economy persist or not over time. If the per capita regional income differences are characterized by a non-zero mean stationary, there is a stochastic process (Pesaran, 2007). Nevertheless, a test for the stationarity of regional output differences may not reject the unit root hypothesis and thus wrongly conclude that there is no convergence. Therefore, the stationarity is not a necessary condition for the existence of convergence (Magrini, 2004; Nahar and Inder, 2002). Moreover, some unit root tests are sensitive to initial conditions, making them unsuitable for examining convergence. Even the ADF test which is more robust to initial conditions has no power when a time trend is included (Magrini, 2004). Alternatively, stochastic convergence can be defined as the cointegration with cointegrating vector [1, -1]′ among time series (Miller and Genc, 2004) otherwise the presence of cointegration is a necessary but no sufficient condition for convergence (Pesaran, 2007). Occasionally, weak stochastic convergence is examined, namely the cointegration in income pairs with unknown vector (Holmes et al.; 2014).

In some cases, stochastic convergence can be really close to the club convergence. Pesaran (2007) finds evidence for club convergence defining as "club" the countries that their income gaps are stationary with a constant mean. There are, also, methods that use clustering approaches to examine club convergence which are closer to the meaning of stochastic convergence (Beylunioğlu et al., 2020).

Although Johnson and Papageorgiou (2020) conclude that it is hard to define "*convergence*" since the notion of convergence is vast and it can be defined with a lot of ways, the types of convergence are represented briefly in *Fig.1*. Moreover, there are issues with econometric approaches and data measurement, so the empirical applications are challenging.

As we already have mentioned convergence is a fascinating topic in the economic literature. The importance of regional convergence can be perceived from the number of researches.

A host of papers, indeed, study regional convergence, using various methodologies, for plenty of countries like Greece (Tsionas, 2002; Moroianu-Dumitrescu and Novac, 2020; Arvanitopoulos et al., 2019), Italy (Iuzzolino et al., 2011; Novac and Moroianu-Dumitrescu, 2020b), France (Novac and Moroianu-Dumitrescu, 2020a;), China (Zhang et al., 2018), Russia (Lehmann et al., 2020; Kholodilin et al., 2009), UK (Mcguinness and Sheehan, 1998), Indonesia (Aginta et al., 2021), etc.. The case of the USA has commanded an extraordinary amount of attention in the recent literature, which yields different conclusions about convergence (Miller and Genc, 2004; Evans and Karras, 1996a; Evans and Karras, 1996b; Barro and Sala i Martin, 1990; Barro and Sala i Martin, 1992; Carvalho and Harvey, 2005; Miles, 2020; Lee, 2004; Rey, 2001; Naghshpour and Nissan, 2017; Mitchener and Mclean, 1999; Rey and Montouri, 1999; Ganong and Sloag, 2017). Moreover, convergence in Mexico and North America has been analyzed with particular focus on NAFTA pre- and post-eras (Díaz-Dapena et al., 2019; Diaz-Bautista, 2008; Cabral and Mollick, 2012; Easterly et al., 2003; Madariaga et al., 2004). Except for the USA, an enormous interest has gathered in the EU too since economists try to examine if European regions, eventually, converge

(Holobiuc, 2020; Giuseppe and Gianfranco, 2004; Quah, 1996; Novac and Moroianu-Dumitrescu, 2020c; Neven, 1995; Pintera, 2021; Canova, 2004).

Recognizing the importance of regional convergence, we try to examine if provinces in Canada, which is one of the biggest economic powers in the world, converge. Díaz-Dapena et al. (2019) mention Canada as an example of countries where the continental core, i.e. USA., will enhance it since its major cities are located close to the U.S. border. James and Krieckhaus (2008), also, refer that the case of regional convergence in Canada is fascinating due to its provincial inequality and Gunderson (1996) claims that inequalities between regions are more important than those within a region. Breau and Saillant (2016), also, agree that Canada continues to have one of the largest regional disparities in GDP per capita in OECD countries.

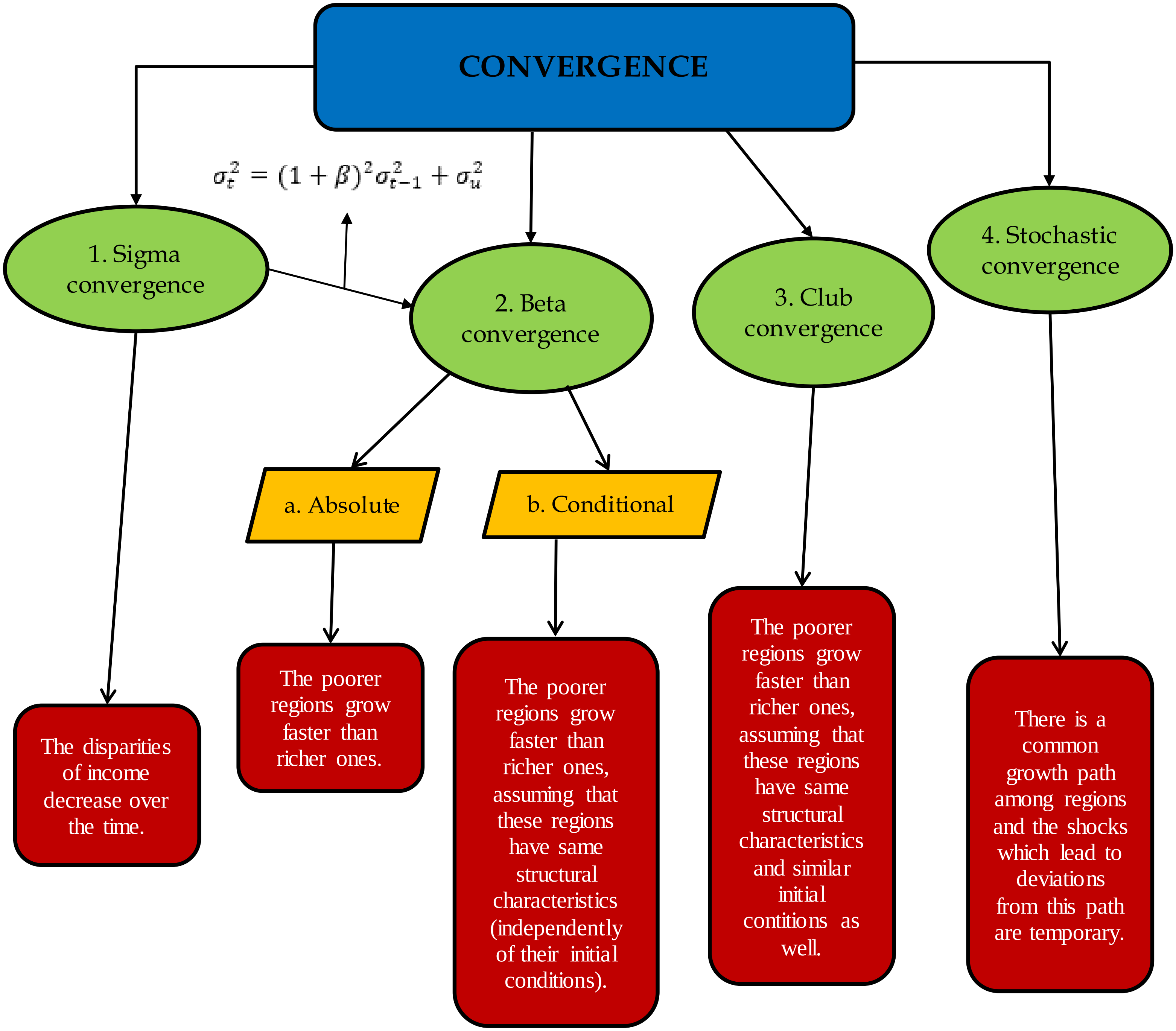
This paper examines sigma, beta, stochastic (weak) and club convergence in Canadian provinces for the period 1926-2020 and subperiods. Regarding stochastic convergence, as far as we know there isn't any other paper that use pairwise approaches in the differences of income or cointegration test in incomes of two provinces for *all possible pairs among Canadian provinces.* Our empirical results show that sigma convergence exists since the standard deviation of real household disposable income declines over the year. Moreover, beta convergence occurs for the whole period 1926-2020 and the subperiod 1950-2020 but not for the periods 1981-2020 and 1996-2020. In contrast, the unit root tests show a complete lack of stochastic convergence while the cointegration tests indicate stochastic convergence for the period 1949-2020. Strong stochastic cointegration doesn't happen. However, the data doesn't support convergence since beta and stochastic convergence (weak) don't occur simultaneously, except for the period 1949/50-2020 where convergence occurs.

Furthermore, robustness checks, using other variables for real personal income, show that the results of sigma, beta convergence are, on average, robust although there some important differences. First, in case of absolute convergence, only in the main variable the exclusion of Newfoundland and Labrador can lead to lack of convergence.

Secondly, regarding stochastic convergence, the results depend on the variable which measures the income and the methodology. First, in case of cointegration tests with unknown vector, only the household income (*lnhi*) indicates that there is stochastic convergence in the period 1981-2016. Secondly, unit root tests and cointegration tests with known and unknown vector lead to different results since according to the unit root tests and cointegration test with known vector there is no stochastic convergence. In addition, we analyze sigma, absolute and stochastic convergence for house price indices for the monthly period 1990M7-2022M6 for 11 Canadian cities to confirm the lack of convergence after 1990 since house price indices could be a good proxy for economic activity. Finally, Phillips and Sul's (2007) method is used to define the clubs for the measures of personal income. It seems that there is club convergence only for the periods 1981-2020 and 1996-2020 and there are one or more clubs (if there is one club that doesn't include all provinces). Nevertheless, the club classification depends on the variable.

This article is divided as follows. In section 2, we discuss the previous literature. In sections 3 and 4, the data and the methodology are referred to, respectively. In section 5, we present our empirical results. In section 6, robustness tests are mentioned. Finally, section 7 concludes.

***Figure 1**: Types of convergence*



2. Previous literature

There are numerous studies[4] of Canadian regional per capita income convergence. Some of them found evidence of strong convergence (Coulombe and Lee, 1995; Gunderson, 1996; Coulombe, 2000; DeJuan and Tomljanovich, 2005), and some support that convergence isn't a smooth, continuous process (Brown and Macdonald, 2015). Most of them focus on pre-2010 period, using different time spans and income measures. There are, also, a few studies that use time series techniques (Afxentiou and Serletis, 1998; DeJuan and Tomljanovich, 2005). Analytically:

Coulombe with his coauthors have contributed to literature significantly publishing several papers. Some of them are:

- First, Coulombe and Lee's (1995) analysis indicates that there is convergence for the 1961-1991 period and three subperiods for six income measures.
- Second, Coulombe and Tremblay (1998) for the 1951-1996 period confirm that sigma and beta convergence have taken place in Canada and they claim that disparities in human capital can largely explain disparities in Canadian per capita income.
- Moreover, Coulombe and Day (1999) analyze the disparities between Canadian provinces using the standard deviation of the logarithm of personal income per capita for the 1929-1995 period, output per capita for the 1964-1992 period, and output per worker for the 1967-1992 period. Although the disparities in output per capita are higher than those in personal income per capita and output per worker, disparities in personal income per capita have decreased, so we can say that there is sigma convergence for the last income measure. They, also, find that the estimate of the speed of

[4] Some of them are referred to by Gunderson (1996).

convergence, i.e. the rate that poor provinces converge at rich ones, is positive and statistically significant for all measures, either excluding Alberta or not.

- In addition, Coulombe (2000) examining the 1950-1996 period finds σ and β convergence. He, also, estimates unit root tests providing useful information. He claims that if convergence is occurring, since the variable isn't in equilibrium, the series should be trend stationary and the trend's coefficient should be negative for the rich provinces and positive for the poor ones. Similarly, if the series is in a steady state, the series should be stationary and the trend's coefficient should be equal to zero. He shows that there isn't a unit root for the majority of provinces. However, this unit root has low power in the existence of structural breaks. He ends up that the unit root tests, probably, aren't the proper way to describe the shape of the time trend and structural breaks should be taken into consideration.
- Finally, Coulombe (2003) confirms the existence of conditional convergence in both human capital and personal income without transfers for the 1950-1996 period. Indeed, he finds that the evolution of human capital is explained more than the evolution of personal income through the process of conditional convergence (R^2 is 0.81 and 0.26 respectively). He, also, supports that his estimations of convergence speed are higher than those of absolute convergence in Coulombe and Tremblay (2001) implying that absolute convergence underestimates the convergence speed.

Some studies use cross section and panel approaches too, concluding that panel convergence's estimations are higher.

- To begin with, Ralhan and Dayanandan (2005) use both the annual and 5-year average of per capita real net provincial domestic product for the period 1981-2001 and they apply OLS, fixed and random effects, and the first-differenced GMM and system GMM estimators. They conclude that there is conditional and unconditional convergence for most models suggesting that the panel methods end up with a higher convergence rate than OLS.

- Finally, Hamit-Haggar (2013) tests if Canadian provinces converge in the 1981-2008 period, following Phillips and Sul's (2007) method, which allows for heterogeneity. His findings indicate that there are three convergent clubs within Canada but not full convergence. Newfoundland and Labrador, Ontario, Saskatchewan, Alberta, and British Columbia (i.e. the provinces with high GDP per capita) converge to their respective steady-state growth paths. Similarly, New Brunswick, Quebec, and Manitoba (second group) and Prince Edward Island and Nova Scotia (third club) converge to their steady-state equilibrium. The third club doesn't converge in the cases of labor productivity, capital intensity, and TFP.

There are, also, researchers who focus on disparities in Canadian provinces.

- Capeluck (2014) reports that Canadian provinces have converged (sigma convergence) for most of the economic indicators which included in his analysis.
- In the same concept, Halliwell (1996) finds that convergence of average income levels among provinces has been taking place. Specifically, there is a rapid reduction of variation in income per capita after 1975. However, when British Columbia, Alberta, and Saskatchewan are excluded for the same time, income measure variation has slightly decreased from 1961 to 1989. Using the variation of disposable income per capita among nine provinces, where Newfoundland and Labrador is excluded, for the 1926-90 period, he ends up that the existence of sigma convergence is much clearer.
- Furthermore, Carayannis and Rajiv Mallick (1996) measure the regional income disparity which for most measures and for 8 provinces decline, indicating sigma convergence for the 1961-1992 period.

- On the other hand, Geloso et al. (2016) although finding σ convergence in total income pc and disposable income pc show that this convergence is affected by differences in household size. Indeed, when income is divided by the square root of the number of household members (total income AEQ and disposable income AEQ) dispersion in both AEQ variables is increased after around 1990.
- Finally, Gutoskie and Macdonald (2019) show that there is sigma convergence when excluding Alberta, Saskatchewan, and Newfoundland and Labrador from the sample during 1950-2016. Otherwise, there is some time where disparities increased, namely after 1970, 1986, and in the early 2000s due to the increase in energy prices for the first and third years and due to their reduction in the second year.

Sigma and/or beta convergence are confirmed by other authors too:

- such as Dunaway et al. (2003), who study the 1961-2000 period and they find both types of convergence.
- James and Krieckhaus (2008) examine decade averages of economic growth in ten Canadian provinces during each of the five decades in 1950-1990 using OLS (with panel corrected standard errors and fixed time effects) which capture national variation. They find that provincial growth depends on national growth rates and they confirm the conditional convergence in Canadian provinces at the 1%.
- Moreover, Lee (1996) finds sigma and beta convergence for the 1968-1992 period.
- Finally, Irwin and Inwood (2002) include in their research the initial four provinces of Canada (Quebec, Ontario, New Brunswick, and Nova Scotia) for the years 1871 and 1891. They claim that the eastern provinces had significantly lower per capita income than did Ontario which was a high-

income province and that substantial differences remain at the end of the 19th century.

As we mentioned the majority of studies confirms convergence. Nevertheless, there are papers that support something slightly different.

- Brown and Macdonald (2015) examine the provincial convergence of per capita household disposable income in Canada from 1926 to 2011. They find that there are periods of divergence[5] corresponding to large external shocks. They, also, run a cointegration test for two periods: from 1926 to 2011 and from 1997 to 2011. Only one pair is applied for the first period: Alberta and Saskatchewan which aren't cointegrated. In the second period, they examine three pairs: Alberta and Saskatchewan, Alberta and Newfoundland and Labrador, and Saskatchewan and Newfoundland and Labrador. They reject cointegration using Johansen trace at the 10% in all cases, except for the second pair. Finally, they show that there is sigma convergence for non-divergence eras. In brief, the paper finds that convergence isn't a smooth, continuous process.
- Furthermore, Breau and Saillant (2016) find unconditional convergence for Canadian provinces during the 1981–2010 period and the 1981-1996 subperiod, but not for the 1996 2010 period where the coefficients of β-convergence are statistically insignificant. However, when they use the 287 census divisions for the 1996–2006 period and end up that the coefficient for β-convergence is positive and statistically significant indicating divergence.

Last but not least, there are a few studies that use not only traditional approaches but also time series methods. Such as:

[5] 1) the Great Depression (1926 -1936)
2) the postwar transition (1945 - 1951)
3) the oil price shocks (1973 - 1986)
4) the commodity boom of the early 21st century (1996 - 2011).

- According to Afxentiou and Serletis (1998), there is absolute convergence for the 1961-1991 period and the subperiods 1961-1971, 1971-1981, and 1981-1991 for Canadian provinces. However, when Ontario is used as the "core", only four provinces have a negative, but non-significant convergence's coefficient, suggesting that lack of convergence toward Ontario. As far as we know, they are the first who used time series methods, i.e cointegration tests, to examine convergence in Canadian provinces. The Johansen test in three groups[6] shows that there is convergence only in the case of the rich provinces. In summary, they conclude that Canada isn't an economically homogeneous country and, in the cases, where there is convergence, this process is at best very slow.
- Moreover, in more recent paper, DeJuan and Tomljanovich (2005) use time series techniques to examine convergence in Canadian provinces from 1926 to 1996. They support both stochastic convergence and b-convergence for the majority of Canadian provinces, after allowing for a structural break in the data. They end up that b-convergence across Canadian provinces is occurring for the most part during the 1946–1996 period and not during the 1926– 1946 period. They, also, using unit root tests in output, suggest that there is stochastic convergence for the majority of Canadian provinces for the whole period and all provinces in the 1946–1996 period. Moreover, they find relative stable disparities in provinces in the pre-World War II sample and sigma convergence for the post-World War II sample. Pesaran (2007) criticize this method of stochastic convergence, namely the unit root tests in income, since the presence of a unit root in output doesn't necessarily indicate stochastic convergence.

[6] First group, the Western group: Alberta, Manitoba, Saskatchewan, and British Columbia.
Second group, is the Atlantic provinces: Newfoundland. New Brunswick, Nova Scotia, and Prince Edward Island.
Third group, the rich provinces: Ontario, Quebec, Alberta, and British Columbia.

- Finally, Shiller (2009) examines Canadian 10 provinces and 2 territories from 1951 to 1990. He finds that there is sigma convergence and he can't reject the non-convergence hypothesis running unit root/stationarity tests for per capita Canadian dispersion measure. He also, supports beta convergence for all sample periods and subperiods, except for the subperiods 1976-1990 and 1971-1980. He, also, examines the stochastic convergence using unit root/stationarity tests in income where KPSS indicates that there is no convergence for the majority of provinces but it is for territories.

Table 1: Previous literature

Author (date)	Title	Sample	Variables	Type of convergence	Methodology	Conclusions
1.Afxentiou and Serletis (1998)	"Convergence across Canadian provinces"	1966-91 1961-71 1971-81 1981-91 10 provinces	Real per capita GDP	Absolute convergence and Stochastic convergence	Cross- sectional data Johansen's cointegration	• There is absolute convergence • It seems that there is no convergence toward Ontario • Johansen test shows that there is cointegration only in rich provinces.
2.Breau and Saillant (2016)	"Regional income disparities in Canada: exploring the geographical dimensions of an old debate"	1981–2010, 1981-96 and 1996-2010 For 10 provinces 1996–2006 for 287 census division	Real personal income per capita Average total income for census division data	Sigma convergence and Absolute convergence	Standard deviation and coefficient of variation Cross-section regression Spatial dependence models	• There is convergence from 1981 to the mid-1990s. • There is no absolute convergence for the 1996-2010 period. • When census divisions data is used the lack of convergence in 1996-2010 for provinces turn into divergence. • In the case of spatial dependence models, there is divergence

3.Brown and Macdonald (2015)	"Provincial convergence and divergence in Canada, 1926 to 2011"	1926-2011 1949-2011 1926-36, 1936-45, 1945-51, 1951-73, 1973-86, 1986-96 and 1996 -2011 10 provinces	Nominal and real per capita household disposable income	Sigma Convergence Absolute Convergence and Stochastic convergence (for 2 time periods and 3 pairs)	Standard deviation Non-linear least squares Johansen cointegration test	• There are periods of divergence corresponding to shocks, so convergence isn't a smooth, continuous process. • There is sigma convergence for non-divergence eras. • There is stochastic convergence only for the group: Alberta and Newfoundland and Labrador.
4.Capeluck (2014)	"Convergence across provincial economies in Canada trends, drivers and implications"	Depend on variable Nominal/ real GDP pc: 1961/81, 1990 and 2012 10 provinces	25 variables related to income, productivity, the labor market, well-being, and fiscal capacity.	Sigma convergence	Coefficient of variation (CV)	• CV is always higher for all nominal variables than for its relative real variable • There are significant disparities in nominal and real GDP pc. However, there is sigma convergence in the long-term period.

5.**Carayannis and Rajiv Mallick** **(1996)**	"Regional income disparities in Canada: implications for theories of regional convergence"	1961-1992 8 provinces	Per capita income	Sigma convergence	Percent of per capita income in a province to the nation, Weighted coefficient of income variation. Theil's entropy measure of industrial concentration. The entropy measure of regional income disparity into a component reflecting the regional disparity in employment rates and A component reflecting the regional disparity in GDP per worker dissimilarity index based on the Lorenz curve	• There is sigma convergence for most measures.

6.Coulombe (2000)	"New evidence of convergence across Canadian provinces: role of urbanization"	1950-1996 10 provinces	Personal income and Personal income less government transfers.	Sigma convergence and Conditional Convergence	Standard deviation GLS (linear) estimations using cross-section weighted regressions (pooled panel method) Unit root tests (ADF, PP) to avoid spurious regressions	• There are σ and β convergence. • There isn't a unit root for the majority of provinces' income indicating that the variables are stationary. • However, these unit root tests have low power in the existence of structural breaks, thus structural breaks should be taken into consideration.
7.Coulombe (2003)	"Human capital, urbanization and Canadian provincial growth"	1950–95 (5 years) 10 provinces	Provincial personal income less government transfers to individuals	Conditional convergence	Iterated FGLS (linear) estimations	• There is conditional convergence. • The absolute convergence underestimates the convergence speed.
8.Coulombe and Day (1999)	"Economic growth and regional income disparities in Canada and the northern United States"	1929-95 (pi) 1964-92 (oc) 1967-92 (ow) 10 provinces	Personal income per capita (pi), Output per capita (oc) and Output per worker (ow)	Sigma convergence and Absolute Convergence	Standard deviation Pooled time-series cross-section	• There is sigma convergence for pi and a slight reduction in disparities of other measures. • The estimation of the speed of convergence, i.e. the rate that poor provinces converge at rich ones, is positive and statistically significant for all measures (with and without Alberta).

8.Coulombe and Day (1999)	"Economic growth and regional income disparities in Canada and the northern United States"	1929-95 (pi) 1964-92 for output pc 1967-92 for output pw 10 provinces	Personal income per capita (pi) Output per capita and Output per worker	Sigma convergence and Absolute Convergence	Standard deviation Pooled time-series cross-section	• There is sigma convergence for pi and a slightly reduction in disparities of other measures. • The estimation of the speed of convergence, i.e. the rate that poor provinces converge at rich ones, is positive and statistically significant for all measures (with and without Alberta).
9.Coulombe and Lee (1995)	"Convergence across Canadian provinces, 1961 to 1991"	1961-91 1961-71, 1971-81, 1981-91 10 provinces	Earned income pc Personal income pc (PI) PI minus government transfers pc (PIT) Personal disposable income pc GPP deflated by a	Absolute convergence	Pooled cross-section time series	• There is absolute convergence for all measures. • Dividends and net interest earnings don't change the convergence rate significantly since the relative estimation is similar for PIT and El. • The convergence rate is significantly higher when transfers to persons are added to PIT (PI) than the PI's rate, so the exclusion of transfers is important for the regional convergence in Canada. • Regional convergence for output measures is higher than income measures.

			national price pc GPP deflated by provincial implicit price indices pc			
10. Coulombe and Tremblay (1998)	"Human capital and regional convergence in Canada"	1951-1996 10 provinces	Personal income pc and Personal income pc minus government transfers pc	Sigma convergence and Absolute convergence	Standard deviation and Cross-country empirical analysis	• There are both sigma and beta convergence. • Disparities in human capital can largely explain disparities in income pc.
11.DeJuan and Tomljanovich (2005)	"Income convergence across Canadian provinces in the 20th century: Almost but not quite there"	1926 -96 1926-46 and 1946-96 10 provinces	Real personal income pc	Sigma convergence Beta convergence and Stochastic convergence	unweighted cross-sectional standard deviation OLS based on Vogelsang's (1998) approach Unit root test (ADF) to income	• There isn't evidence for sigma convergence before 1946 but there is after that. • b-convergence is occurring for most provinces during the 1946–1996 period. • There is stochastic convergence for the majority of Canadian provinces pre-World War II sample and all provinces after WWII.

12. Geloso et al. (2016)	"Demographic change and regional convergence in Canada"	1926 – 2013 10 provinces	Total income (pc and AEQ) and Disposable income (pc and AEQ)	Sigma convergence	Weighted coefficient of variation	• There is sigma convergence for income pc and disposable income pc. • The results are affected by differences in household size. i.e. when income is divided by the square root of the number of household members (AEQ). • The dispersion in both disposable income AEQ and total income AEQ increased after 1990 approximately.
13. Gutoskie and Macdonald (2019)	"Income Growth per Capita in the Provinces since 1950"	1950-2016 10 provinces	Household income per capita pc and real household income per capita pc	Sigma convergence	Standard deviation	• During some times, i.e. after 1970, 1986, and in the early 2000s, the disparities increased. • There is sigma convergence when Alberta, Saskatchewan, and Newfoundland and Labrador are excluded from the sample.
14. Halliwell (1996)	"Convergence and migration among provinces"	1961-89 for GDP pc 1926-91 for PDI 10 provinces	GDP pc and Personal disposable income pc (PDI)	Sigma convergence	Standard Variation	• There is sigma convergence for PDI and for GDP pc after 1950 and 1975 respectively. • When British Columbia, Alberta, and Saskatchewan are excluded there is no convergence for GDP pc in the 1961-1989 period.

15.Hamit-Haggar (2013)	"A note on convergence across Canadian provinces new insights from the club clustering algorithm"	1981-2008 10 provinces	Real GDP per capita	Absolute convergence And Club convergence	Phillips and Sul's (2007) panel approach	• No absolute convergence at the 5%. • Convergence club (3 groups).
16.James and Krieckhaus (2008)	"Canadian regional development: the quest for convergence"	Decade-averages for 1950-90 10 provinces	Real personal income per person (divided by national CPI)	Conditional convergence	OLS with Panel corrected standard errors and fixed effects (cross-section approach)	• Conditional convergence at the 1%.
17. Dunaway et al. (2003)	"Regional convergence and the role of federal transfers in Canada"	1961-2000 10 provinces	Real GDP pc	Sigma convergence and Conditional convergence	Coefficient of variation Three-stage least squares regression	• There are both sigma and beta convergence.

18.Ralhan and Dayanandan (2005)	"Convergence of income among provinces in Canada – An application of GMM estimation"	1981-2001 and Five-year data for the same period 10 provinces	Real net provincial domestic product per capita (NPDP)	Unconditional and Conditional convergence	OLS (cross-section) Fixed and random effects The first-differenced GMM System GMM estimators	• There are conditional and unconditional convergence for the most models. • The panel methods give a higher estimation of convergence rate than OLS.
19.Shiller (2009)	"Regional convergence in per capita personal income in the US and Canada"	1951-90, 1976-90, 1951-60, 1961-70 and 1971-80 10 provinces and 2 territories	Real per capita income	Sigma convergence Absolute convergence and Stochastic convergence	Unweighted standard deviation Cross-sectional regression and pooled cross-section time series Unit root tests (ADF, PP, KPSS) to income	• There is sigma convergence. • Absolute convergence is supported for most periods. • There is no stochastic convergence for the majority of provinces but there is for territories.

3. Data

We use data for the logarithm of real household disposable income per capita (*hdi*) of 10 Canadian provinces in the period 1926-2020. These provinces are: Alberta (AB), British Columbia (BC), Manitoba (MB), New Brunswick (NB), Newfoundland and Labrador (NL), Nova Scotia (NS), Ontario (ON), Prince Edward Island (PE), Quebec (QC) and Saskatchewan (SK). For NF, the data starts from 1949, which is the year when the province joined the Canadian Confederation. We exclude the 3 Canadian Territories for our analysis because the Northwest Territories and the Nunavut became 2 independent territories in 1999.

The main source of our data is Statistics Canada's CANSIM database. Analytically, we use household disposable income per capita from CANSIM Table: 36-10-0229-01[7] for the period 1926-2016 and from CANSIM Table: 36-10-0612-01[8] for the period 2016-2020. Finally, we divide it by the national Consumer Price Index (CPI) (CANSIM Table: 18-10-0004-01[9]) because the data for provincial CPI started at the end of 1978.

[7] Long-run provincial and territorial data
https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3610022901

[8] Adjusted household disposable income, Canada, provinces and territories, annual (x 1,000,000)
https://www150.statcan.gc.ca/t1/tbl1/en/cv.action?pid=3610061201

[9] Consumer Price Index, monthly, not seasonally adjusted
https://www150.statcan.gc.ca/t1/tbl1/en/cv.action?pid=1810000401
The data was monthly and we turn our data in annual frequency taking the average.

3.1. Beta convergence

We use the growth rate of *hdi* to analyze absolute convergence.

$$g_{i,t} = (hdi_{i,t} - hdi_{i,t-1})/hdi_{i,t-1} \quad (1)$$

Thus, we estimate absolute convergence for the below periods:

1. 1927-2020 (without NL)
2. 1927-1980 (without NL)
3. 1927-1949 (without NL)
4. 1950-2020 (without NL)
5. 1950-2020
6. 1981-2020
7. 1996-2020

3.2. Stochastic convergence

We use *lnhdi* and estimate stochastic convergence for periods:

1. 1926-2020 (without NL)
2. 1926-1980 (without NL)
3. 1949-2020
4. 1981-2020

4. Methodology

According to DeJuan and Tomljanovich (2005) both stochastic convergence and β-convergence are required for actual convergence to occur. Otherwise, not only shocks to regional real per capita income should be temporary, but also poorer regions should grow more than richer regions. However, sigma convergence has an indispensable role in this process too.

4.1. Sigma convergence (σ – convergence)

We analyze σ convergence using both standard deviations and coefficient of variation of the logarithm of real household disposable income per capita.

4.2. Beta convergence (β – convergence)

We examine beta convergence, both absolute and conditional, using panel estimates. Analytically we use i) Pooled OLS with robust standard errors, ii) fixed effects models with robust (FE) and jackknife standard errors (FE Jackknife), iii) random effects models (RE) with robust standard errors, and iv) OLS with Panel corrected standard errors (PCSE).

If β is statistically significant and negative, there is convergence. We run a two-sided t-test and after that we check the sign because we want to check for divergence too.

i) The pooled OLS assumes that there aren't heterogeneity and all the regions are homogenous. The equation for absolute is given in bellow sentence:

$$g_{i,t} = a + \beta lnhdi_{i,t-1} + e_{i,t} \qquad (2)$$

ii) The FE model takes into account the diversity between regions and in this way it tries to quantify the heterogeneity that exists in the system. We use the variable μ_i to estimate how different the regions are in a specific time. Hence, we have the *equation (3)* for absolute.

$$g_{i,t} = a + \beta lnhdi_{i,t-1} + \mu_i + e_{i,t} \tag{3}$$

where,

The constant term a, which is named "global constant", is common for every region. The $lnhdi_{i,t-1}$ is the first lag of the logarithm of real household disposable income pc. It is the indispensable variable that we care about, since if a significant deferent than zero and negative coefficient, it will imply that regions with lower income grow more than richer regions, so convergence will exist. The variable μ_i is the variable that causes different constant terms for every region. If μ_i is statistically insignificant, then the regions don't differ from each other and there isn't heterogeneity. So, in this case, with $\mu_i = 0$ we have a pooled OLS. For this reason, the μ_i is called fixed effect or individual effect.

The FE model can take into account, apart from heterogeneity between regions, the heterogeneity between years using a time-specific intercept (λ_t) to estimate how different a specific region is in different periods. In this paper, we will not examine this case.

It is important to be mentioned that Jackknife residuals improve the models since Jackknife variance estimators are superior than cluster-robust variance estimator and Eicker-Huber-White estimator in terms of full downward worst-case bias and worst- case Type I error (Hansen, 2022). Specifically, Jackknife method is a leave-one-out strategy of the estimation of a parameter (Nisbet, 2009). The Jackknife estimator is an unbiased estimator of variance according to McIntosh (2016). However, the same author refers that this estimator is slightly biased upward and don't fit well in some cases. Nevertheless, Miller (1974) mentions that Jackknife estimator has smaller bias than normal distribution.

Thus, FE Jackknife is an alternative method which leads to better results. The replications are based on clusters, i.e. here, on average, on 9 or 10 provinces.

iii) The RE model or otherwise error component model, like FE, takes into account the heterogeneity between regions. However, this heterogeneity appears inside the model in a different way, as we can see by *eq. (4)* for absolute convergence.

$$g_{i,t} = a + \beta lnhdi_{i,t-1} + w_{i,t} \tag{4}$$

where,

$$w_{i,t} = \varepsilon_i + v_{i,t}$$

iv) The PCSE is pooled OLS with different standard errors. According to James and Krieckhaus (2008) this method non only corrects for contemporaneous correlation, i.e correlation of the errors across countries but also panel heteroscedasticity, concluding in better inference from linear models. So, the estimations of our variable remain the same as those of Pooled OLS. However, their standard error changed and therefore the statistics values and the variables' significance.
In next section, the results are interpreted by FE Jackknife method.

4.2. Stochastic convergence

As we already have mentioned, in the case of stochastic convergence we use time series approaches. We follow Holmes et al. (2014) who use a pairwise econometric procedure (Pesaran, 2007).

To begin with, the definition of real per-capita income gaps/differences between states i and j is:

$$y_t = y_{ij,t} = lnhdi_{i,t} - lnhdi_{j,t} \tag{5}$$

It is important to mention, here, that one of the advantages of the pairwise approach is that the order of substruction doesn't matter and doesn't change the result (Holmes et al., 2014). Moreover, in contrast to other approaches where benchmarks such as country averages or some regions need to be selected, this method doesn't require benchmarks, so it solves the problem of any arbitrariness in this selection (Arvanitopoulos et al., 2019; Pesaran, 2007).

As we have already mentioned stochastic convergence exists whether random shocks to a regional economy don't persist over time or differently when the long-term forecasts of

$$\lim_{n \to \infty} E\left(y_{ij,t+n}/I_t\right) = 0 \tag{6}$$

where,

I_t = all information available at time t

tends to zero as the forecasting horizon approaches infinity or, otherwise y_t is a stationary process (Nahar and Inder, 2002). Holmes et al. (2014)[10] refer:

> "This weaker form of convergence is consistent with Definition 2.2 in Bernard and Durlauf (1995), where long-run income forecasts are proportional. This means that the two series contain a common stochastic trend insofar as they share the same determinants in the long run, but in the long run they respond to permanent shocks with different weights."

However, Nahar and Inder (2002) show that stationarity is not a necessary condition for the existence of convergence.

Alternative, stochastic convergence there is if $lnhdi_{i,t}$ and $lnhdi_{j,t}$ are cointegrated. Holmes et al. (2014)[11] mention:

> "Definition 2.1 in Bernard and Durlauf (1995). According to this definition, for two states to converge, their incomes must be cointegrated, and the cointegrating vector must be equal to [1, -1]. This means that in the long run the incomes of the two states contain a common stochastic trend (i.e., they share the same determinants) and respond to permanent shocks with the same weights."

In this paper, following the pairwise approach, we use unit root tests, a stationarity test (KPSS), and cointegration tests to confirm or not the stochastic convergence. Analytically, we use:

i) Augmented Dickey and Fuller unit root test (ADF)
ii) Kwiatkowski, Phillips, Schmidt, and Shin stationarity test (KPSS)
iii) Zivot-Andrews unit root test (ZA)

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[10] Holmes et al. (2014), "A note on the extent of U.S. regional income convergence", page 1638.
[11] Holmes et al. (2014), "A note on the extent of U.S. regional income convergence", page 1639.

iv) Elliott et al. (1996) unit root tests (ERS)

v) Kapetanios et al. (2003) unit root test (KSS)

vi) Sollis (2009) unit root test (AESTAR)

vii) Bootstrap unit-root test for a random walk with drift (bootstrapped)

viii) Johansen cointegration between two logarithms personal income per capita.

i) *Firstly*, a common unit root test is the Augmented Dickey Fuller (ADF) test. In *eq. (7)* is represented the rudimentary model which is estimated. The intercept (μ) and/or trend (λt) can be omitted. In our case trend is omitted.

$$\Delta y_t = \mu + \lambda t + \psi y_{t-1} + \sum_{i=1}^{p} a_i \Delta y_{t-i} + u_t \qquad (7)$$

where,

$\sum_{i=1}^{p} a_1 \Delta y_{t-1}$ correct possible autocorrelation (A/C).

p = the number of lags that are defined by information criteria, i.e. AIC, SBIC, HQIC. In this case, we use SBIC.

We reject or not the non-stationarity using the below hypotheses:

$$H_0: \psi = 0, \ \ i.e. \ there \ is \ a \ unit \ root$$

$$H_1: \psi < 0, \ \ i.e. \ there \ isn't \ a \ unit \ root$$

ii) *However*, the ADF unit root test has low power when the process is stationary but the unit root is close to the boundary. For this reason, the Kwiatkowski, Phillips, Schmidt, and Shin (KPSS) stationarity test is used. This stationarity test has a different null hypothesis from the previous unit root test.

$$H_0: There\ isn't\ a\ unit\ root$$

$$H_1: There\ is\ a\ unit\ root$$

Unfortunately, the previous tests don't work well if there are structural breaks in the variables (Coulombe, 2000). Thus, we use a breakpoint unit root test taking into consideration possible breaks.

iii) *Thirdly*, a breakpoint unit root test is Zivot-Andrews (ZA) test which allows the break date to be selected endogenously (Herranz et al., 2017; Narayan and Smyth, 2005) using *eq. (8)*:

$$\Delta y_t = \mu + \lambda t + \psi y_{t-1} + \sum_{i=1}^{p} a_i \Delta y_{t-i} + b\tau_t(t_{used}) + u_t \tag{8}$$

where,

$t_{used} = {}^{T_b}/_{T}$,

T_b = the breakpoints

T= Observation

$\tau_t(t_{used})$ = allows for the break

1. in the level

$$\tau_t(t_{used}) = \begin{cases} 1 & t > t_{used} \\ 0 & otherwise \end{cases}$$

2. in the deterministic trend

$$\tau_t(t_{used}) = \begin{cases} t - t_{used} & t > t_{used} \\ 0 & otherwise \end{cases}$$

We run the ZA unit tests using breaks in both level and trend. ZA unit root tests, also, use the same hypotheses as the ADF test:

$$H_0: There\ is\ a\ unit\ root\ with\ a\ break$$

$$H_1: There\ isn't\ a\ unit\ root\ with\ a\ break$$

iv) *Furthermore*, Elliott et al. (1996) unit root is used (ERS) which is an ADF test on Generalized Least Square (GLS) demeaned data (Lopez, 2003). Analytically, ERS or ADF-GLS is a two-step process. In the first step, the time series is modified to GLS detrended data, i.e. the mean GLS remove from the variable, and in the second step an ADF test is used to identify the existence of the unit root. This technique seems to improve the power of ADF significantly (Otero and Baum, 2017; Wu, 2010; Cottrell, 2021; Vougas, 2007; Elliott et al., 1992).

$$\Delta y_t{}^d = \psi y_{t-1}{}^d + \sum_{i=1}^{p} a_i \Delta y_{t-i}{}^d + u_t \quad (9)$$

where,

$y_t{}^d$ = GLS demeaned g_t [12]

[12] Its calculation depends on the existence on not of a trend in the model.

The below hypotheses are similar to ADF unit root tests.

$$H_0: \psi = 0, \ \ i.e. \ there\ is\ a\ unit\ root$$

$$H_1: \psi < 0, \ \ i.e. \ there\ isn't\ a\ unit\ root$$

v) *In addition*, the Kapetanios et al. (2003) (KSS) unit root test with a null hypothesis, i.e., the processes are highly persistent and the alternative of a globally stationary Exponential Smooth Transition Autoregressive process (ESTAR model), could be more consistent and more powerful than the ADF (Kapetanios et al., 2003; Arvanitopoulos et al., 2019). This nonlinear unit root is written as follows:

$$\Delta y_t = \mu + \psi y_{t-1}{}^3 + \sum_{i=1}^{p} a_i \Delta y_{t-i} + u_t \qquad (10)$$[13]

The below hypotheses are similar to ADF unit root tests too.

$$H_0: \psi = 0, \ \ i.e. \ there\ is\ a\ unit\ root$$

$$H_1: \psi < 0, \ \ i.e. \ there\ isn't\ a\ unit\ root$$

vi) Moreover, we use another unit root test, defined by Sollis (2009), which name is AESTAR unit root, namely the nonlinear and asymmetric unit root test, which allows for symmetric or asymmetric stationary ESTAR nonlinearity under the alternative. The test, without intercept and deterministic trend, is represented by *eq. (11)*.

$$\Delta y_t = \psi y_{t-1}{}^3 + \delta y_{t-1}{}^4 + \sum_{i=1}^{p} a_i \Delta y_{t-i} + u_t \qquad (11)$$[14]

[13] The critical values with intercept without trend are -1.92, -2.22, and -2.82 at the 10%, 5% and 1% level respectively as they are mentioned by Kapetanios et al. (2003).
[14] The critical values without intercept without trend are 3.577, 4.464 and 6.781 at the 10%, 5%, and 1% level, respectively for T=50 and similarly 3.537, 4.365 and 6.272 for T=100 as they are mentioned by Sollis (2009).

with the null hypothesis:

$$H_0: \psi = \delta = 0, \;\; i.e. \; there \; is \; a \; unit \; root$$

If the unit root hypothesis has been rejected against the alternative of stationary symmetric or asymmetric ESTAR nonlinearity, then can be tested if there is symmetric ($\delta = 0$) or asymmetric ($\delta \neq 0$) ESTAR nonlinearity using a t- test.

vii) The last unit root is a bootstrap unit root test for a random walk with drift (bootstrapped). The below equations represent the unrestricted (*eq. 12*) and restricted models (*eq. 13*) assuming that $\psi = 0$.

$$\Delta y_t = \mu + \psi y_{t-1} + \sum_{i=1}^{p} a_i \Delta y_{t-i} + u_t \quad (12)$$

$$\Delta y_t = \mu + \sum_{i=1}^{p} a_i \Delta y_{t-i} + u_t \quad (13)$$

Then, a bootstrap sample of estimated residuals ($\widehat{u_t}$) is randomly drawled, and bootstrapped demeaned residuals ${u_t}^b$ are obtained. Next, the bootstrap samples (${y_t}^b$) are generated through

$${y_t}^b = y_0 + \sum_{i=1}^{T} {u_{t-1}}^b \quad (14)$$

And for each bootstrap sample, ${y_t}^b$, an ADF unit root is run (Dorta and Sanchez, 2021; Holmes et al., 2011).

$$\Delta {y_t}^b = \mu + \psi {y_{t-1}}^b + \sum_{i=1}^{p} a_i \Delta {y_{t-i}}^b + {u_t}^b \quad (15)$$

It is important to mention here, that the appropriate lag length is selected based on SBIC in ERS unit root test and after that we use the same number of lags in the other unit root tests.

viii) *Finally*, we use the Johansen test. To use this test, we need to use a VECM model as *eq (16)*.

$$\Delta pi_t = \Pi lnhdi_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \Delta lnhdi_{t-i} + u_t \quad (16)$$

where,

$\Pi = (\sum_{i=1}^{k} \beta_i) - I_m$, i.e. Π is a long-run coefficient matrix

$\Gamma_i = (\sum_{j=1}^{i} \beta_j) - I_m$, i.e. Γ is a short-run coefficient matrix

k is the number of lags in the VAR model which are selected based on SBIC

β is the number of coefficients in the VAR model and

m is the number of endogenous variables

The rank of matrix Π gives the number of long-run relationships between m variables.

$$rank(\Pi) = r, \ \ r \leq m - 1 \quad (17)$$

Finding the eigenvalues (λ) of matrix Π, we can use two formulas/ tests, namely, λ_{trace} and $\lambda_{\max}$ tests.

Johansen test is a sequentially tests and the previous formulas use the below hypotheses for λ_{trace} case[15].

[15] The critical values for (λ_{trace}) are 12.53 for null hypothesis r=0 and 3.84 for r=1 at the 5% while there are 10.47 for null hypothesis r=0 and 2.86 for r=1 at the 10%.
The critical values for (λ_{max}) are 11.44 for null hypothesis r=0 and 3.84 for r=1 at the 5% while there are 9.52 for null hypothesis r=0 and 2.86 for r=1 at the 10%.
https://web.pdx.edu/~crkl/ec571/ec571-5.htm#table3

$$H_0: r = 0 \qquad \text{vs} \qquad H_1: 0 < r \leq m$$

If we reject H_0 we will continue with the next hypotheses, otherwise, we stop here and conclude that although our variables are non-stationary, there isn't a long-run relationship.

$$H_0: r = 1 \qquad \text{vs} \qquad H_1: 1 < r \leq m$$

If we reject H_0 we will continue with the next hypotheses, otherwise, we stop here and conclude that there is 1 long-run relationship between our m variables.

$$H_0: r = 2 \qquad \text{vs} \qquad H_1: 2 < r \leq m$$

If we reject H_0 we will continue with the next hypotheses, otherwise, we stop here and conclude that there are 2 long-run relationships between our m variables.

....

$$H_0: r = m - 1 \qquad \text{vs} \qquad H_1: r = m$$

If we don't reject H_0 we conclude that there are m-1 long-run relationships between m variables. Otherwise, we conclude that our variables are eventually stationary.

In the case of $\lambda_{\max}$, the null hypothesis is that the number of cointegrating vectors is r against an alternative of r+1. However, we focus on λ_{trace} since we use a pairwise approach.

In our case Johansen approach became much easier since we cointegrate pairs, so, m = 2. Thus, we look at whether there is cointegration between $lnhdi_{it}$ and $lnhdi_{jt}$ or between $lnhdi_{jt}$ and $lnhdi_{it}$. The order doesn't matter, it is the same. There are $N(N - 1)/2$ possible pairs where N is the number of provinces (Holmes et al., 2014). If we find, for the majority of pairs, cointegration or differently, a long-run relationship, or in other words, we reject the null hypothesis, then there is stochastic convergence.

Beylunioğlu et al. (2020) based on Pesaran (2007) mention that if the rate of rejection of non-stationarity over $N(N-1)/2$ tests is no higher than the employed significant level, i.e. 0.05 then there is evidence in favor of the validity of divergence whereas if the proportion of rejection namely the acceptance of stationarity is higher than this level then there is evidence against divergence. However, in this paper, we support stochastic convergence if the majority of provinces are cointegrated if the majority of income differences is stationary (i.e. a percentage higher or equal to 50%).

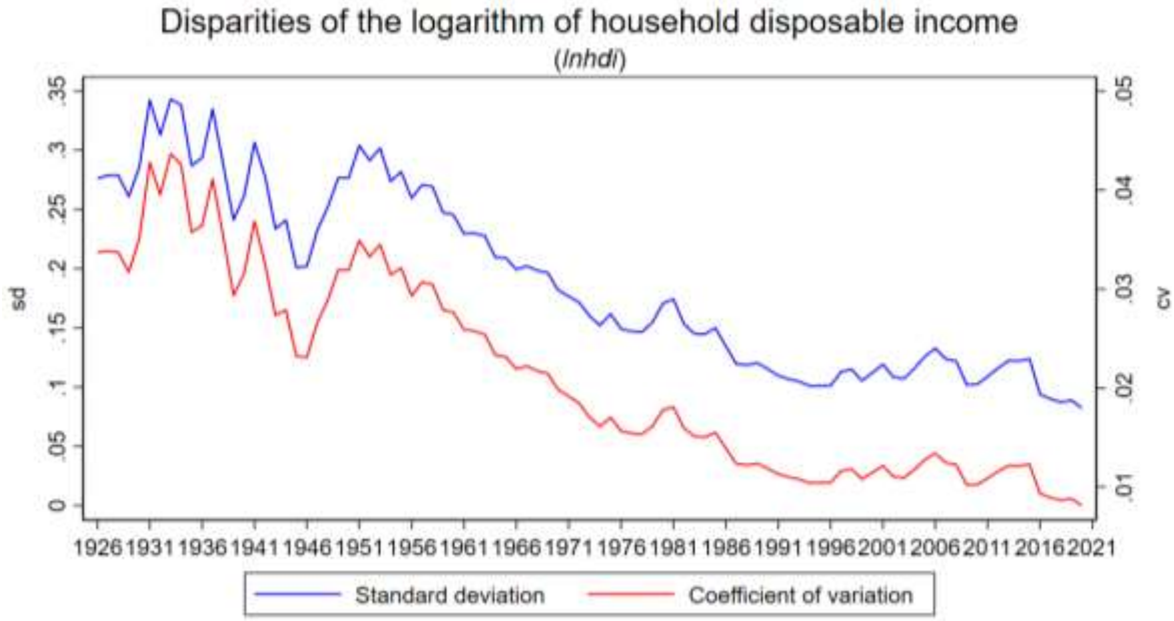
5. Empirical results

We use the 5% significance level in this analysis.

5.1. Sigma convergence

To begin with, we capture the disparity over the years using the standard deviation and the coefficient of variation (σ – convergence) which are represented in below figure (*Fig.2*). It is important to be mentioned that before 1949 these measures show the disparity for 9 provinces while from 1949 and after they show it for all 10 provinces, including Newfoundland and Labrador. Firstly, it is obvious that the two measures agree with each other. Secondly, there are fluctuations, especially in the period before 1950 probably because of the World War II since the year 1949 the disparities reach a low point at around 0.2 (sd) and below 0.15 (cv). After 1950, it seems that the disparities steadily decreased until 1980, probably because of the oil shock this period since oil is a powerful source of energy in Canada and can be found in Canadian provinces like Alberta, Saskatchewan, and Newfoundland and Labrador. In the next years there is a slight tiny reduction and disparities tend to be stabilized. However, after 1996 there are fluctuations around 0.2 (sd) and 0.1 (cv). Finally, in the last years of our sample the disparities dropped.

***Figure 2**: Standard deviation and coefficient of variation of the logarithm of household disposable income (lnhdi)*



5.2. Absolute convergence

It is important, first, to look at our variable in levels among provinces for the initial and final years, so possible chances could be observed.

It is clear that there are changes in the logarithm of our variable in level over the two years. First of all, the levels of *lnhdi* are higher for all provinces in 2020. Secondly, in 1926 Alberta and British Columbia had the highest growth rate, and Manitoba, Ontario, and Saskatchewan followed next while New Brunswick and Nova Scotia, and Prince Edward Island had the lowest values. In contrast, in 2020, although Alberta and British Columbia still have the highest income and similarly, New Brunswick and Prince Edward Island still have the lowest ones, Newfoundland and Labrador takes the place of Manitoba, which has one of the lowest incomes in 2020. Nova Scotia and Quebec have the second ones while Newfoundland and Labrador, Ontario, and Saskatchewan are third ones.

Regarding growth rates from the initial to the final period, i.e. the 1926-2020 period ($lnhdi_{i,2020} - lnhdi_{i,1926}$), it is observed that New Brunswick, Nova Scotia, and Prince Edward Island have the highest changes while Newfoundland and Labrador and Quebec are followed next. The lowest growth rates are noticed in British Columbia, Manitoba, and Ontario.

***Figure 3**: Logarithm of household disposable income in the initial year (lnhdi)*

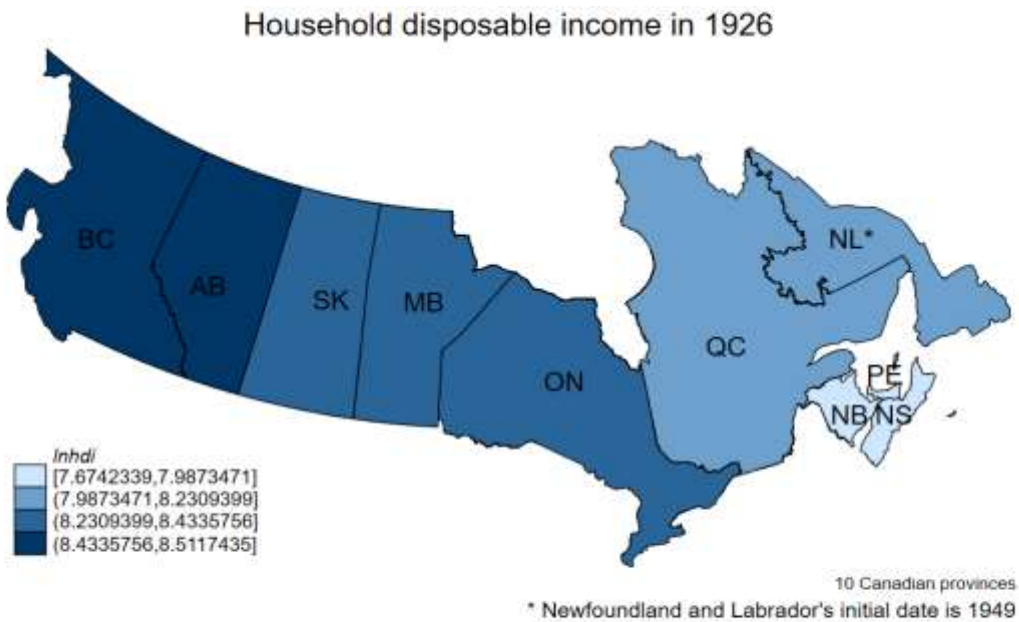
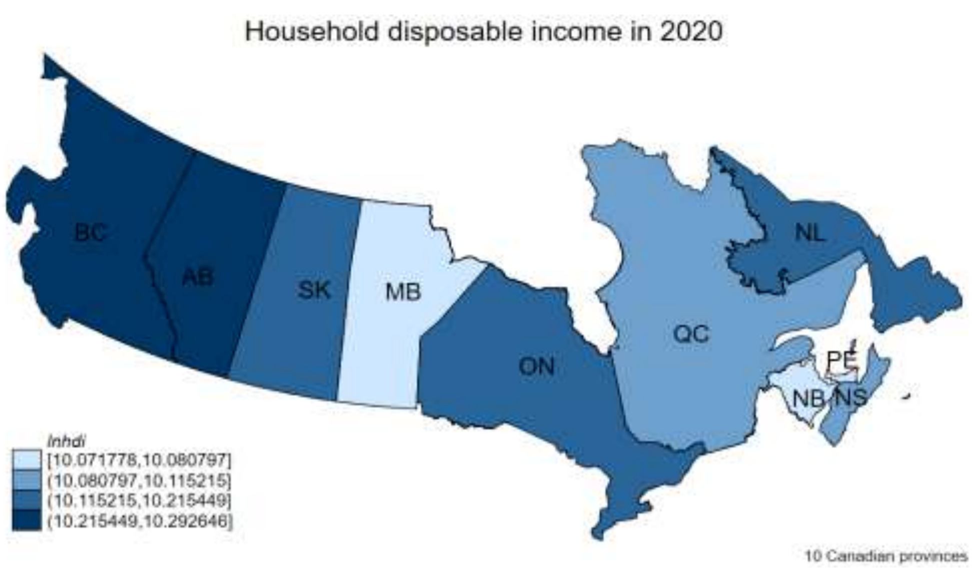


***Figure 4**: Logarithm of household disposable income in the final year (lnhdi)*



As can be noticed from *Table 2*, it seems that there is unconditional convergence at the 5% only for the samples 1927-2020 (except for the PCSE method) and 1950-2020 (all provinces) since the coefficient of $lnhdi_{i,t-1}$ is statistically significant, negative and around -0.013 and -0.018 respectively.

***Table 2**: Absolute convergence for the logarithm of household disposable income (lnhdi)*

Models / Samples	**Pooled OLS**	**FE**	**FE Jackknife**	**RE**	**Hausman test**	**PCSE**
1927-2020 (No NL)	-0.0136478	-0.0134983	-0.0134983	-0.0136478		-0.0136478
	(0.0057307)**	(0.004151)**	(0.0042714)**	(0.0040439)***	0.8819	(0.0071867)*
1927-1980 (No NL)	-0.0100848	-0.0089425	-0.0089425	-0.0100848		-0.0100848
	(0.0100495)	(0.010165)	(0.0107818)	(0.0089722)	0.7629	(0.0148809)
1927-1949 (No NL)	-0.0360725	-0.0500618	-0.0500618	-0.0360725		-0.0360725
	(0.023586)	(0.0240245)*	(0.0294068)	(0.0200785)*	0.5148	(0.0400296)
1950-2020 (No NL)	-0.004008	0.0013649	0.0013649	-0.004008		-0.004008
	(0.0091398)	(0.0067867)	(0.0067981)	(0.0053922)	0.3145	(0.0140979)
1950-2020	-0.0183333	-0.0181742	-0.0181742	-0.0183333		-0.0183333
	(0.005111)***	(0.0032468)***	(0.0032648)***	(0.0029224)***	0.9008	(0.0062483)***
1981-2020	-0.0051181	0.0010327	0.0010327	-0.0051181		-0.0051181
	(0.0078384)	(0.0051375)	(0.0050533)	(0.0041616)	0.168	(0.0129648)
1996-2020	-0.0116917	-0.0160471	-0.0160471	-0.0116917		-0.0116917
	(0.0110537)	(0.0115289)	(0.011739)	(0.006939)*	0.5227	(0.0174135)

Notes:
Coefficients of the previous *lnhdi* are represented in the above table. A negative and statistically significant coefficient indicates absolute convergence.
Robust standard errors in parentheses () except for the FE Jackknife (Jackknife standard errors) and PCSE (panel corrected standard errors).
Dependent variable: growth rate of *lnhdi.*
Statistically significant *: at the 10% **: at the 5% ***: at the 1% (two-sided t test).

In *Fig. 5* and *Fig. 6*, the relevant with absolute convergence slopes are represented. As someone can observe the slopes are slightly negative for both figures, namely for the periods 1927-2020 and 1950-2020 which absolute convergence occurred, according to FE Jackknife (*Table 2*).

***Figure 5**: Scatter plot with linear regression fitted line, period 1927-2020*

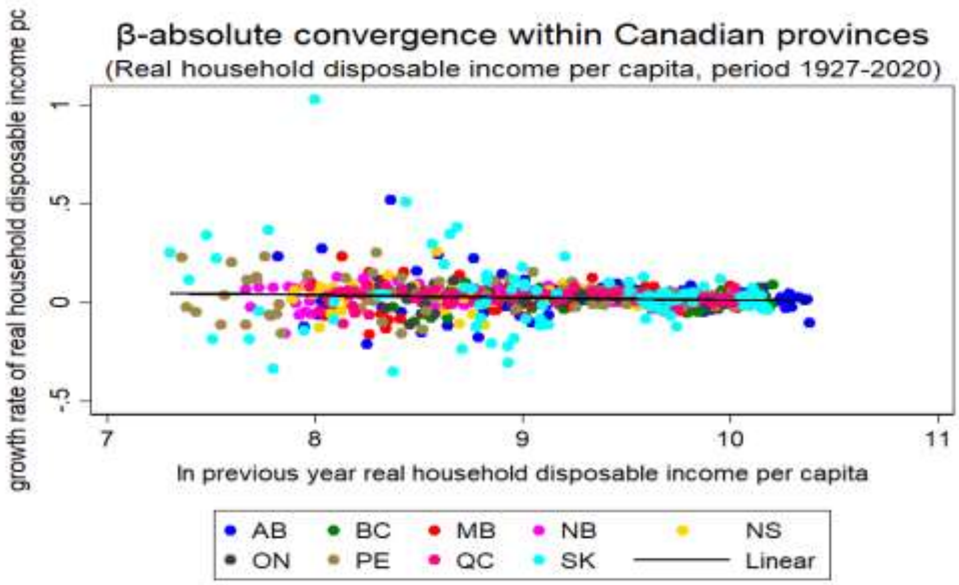
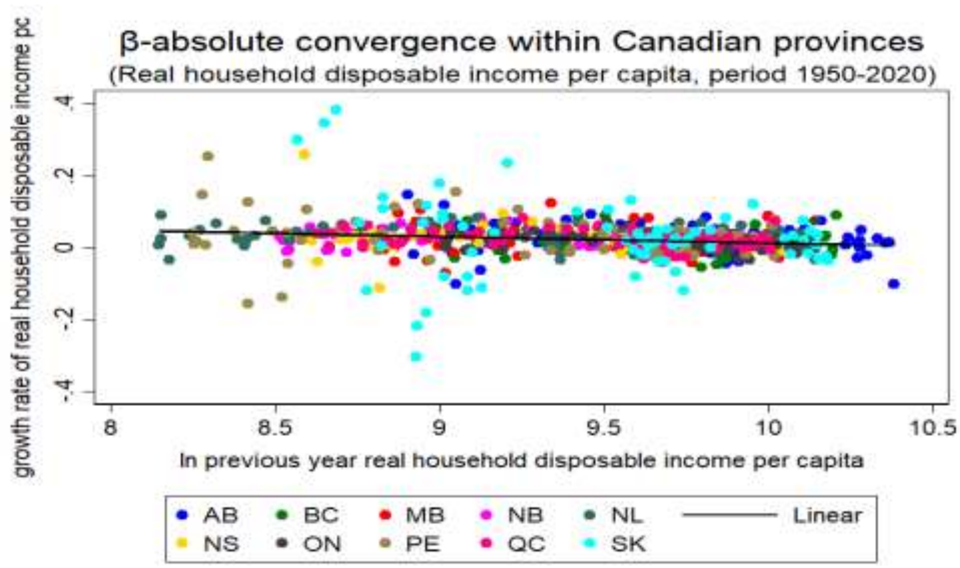


***Figure 6**: Scatter plot with linear regression fitted line, period 1950-2020*



5.3. Stochastic convergence

According to ADF, KPSS, ERS, and bootstrapped unit root tests there is no stochastic convergence for the majority of provinces. The other unit root tests, usually, show higher rejections than the previous one. However, the only case that someone could support that there is stochastic convergence is for the period 1926-2020 taking into account the ZA test which shows 23/36 stationary pairs (about 63.9% of pairs). Nevertheless, we can't accept the stationarity hypothesis. In all other cases, the percentage is below 43% (AESTAR test for the period 1949-2020). On the other hand, analyzing the other aspect of stochastic convergence, namely the cointegration among provincial income, it is obvious that for the first two samples there is no stochastic convergence (*Table 3*). According to the Johansen tests (λ_{trace}), convergence occurred during the period 1949-2020 at the 5% (60% of pairs) at the 10% (around 53.3%) while for the period 1981-2020 these percentages decreased to around 51.1% and 40% respectively. However, it is mentioned that in the 1926-2020 period there is convergence among rich provinces, Alberta, British Columbia, and Ontario (based on *hdi* in 1926) and among poor ones (New Brunswick, Nova Scotia, Prince Edward Island) but not in middle-income ones (Manitoba, Saskatchewan, Quebec) or among provinces of different groups. On the other, in the 1949-2020 period there is regional stochastic convergence among different groups except for rich-middle income pairs but not as a group. In the 1981-2020 period, only rich provinces are cointegrated with each other and the half of the possible pairs among rich and middle-income provinces are cointegrated too.

Thus, taking into consideration Johansen at the statistically significant level of 10% we conclude that there is no stochastic for the majority of provinces for all periods[16] except for the 3rd one since not only poorer provinces are cointegrated with each other but also

[16] However, in the 1981-2020 period we can say that there is stochastic convergence for the richer provinces, i.e. AB, BC, and ON. For the poorest provinces in 1981, namely, NB, NL, and PE only NL are cointegrated with other poor provinces. In the middle-income provinces this year there is no stochastic convergence since of 6 pairs only 1 is cointegrated. Finally, it seems that the half of possible pairs among rich with middle-income provinces are cointegrated.

poorer provinces are cointegrated with richer ones[17]. Johansen test (λ_{max}) gives similar results (*Table 4*).

***Table 3**: Unit root tests and stationarity test for the logarithm of household disposable income (lnhdi)*

Tests / Samples	ADF	KPSS	ZA	ERS	KSS	AESTAR	bootstrapped
1926-2020 (No NL)	6/36	2/36	23/36	13/36	12/36	10/36	6/36
1926-1980 (No NL)	3/36	7/36	14/36	9/36	8/36	2/36	5/36
1949-2020	3/45	4/45	10/45	2/45	16/45	19/45	4/45
1981-2020	3/45	5/45	10/45	0/45	10/45	5/45	6/45

Notes:
Pairwise methods.
Unit root/stationarity tests for income differences among 2 provinces.
The appropriate lag length is selected based on SBIC in ERS unit root test.
There are 45 pairs for the datasets with all 10 provinces while 36 for the datasets without NL (9 provinces).
The numbers indicate the number of tests that the null hypothesis about non-stationarity (stationarity) has been rejected (hasn't been rejected) at the 5% / possible pairs.
There is stochastic convergence if this rate is higher or equal to 50%.

[17] The pairs at the 10% are: AB-NL, AB-ON, AB-PE, BC-NB, BC-NL, BC-PE, MB-NB, MB-NL, MB-NS, MB-PE, NB-NL, NB-QC, NL-NS, NL-ON, NL-QC, NS-ON, NS-PE, ON-PE, ON-QC, PE-QC, PE-SK. The poorest provinces in 1949, i.e NB, NL and PE are cointegrated with each other. The richest ones in 1949 (and 2020 too), namely AB, BC, and ON, don't cointegrate with each other apart from the pair AB-ON. Finally, the rest provinces, the middle-income provinces, except SK, are cointegrated with all the poorest provinces and with some other middle-income provinces but not with the richer ones except for pairs BC-NB and ON-QC. The distribution of the cointegrated pairs shows that there is convergence.

Table 4: Johansen test for the logarithm of household disposable income (lnhdi)

Tests / Samples	Johansen 5%	Johansen 10%	Johansen max 5%	Johansen max 10%
1926-2020 (No NL)	6/36	11/36	3/36	9/36
1926-1980 (No NL)	7/36	4/36	6/36	4/36
1949-2020	27/45	24/45	28/45	24/45
1981-2020	23/45	18/45	24/45	19/45

Notes:
Johansen cointegration test for *lnhdi* between 2 provinces.
The appropriate lag length is selected based on SBIC.
There are 45 pairs for the datasets with all 10 provinces while 36 for the datasets without NL (9 provinces).
The numbers indicate the number of tests that there is cointegration at the 5% and the 10% / possible pairs.
There is stochastic convergence if this rate is higher or equal to 50%.
The critical values for (λ_{trace}) are 12.53 for null hypothesis r=0 and 3.84 for r=1 at the 5% while there are 10.47 for null hypothesis r=0 and 2.86 for r=1 at the 10%.
The critical values for (λ_{max}) are 11.44 for null hypothesis r=0 and 3.84 for r=1 at the 5% while there are 9.52 for null hypothesis r=0 and 2.86 for r=1 at the 10%.

Finally, we examine if the Euclidean distance (*D*) between provinces affects the long-run relationship of *lnhdi*, using a linear probability model, which is estimated by OLS regression (*eq.18*) with dependent variable a Dummy ($C_{i,j}$) which takes the value 1 when there is Johansen cointegration (λ_{trace}) at the 10% and 0 otherwise.

$$C_{i,j} = \begin{cases} 1 & cointegration \\ 0 & otherwise \end{cases}$$

$$C_{i,j} = a_0 + a_1 \left| y_{ij,initial\ year} \right| + a_2 lnD + error_t \qquad (18)$$

Table 5: OLS regression for cointegration determinants (Distance among provinces) (lnhdi)

Models / Samples	OLS Robust	OLS Jackknife	OLS Bootstrap
1926-2020 (No NL)	-0.1411486	-0.1411486	-0.1411486
	(0.0924315)	(0.107669)	(0.1050127)
1926-1980 (No NL)	0.0049723	0.0049723	0.0049723
	(0.0544855)	(0.0581687)	(0.064292)
1949-2020	-0.2449221	-0.2449221	-0.2449221
	(0.0608537)***	(0.0664049)***	(0.0664127)***
1981-2020	-0.0344011	-0.0344011	-0.0344011
	(0.1076082)	(0.1213498)	(0.1235988)

Notes:
Coefficients of *lnD* are represented in the above table.
Relative standard errors in parentheses ().
Dependent variable: Dummy $C_{i,j}$.
Statistically significant *: at the 10% **: at the 5% ***: at the 1%.

In *Table 5*, the results are represented. It seems that distance has a negative effect at the 5% only for the period 1949-2020 (all methods). That suggests that the probability that there is cointegration increases by about 0.245% when the distance is decreased by 1% after 1949[18].

[18] If taking into consideration the Johansen test (λ_{max}) at the 10%, distance will affect negatively the cointegration possibility in the periods 1926-2020 and 1949-2020. The results for the latter period are the same since the max and trace tests end up with exactly the same conclusions.

6. Robustness analysis

6.1. Alternative method for stochastic convergence

Panel unit root and stationarity tests in differences of the logarithm of household disposable income among provinces are used to capture stochastic convergence. Although the results depend on the test, the main conclusion was that there is no pairwise convergence. Further details can be found in *Appendix A*.

6.2. Alternative measures for real household disposable income per capita

Alternative measures, also, are used:

i) the logarithm of real household disposable income per capita which is divided by provincial CPI for the dataset after 1980 (*hdip*)[19]

ii) the logarithm of real household disposable income per capita as a given variable (*hdir*)[20]

iii) the logarithm of real household income per capita (*hi*)[21]

iv) the logarithm of real personal disposable income per capita (*pdi*)[22]

v) the logarithm of real personal income per capita (*pi*)[23]

Overall, the main results about sigma convergence are the same, as *Fig. 7* and *Fig. 8* show.

[19] Further details can be found in *Appendix B*.
[20] Further details can be found in *Appendix C*.
[21] Further details can be found in *Appendix D*.
[22] Further details can be found in *Appendix E*.
[23] Further details can be found in *Appendix F*.

Figure 7: Standard deviation of all different measures

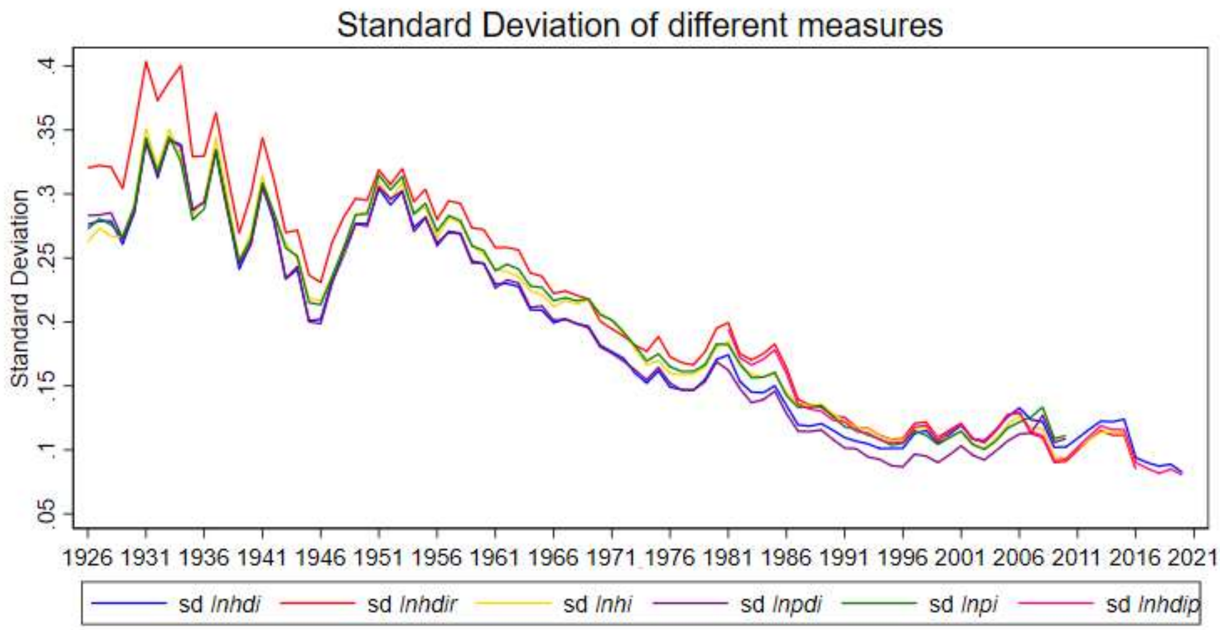
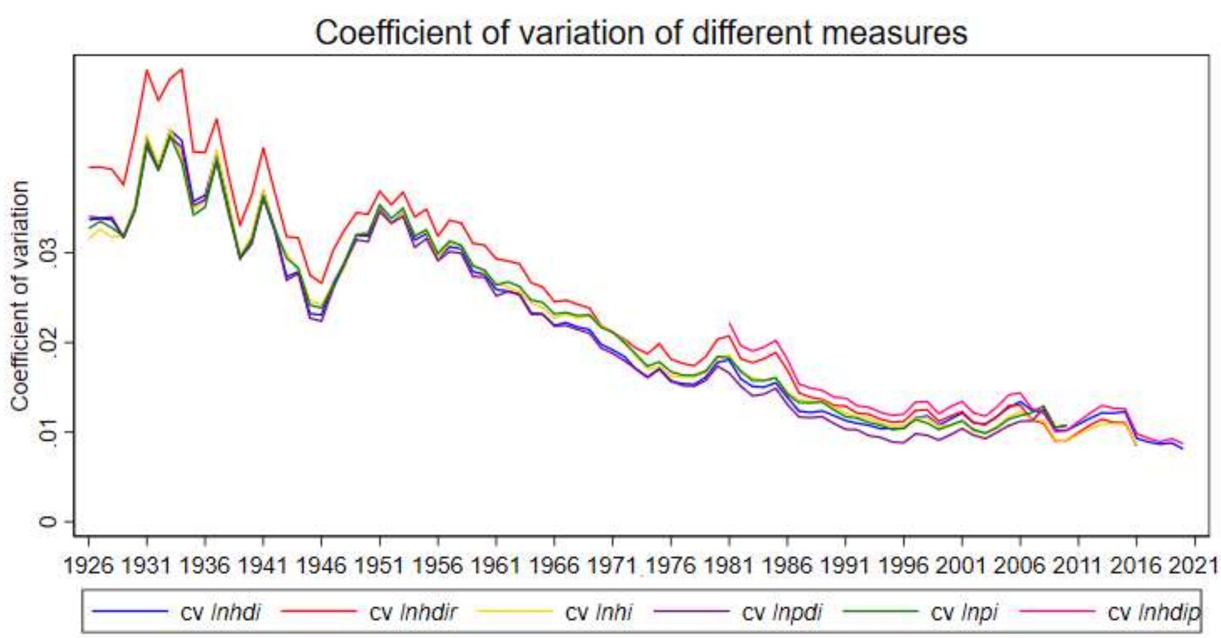


Figure 8: Coefficient of variation of all different measures



Moreover, *lnhdip* ends up in similar conclusions. There is neither absolute convergence in common datasets nor conditional. These coefficients are higher though. Stochastic convergence is absent too. However, the distance in this variable isn't important for cointegration. Furthermore, the rest variables indicate that there is absolute convergence in the whole period and subperiods 1950-2016/2010 with and without NL, in contrast to initial variable where the ignorance of NL can lead to lack of convergence. Except for the fact that the provinces converge in one extra dataset, the coefficients of these measures in some cases are higher (*lnhi*, *lnpdi*) or lower (*lnhdir*, *lnpi*) than the initial ones.

In addition, the results of stochastic convergence using (panel) unit root tests are relative similar. So, we focus on cointegration tests (λ_{trace}). *lnhdi* agrees with *lnhdip* in the lack of stochastic convergence in the period 1981-2016 and *lnhdi* agrees with *lnhdir* too. However, in the case of *lnhi*, convergence occurs for the periods 1949-2016 and 1981-2016 for 57%-69% and 57%-65% of pairs at the 5% and 10% respectively. *lnpdi* and *lnpi* confirm, also, stochastic convergence in 1949-2010 for 60%-65% of pairs and 88%-80% respectively (at the 5%-10%). Finally, about the role of distance in the possibility of a long-run relationship, it is positive in the cases of *lnpi* and *lnhi* for the period 1926-1980. It is negative in the cases of *lnhi* for the period 1949-2016 and *lnhdir* for the periods 1926-2016 and 1949-2016. The coefficients of *lnhdir* and *lnhi* for the dataset 1949-2016 are lower than those on *lnhdi* in 1949-2020. Last, the distance isn't important at all in the case of *lnpi*.

***Table 6**: Cointegrated pairs based on income groups in the 1949-Final year period*

Variable/ Income groups	*lnhdi*	*lnhdir*	*lnhi*	*lnpdi*	*lnpi*
Rich (R)	1/3	2/3	5 /6	4/6	9/10
Middle-income (M)	1/6	5/10	2/6	3/6	3/3
Poor (P)	2/3	0/1	1/1	0/1	1/1
RM	1/12	6/15	9/16	9/16	11/15
RP	9/9	6/6	8/8	7/8	7/10
PM	10/12	9/10	6/8	4/8	5/6

Notes:
Sample: 1949- final year, i.e. 2020 for *lnhdi*, 2016 for *lnhdir*, *lnhi* and 2010 for *lnpdi*, *lnpi*.
Johansen λ_{trace} at the 10%.
The income groups were defined based on the variable's value in 1949.
In cells: cointegrated pairs / possible pairs.
The appropriate lag length is selected based on SBIC.

Table 7: Cointegrated pairs based on income groups in the 1981-Final year period

Variable/ Income groups	*lnhdi*	*lnhdir*	*lnhi*	*lnhdip*
Rich (R)	3/3	1/3	2/3	2/3
Middle-income (M)	1/6	3/3	7/10	1/3
Poor (P)	2/3	4/6	1/1	3/6
RM	6/12	5/12	10/15	6/9
RP	3/9	3/12	2/6	5/12
PM	3/12	3/9	4/10	4/12

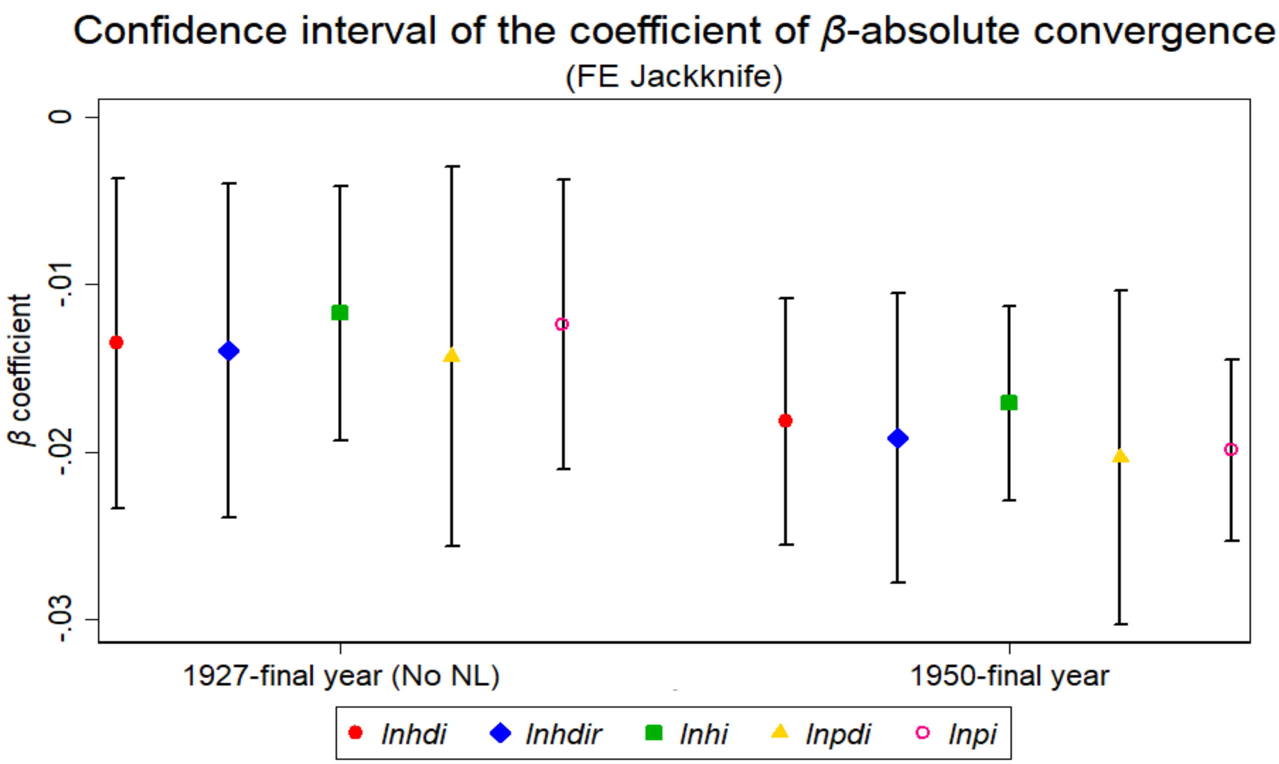
Notes:
Sample: 1981- final year, i.e. 2020 for *lnhdi*, *lnhdip*, 2016 for *lnhdir*, *lnhi*
Johansen λ_{trace} at the 10%.
The income groups were defined based on the variable's value in 1981.
In cells: cointegrated pairs / possible pairs
The appropriate lag length is selected based on SBIC

Taking a more thorough look at stochastic convergence, it is clear that for the whole period while all variables agree that there is no stochastic convergence (according to Johansen λ_{trace}) only *lnhdi* and *lnpi* report that there is convergence among rich provinces. The first one supports it for poor income groups too. As it is mentioned before, there is convergence among provinces in 1949-2020. However, the richer provinces don't converge according to *lnhdi* and *lnhi* while they are cointegrated with each other according to other variables. So do the middle-income ones. Regarding to the poorest economies, all variables apart from *lnhdir* and *lnpdi* show convergence. Moreover, the rich-poor group and poor-middle-income group tend to converge for all variables whereas the rich-middle-income group only for *lnhi*, *lnpdi* and *lnpi*. Finally, in the 1981-2020 period, for the initial variable, the rich provinces are cointegrated with each other and poor ones too. Moreover, half of the possible pairs among rich with middle-income provinces are cointegrated. Similarly for the variable *hdip*. On the other hand, *lnhdir* finds stochastic convergence in middle-income provinces and poor ones but not in rich ones or among groups. On the contrary, *lnhi* indicates that poor provinces, rich ones and middle-income ones are cointegrated as separated groups but not together, except for the majority of rich with middle-income pairs. *Table 6* and *Table 7* summarize the above information.

It is observed that the results depend on the measure of income and the methodologies. Sigma and absolute convergence seem to be the most robust in the variety of measures. However, the conclusions about stochastic convergence can differ significantly and therefore the role of distance.

In *Fig.9* the confidence interval of the coefficient of β-convergence is represented for 2 datasets, namely, the 1927-final year without NL and 1950-final year, where the final year is 2020 for *lnhdi*, 2016 for *lnhdir* and *lnhi* and 2010 for *lnpdi* and *lnpi*.

***Figure 9**: Confidence interval of the coefficient of β – absolute convergence*



Notes: Final year, i.e. 2020 for *lnhdi*, 2016 for *lnhdir*, *lnhi* and 2010 for *lnpdi*, *lnpi*

Briefly, it would be interesting to be mentioned that in cases of unconditional convergence, disposable measures end up in higher estimations, in absolute terms. In the

Johansen test, the two groups of variables conclude in similar results with non-disposable income to support a greater number of pairs that are cointegrated.

To see if the variables can follow the same path, we run the panel cointegration tests for the pairs of variables with *lnhdi*.

The hypotheses are:

$$H_0: There\ isn't\ cointegration$$

$$H_1: All\ panels\ are\ cointegrated$$

The majority of tests indicate that the variables are cointegrated at the 5% (*Table 8*). Exclude the pairs:

3. *lnhdi-lnpdi* for the period 1926-2010 (Kao and Petroni tests)
4. *lnhdi-lnhdir* for the period 1949-2016 (Kao and Petroni tests)
5. *lnhdi-lnpdi* and *lnhdi-lnpi* for the period 1949-2010 (Kao test)
6. *lnhdi-lnhdip* for the period 1981-2020 (Kao and Petroni tests)
7. *lnhdi-lnhdir*, *lnhdi-lnhi* and *lnhdi-lnhdip* for the period 1981-2016 (Kao and Petroni tests)

These results are important since show that the choice of variable is important, especially for some periods since the variables don't follow the same patterns and therefore the results of all kinds of convergence can be affected. Nevertheless, in *Table 8* correlations are reported too indicating that all the pairs are positive and strongly correlated since all correlations are close to unit.

Table 8: *Panel cointegration tests and correlations for the pairs of variables with lnhdi*

Tests/ Samples	Kao	Petroni	Westerlund	Correlation
1926-2016				
lnhdi-lnhdir	0	0	0.0033	[0.9982]
lnhdi-lnhi	0.0003	0.0001	0.0056	[0.9987]
1926-2010				
lnhdi-lnpdi	0.284	0.0543	0.0128	[0.9986]
lnhdi-lnpi	0.0005	0	0.0032	[0.9981]
1926-1980				
lnhdi-lnhdir	0	0	0.0056	[0.9961]
lnhdi-lnhi	0.0002	0.0001	0.0056	[0.9983]
lnhdi-lnpdi	0	0	0.0012	[0.9974]
lnhdi-lnpi	0	0	0.004	[0.9968]
1949-2016				
lnhdi-lnhdir	0.2745	0.1258	0.0151	[0.9986]
lnhdi-lnhi	0.0261	0.0169	0.0023	[0.9977]
1949-2010				
lnhdi-lnpdi	0.2893	0.0002	0.0046	[0.9973]
lnhdi-lnpi	0.1114	0.0132	0.0015	[0.9967]
1981-2020				
lnhdi-lnhdip	0.1623	0.1074	0.0098	[0.9936]
1981-2016				
lnhdi-lnhdir	0.1582	0.385	0.0135	[0.9926]
lnhdi-lnhi	0.1488	0.1113	0.0456	[0.9862]
hdi-hdip	0.2273	0.2433	0.0157	[0.9932]

Notes:
p-values are represented for cointegration tests.
$p < 0.05$ statistically significant at the 5%.
Cointegration tests with the null hypothesis that panel aren't cointegrated.
Correlations are represented in parentheses [].

6.3. Household price measures

Following Meen (1999) who suggests that there is a ripple effect between regional house prices and the economy, we use the house price index (*i*), the seasonally adjusted house price index (*sai*) and the sales pair count (*sp*) for 11 metropolitan areas for the monthly period 1990M7-2022M6 and some subperiods.

We find that there is a divergence for the house price index and the seasonally adjusted house price index, especially in the periods before 2005 and after 2007. However, the sales pair count support, strongly, that there is absolute convergence. Furthermore, the unit root tests disagree among variables and the only cases that stochastic convergence is supported are when the sales pair counts measure is used. However, the Johansen tests are in favor of stochastic convergence for all measures.

We, also, use the composite benchmark price which is a proxy for house price levels to confirm divergence in our data. This variable, indeed shows a divergence after 2007[24].

Briefly, in the only case that the house price data we use supports convergence is when the sales pair count measure is used. In the other case, the lack of convergence is confirmed, a result that agree with the initial results. However, in the house price indices, the divergence is confirmed something which doesn't occur in the cases of incomes.

[24] For further details see *Appendix G*.

6.4. Club convergence

According to Phillips and Sul's (2007) method there is no club convergence for the majority of datasets and variables. In only periods that there is club convergence are the periods 1981-Final year and 1996-Final year. Specifically, there is either more than one convergent club or one convergent club which don't include all provinces (club convergence). However, the club classification depends on the variable. Finally, we check for stochastic convergence in these clubs and there isn't stochastic convergence apart from the case of *lnhdip* in the 1981-Final year period[25].

6.5. Strong cointegration with known cointegrating vector [1,-1]′ for main variable (lnhdi)

Applying the definition of strong convergence in the logarithm of household disposable income, it is observed that there is no stochastic cointegration in any period. The highest percentage of pairs which are strongly cointegrated (namely cointegrating vector is [1,-1]′) is about 31.1 % and 33.3% at $a = 5\%$ and $a = 10\%$ respectively[26].

7. Conclusions

Although some economies have been grown rapidly, the distribution of income has become more unequal. Thus, the convergence issue has indispensable policy implications. If there is convergence in a single steady state or in multiple steady states or if there is divergence or lack of convergence is a crucial factor and it should be taken into

[25] For further details see *Appendix H*.
[26] For further details see *Appendix I*.

consideration. Therefore, if necessary, different policies intervention should be taken in economies in order to close the income gap across them.

This paper examines sigma, beta, stochastic and club convergence in Canadian provinces for the period 1926-2020 and subperiods. Regarding stochastic convergence, as far as we know there isn't any other paper that use pairwise approaches in the differences of income or cointegration test in incomes of two provinces for all possible pairs among provinces. Our empirical results show that there is no convergence, neither beta nor sigma and stochastic, before 1950 as DeJuan and Tomljanovich (2005) have referred to for their pre–World War II data. However, generally, *the sigma convergence exists* since the *standard deviation* of real household disposable income *declines over the year*.

Moreover, there is *absolute convergence for the whole period samples and post-World War II data*. Furthermore, *stochastic convergence doesn't seem to happen if we take into consideration the unit root/ stationarity tests*, in contrast to DeJuan and Tomljanovich (2005) who support stochastic convergence when they use unit root tests. However, for the second recent datasets and some measures *weak stochastic convergence (cointegration test) is supported*. Hence, this different conclusion can be due to the fact that *stationarity could be not a necessary condition for the existence of stochastic convergence* as Nahar and Inder (2002) said. Nevertheless, it seems that there is stochastic convergence in the 1949-2020 and 1981-2020 periods either among all provinces, i.e. as *lnhi* indicates for both periods, or among some income groups.

However, given that beta and stochastic convergence don't meet each other, the hypothesis of convergence can't be confirmed in the case of the Canadian province for the majority of samples, except for *the 1949/50-2020 period where both stochastic and absolute convergence occur*, so the case of *convergence among provinces indeed happens*.

Briefly, robustness checks, using other variables for real personal income, show that the results of *sigma and beta are, on average, robust* while the results for *stochastic convergence depend on the variable which measures the personal income and the method*. We, also, analyze sigma, absolute and stochastic convergence for house price indices for the monthly period 1990M7-2022M6 for 11 Canadian cities to *confirm the lack of convergence after 1990* since house price indices could be a good proxy for economic activity. Finally, Phillips and Sul's (2007) method is used to define the clubs for the measures of personal income and it seems that *in the periods 1981-2020 and 1996-2020 there are club convergence*. Specifically, there clubs that don't include all provinces. Nevertheless, that *categorization into clubs depends on the variable*.

In addition, some interesting results arrive from this analysis and some of them confirm or not previous researches:

Firstly, we could say for the case of sigma and beta convergence that the use of provincial CPI instead of national one for household disposable income doesn't affect the results about convergence in the dataset after 1981, a finding that was made by Coulombe and Lee (1995) too. However, when Phillips and Sul's (2007) method is used different clubs are defined and therefore some different results have appeared. *So, it would be proper to be done a distinction between them*. It can, also, be referred to that the given variable for household disposable income and the variable we made give similar results.

Secondly, our results about the similarity between disposable and non-disposable income since comparing *lnhdir*/*lnhdi* with *lnhi* and *lnpdi* and *lnpi* end up in different results in absolute and/or stochastic convergence and therefore in the distance's probit regressions. So, *it is important the distinction between disposable and non-disposable variables*. Coulombe and Lee (1995) refer to the importance to transmit the transfer and they end up that in the case of disposable income the speed of convergence is higher. This result could be confirmed by this paper too since in cases of disposable incomes the coefficients of absolute convergence are higher, in absolute terms and therefore the speed of convergence is greater too. Thus, we can conclude from their study (indirectly) and this paper that is significant this separation in income measure.

Thirdly, both the econometric methods and also the choice of standard errors are significant since they can lead to dissimilar results.

Moreover, *structural breaks are important* since in some cases, stochastic convergence can occur if the ZA break unit root test is taken into consideration. The importance of structural breaks is confirmed by DeJuan and Tomljanovich (2005) and Coulombe (2000) too. However, Johnson and Papageorgiou (2020) mention that it is hard sometimes to interpret the results when structural breaks are included and, also, they refer that when the difference among provinces is stationary when structural breaks is permitted "… *a conclusion of convergence is then conditional on the occurrence of the break*"[27].

Furthermore, *strong cointegration, namely cointegration with known cointegrating vector [1,-1]' is harder to confirm*. In case of *lnhdi* there is no strong cointegration for the majority of pairs and therefore the strong definition of stochastic convergence is rejected.

Finally, convergence is supported when the sales pair count measure is used. In the other case, the lack of convergence is confirmed, a result that agrees with the main results. *However, in the house price indices, the divergence is confirmed something that doesn't occur in the cases of incomes*.

We conclude that although there is sigma convergence, there is no convergence in Canadian provinces as DeJuan and Tomljanovich (2005) mention it, *since both stochastic convergence and β-convergence are required for actual convergence to occur, except for the period 1949/50-2020 in which convergence occurs*. However, *our results depend on the variable, the methodology* (i.e. model, standard errors) *and the definition of convergence* (i.e. strong or weak convergence). To sum up, we can say that *there is no convergence in last decades (after 1980) although the inequality among Canadian provinces tend to fall*, as Johnson and Papageorgiou (2020) mentioned too in terms of countries.

[27] Johnson, P., and Papageorgiou, C. (2020), "What remains of cross-country convergence?", page 159.

References

Afxentiou, P. C., Serletis, A. (1998). Convergence across Canadian provinces. *Canadian Journal of Regional Science*, *21*(1), 111-126.

Aginta, H., Gunawan, A. B., Mendez, C. (2021). Regional income disparities and convergence clubs in Indonesia: new district-level evidence. *Journal of the Asia Pacific Economy*, 1-33. DOI: 10.1080/13547860.2020.1868107

Andre, C., Christou, C.,Gupta, R. (2022). *Revisiting International House Price Convergence Using House Price Level Data* (No. 202226).

Arbia, G., Piras, G. (2005). Convergence in per-capita GDP across European regions using panel data models extended to spatial autocorrelation effects.

Arvanitopoulos, T., Monastiriotis, V., Panagiotidis, T. (2021). Drivers of convergence: The role of first-and second-nature geography. *Urban Studies*, *58*(14), 2880-2900.

Barro, R. J., Sala-i-Martin, X. (1990). Economic growth and convergence across the United States.

Barro, R. J., Xavier Sala-i-Martin. (1992). Convergence. *Journal of Political Economy*, *100*(2), 223–251. http://www.jstor.org/stable/2138606

Baumol, W. J. (1986). Productivity growth, convergence, and welfare: what the long-run data show. *The american economic review*, 1072-1085.

Bernard, A. B., Durlauf, S. N. (1995). Convergence in international output. *Journal of applied econometrics*, *10*(2), 97-108.

Beylunioğlu, F. C., Yazgan, M. E., Stengos, T. (2020). Detecting convergence clubs. *Macroeconomic Dynamics*, *24*(3), 629-669.

Breau, S., Saillant, R. (2016). Regional income disparities in Canada: Exploring the geographical dimensions of an old debate. *Regional Studies, Regional Science*, *3*(1), 463-481.

Brown, W. M., Macdonald, R. (2015). *Provincial convergence and divergence in Canada, 1926 to 2011*. desLibris.

Cabral, R., Mollick, A. V. (2012). Mexico's regional output convergence after NAFTA: a dynamic panel data analysis. *The Annals of Regional Science*, *48*(3), 877-895.

Canova, F. (2004). Testing for convergence clubs in income per capita: a predictive density approach. *International Economic Review*, *45*(1), 49-77.

Capeluck, E. (2014). *Convergence across provincial economies in Canada: trends, drivers, and implications* (No. 2014-03). Ottawa: Centre for the Study of Living Standards.

Carayannis, E. G., Mallick, R. (1996). Regional income disparities in Canada: Implications for theories of regional convergence. *Review of Regional Studies*, *26*(1), 55-74.

Carlino, G. A., Mills, L. O. (1993). Are US regional incomes converging?: A time series analysis. *Journal of monetary economics*, *32*(2), 335-346.

Carvalho, V. M., Harvey, A. C. (2005). Growth, cycles and convergence in US regional time series. *International Journal of Forecasting*, *21*(4), 667-686.

Caselli, F., Esquivel, G., Lefort, F. (1996). Reopening the convergence debate: a new look at cross-country growth empirics. *Journal of economic growth*, *1*(3), 363-389.

Christopoulos, D., Smyrnakis, D., Tzavalis, E. (2022). Human Capital Threshold Effects in Economic Development: A Panel Data Approach With Endogenous Threshold. *Available at SSRN 4240853*.

Cottrell, A. (2021). *Response surfaces for DF-GLS p-values* (No. 8). Universita' Politecnica delle Marche (I), Dipartimento di Scienze Economiche e Sociali.

Coulombe, S. (2000). New evidence of convergence across Canadian provinces: The role of urbanization. *Regional Studies*, *34*(8), 713-725.

Coulombe, S. (2003). Human capital, urbanization and Canadian provincial growth. *Regional Studies*, *37*(3), 239-250.

Coulombe, S., Day, K. M. (1999). Economic growth and regional income disparities in Canada and the Northern United States. *Canadian Public Policy/Analyse de politiques*, 155-178.

Coulombe, S., Lee, F. C. (1995). Convergence across Canadian provinces, 1961 to 1991. *Canadian Journal of Economics*, 886-898.

Coulombe, S., Tremblay, J. F. (2001). Human capital and regional convergence in Canada. *Journal of Economic Studies*.

Coutinho, L., Turrini, A. (2019). Convergence and macroeconomic imbalances. *Quarterly Report on the Euro Area (QREA)*, *18*(1), 37-51.

DeJuan, J., Tomljanovich, M. (2005). Income convergence across Canadian provinces in the 20th century: Almost but not quite there. *The Annals of Regional Science*, *39*(3), 567-592.

Diaz-Bautista, A. (2008). Economic integration, regional convergence and growth in North America. *Análisis Económico*, *23*(54), 31-51.

Díaz-Dapena, A., Fernández-Vázquez, E., Garduño-Rivera, R., Rubiera-Morollon, F. (2019). Economic integration and regional convergence: effects of NAFTA on local convergence in Mexico, 1980–2008. *Applied Economics*, *51*(50), 5515-5527.

Dorta, M., Sanchez, G. (2021). Bootstrap unit-root test for random walk with drift: The bsrwalkdrift command. *The Stata Journal*, *21*(1), 39-50.

Du, K. (2017). Econometric convergence test and club clustering using Stata. *The Stata Journal*, *17*(4), 882-900.

Dunaway, M. S. V., Kaufman, M. M. D., Swagel, M. P. (2003). *Regional convergence and the role of federal transfers in Canada*. International Monetary Fund.

Easterlin, R. (1960). Regional growth of income. In: Kuznets S, Miller A, Easterlin R (eds). Population redistribution and economic growth in the United States 1870–1950. *American Philosophical Society*, Philadelphia

Easterly, W., Fiess, N., Lederman, D., Loayza, N. V., Meller, P. (2003). NAFTA and Convergence in North America: High Expectations, Big Events, Little Time [with Comments]. *Economia*, *4*(1), 1-53.

Elliott, G., Rothenberg, T. J., Stock, J. H. (1992). Efficient tests for an autoregressive unit root.

Elliott, G., Rothenberg, T. J., Stock, J. H. (1996). Efficient tests for an autoregressive unit root. *Econometrica*, 64: 813–836

Evans, P., Karras, G. (1996a). Convergence revisited. *Journal of monetary economics*, *37*(2), 249-265.

Evans, P., Karras, G. (1996b). Do economies converge? Evidence from a panel of US states. *The review of Economics and Statistics*, 384-388.

Campbell, J. Y., Mankiw, N. G. (1989). International evidence on the persistence of economic fluctuations. *Journal of Monetary Economics*, *23*(2), 319-333.

Galor, O. (1996). Convergence? Inferences from theoretical models. *The economic journal*, *106*(437), 1056-1069.

Ganong, P., Shoag, D. (2017). Why has regional income convergence in the US declined?. *Journal of Urban Economics*, *102*, 76-90.

Geloso, V., Kufenko, V., Prettner, K. (2016). Demographic change and regional convergence in Canada.

Genc, I. H., Miller, J. R., Rupasingha, A. (2011). Stochastic convergence tests for US regional per capita personal income; some further evidence: a research note. *The Annals of Regional Science*, *46*(2), 369-377.

Gunderson, M. (1996). Regional productivity and income convergence in Canada under increasing economic integration. *Canadian Journal of Regional Science*, *19*(1), 1-24.

Gutoskie, J., Macdonald, R. (2019). *Income Growth per Capita in the Provinces since 1950*. Statistics Canada. Statistique Canada.

Hansen, B. E. (2022). *Jackknife Standard Errors for Clustered Regression*. Working paper, University of Wisconsin.

Hamit-Haggar, M. (2013). A note on convergence across Canadian provinces: new insights from the club clustering algorithm. *The Annals of regional science*, *50*(2), 591-601.

Helliwell, J. F. (1996). Convergence and migration among provinces. *The Canadian Journal of Economics/Revue canadienne d'Economique*, *29*, S324-S330.

Herranz, E., Gentle, J., Wang, G., Risk, T. (2017). Unit Roots in Time Series with Changepoints. *International Journal of Statistics and Probability*, *6*(6).

Holmes, M. J., Otero, J., Panagiotidis, T. (2011). Investigating regional house price convergence in the United States: Evidence from a pair-wise approach. *Economic Modelling*, *28*(6), 2369-2376.

Holmes, M. J., Otero, J., Panagiotidis, T. (2014). A note on the extent of US regional income convergence. *Macroeconomic Dynamics*, *18*(7), 1635-1655.

Holobiuc, A. (2020). CHALLENGES FOR REGIONAL CONVERGENCE IN THE EUROPEAN UNION. *Annals of' Constantin Brancusi' University of Targu-Jiu. Economy Series*, (3).

Inwood, K., Irwin, J. (2002). Land, Income and Regional Inequality: New Estimates of Provincial Incomes and Growth in Canada, 1871-1891. *Acadiensis*, *31*(2), 157-184.

Iuzzolino, G., Pellegrini, G., Viesti, G. (2011). Convergence among Italian regions, 1861-2011. *Bank of Italy Economic History Working Paper*, (22).

James, P., Krieckhaus, J. (2008). Canadian regional development: The quest for convergence. *Canadian Journal of Political Science/Revue canadienne de science politique*, *41*(1), 187-202.

Johnson, P., and Papageorgiou, C. (2020). What remains of cross-country convergence?. *Journal of Economic Literature*, *58*(1), 129-75.

Kapetanios, G., Shin, Y., Snell, A. (2003). Testing for a unit root in the nonlinear STAR framework. *Journal of econometrics*, *112*(2), 359-379.

Kholodilin, K. A., Oshchepkov, A., Siliverstovs, B. (2009). *The Russian regional convergence process* (No. 09-216). KOF Swiss Economic Institute, ETH Zurich.

Kuznets, S. (1955). Economic growth and income inequality. *American Economic Review*, 45:1–28

Lee, F. C. (1996). Convergence in Canada?. *The Canadian Journal of Economics/Revue canadienne d'Economique*, *29*, S331-S336.

Lee, K., Pesaran, M. H., Smith, R. (1997). Growth and convergence in a multi-country empirical stochastic Solow model. *Journal of applied Econometrics*, *12*(4), 357-392.

Lee, S. I. (2004). Spatial data analysis for the US regional income convergence, 1969-1999: A critical appraisal of β-convergence. *대한지리학회지= Journal of the Korean Geographical Society*.

Lehmann, H., Oshchepkov, A. Y., Silvagni, M. (2020). Regional convergence in Russia: estimating a neoclassical growth model. *Higher School of Economics Research Paper No. WP BRP*, *232*.

Lopez, C. (2003). Panel Unit Root Tests with GLS-Detrending with an Application to Purchasing Power Parity. *WP, University of Amsterdam Econometrics and Empirical Economics*.

Madariaga, N., Montout, S., Ollivaud, P. (2004). Regional convergence, trade liberalization and agglomeration of activities: an analysis of NAFTA and MERCOSUR cases. *Cahiers de la MSE, Maison des Science Economiques, Université de Paris Panthéon-Sorbonne*.

Magrini, S. (2004). Regional (di) convergence. In *Handbook of regional and urban economics* (Vol. 4, pp. 2741-2796). *Elsevier*.

Mcguinness, S., Sheehan, M. (1998). Regional convergence in the UK, 1970-1995. *Applied economics letters*, *5*(10), 653-658.

McIntosh, A. (2016). The Jackknife estimation method. *arXiv preprint arXiv:1606.00497*.

Meen, G. (1999). Regional house prices and the ripple effect: a new interpretation. *Housing studies*, *14*(6), 733-753.

Miles, W. (2020). Regional convergence-and divergence-in the US. *Research in Economics*, *74*(2), 131-139.

Miller, J. R., Genc, I. (2005). Alternative regional specification and convergence of US regional growth rates. *The Annals of Regional Science*, *39*(2), 241-252.

Miller, R. G. (1974). The jackknife-a review. *Biometrika*, *61*(1), 1-15.

Mitchener, K. J., McLean, I. W. (1999). US regional growth and convergence, 1880–1980. *The Journal of Economic History*, *59*(4), 1016-1042.

Moroianu-Dumitrescu, N., Novac, A. (2020). Dynamical Model of Regional Convergence: Clubs in Greece and Poland. *Revista Română de Statistică-Supliment nr*, 159.

Naghshpour, S., Nissan, E. (2018). State and regional convergence in economic freedom of North America. *Journal of Regional Analysis & Policy*, *48*(2), 3776.

Nahar, S., Inder, B. (2002). Testing convergence in economic growth for OECD countries. *Applied Economics*, *34*(16), 2011-2022.

Narayan, P. K., Smyth, R. (2005). Structural breaks and unit roots in Australian macroeconomic time series. *Pacific Economic Review*, *10*(4), 421-437.

Neven, D., Gouymte, C. (1995). Regional convergence in the European Community. *JCMS: Journal of Common Market Studies*, *33*(1), 47-65.

Nisbet, R., Elder, J., Miner, G. D. (2009). *Handbook of statistical analysis and data mining applications*. Academic press, Chapter 11, 215-233 .

Novac, A., Dumitrescu-Moroianu, N. (2020a). Dynamic Model of Regional Convergence. *Romanian Statistical Review-Suppl*, *6*, 49-60.

Novac, A., Moroianu-Dumitrescu, N. (2020b). Regional Convergence Dynamic Clubs in Italy. *Revista Română de Statistică-Supliment nr*, 107.

Novac, A., Moroianu-Dumitrescu, N. (2020c). Regional convergence dynamical clubs in UE: Integration before and after the financial crisis. *Romanian Statistical Review*, (4).

Otero, J., Baum, C. F. (2017). Response surface models for the Elliott, Rothenberg, and Stock unit-root test. *The Stata Journal*, *17*(4), 985-1002.

Pesaran, M. H. (2007). A pair-wise approach to testing for output and growth convergence. *Journal of econometrics*, *138*(1), 312-355.

Phillips, P. C., Sul, D. (2007). Transition modeling and econometric convergence tests. *Econometrica*, *75*(6), 1771-1855.

Phillips, P. C., & Sul, D. (2009). Economic transition and growth. *Journal of applied econometrics*, *24*(7), 1153-1185.

Pintera, J. (2021). *Regional Convergence in the European Union: What are the Factors of Growth?* (No. 20/2021). IES Working Paper.

Quah, D. T. (1996). Regional convergence clusters across Europe. *European economic review*, *40*(3-5), 951-958.

Ralhan, M., Dayanandan, A. (2005). Convergence of income among provinces in Canada–an application of GMM estimation. *University of Victoria-Econometrics Working Paper*.

Rey, S. J. (2001). Spatial empirics for economic growth and convergence. *Geographical analysis*, *33*(3), 195-214.

Rey, S. J., Montouri, B. D. (1999). US regional income convergence: a spatial econometric perspective. *Regional studies*, *33*(2), 143-156.

Schnurbus, J., H. Haupt, V. Meier. (2017). Economic transition and growth: A replication. *Journal of Applied Econometrics*, 32, 1039–1042.

Seo, M. H., Shin, Y. (2016). Dynamic panels with threshold effect and endogeneity. *Journal of Econometrics*, *195*(2), 169-186.

Shiller, I. (2009). Regional Convergence in per Capita personal Income in the US and Canada. *World Academy of Science, Engineering and Technology*, *31*.

Sollis, R. (2009). A simple unit root test against asymmetric STAR nonlinearity with an application to real exchange rates in Nordic countries. *Economic modelling*, *26*(1), 118-125.

Solow, R. M. (1956). A contribution to the theory of economic growth. *The quarterly journal of economics*, *70*(1), 65-94.

Tsionas, E. G. (2002). Another look at regional convergence in Greece. *Regional Studies*, *36*(6), 603-609.

Vougas, D. V. (2007). GLS detrending and unit root testing. *Economics Letters*, *97*(3), 222-229.

Wei, C. (2004). *Economic growth and convergence across Canada* (Doctoral dissertation, Arts and Social Sciences: Economics).

Williamson, J. G. (1965). Regional inequality and the process of national development: a description of the patterns. *Economic development and cultural change*, *13*(4, Part 2), 1-84.

Wu, S. (2010). Lag length selection in DF-GLS unit root tests. *Communications in Statistics-Simulation and Computation*, *39*(8), 1590-1604.

Zhang, W., Xu, W., Wang, X. (2019). Regional convergence clubs in China: identification and conditioning factors. *The Annals of Regional Science*, *62*(2), 327-350.

Appendices

Appendix A: Panel unit root tests for stochastic convergence

We run robustness tests about stochastic convergence using panel unit root tests as *Table A1* shows. There are 4 groups for the test depending on their hypotheses.

1. *First group*:

Levin-Lin-Chu (LLC), Harris-Tzavalis (Tzavelis), Breitung (Breitung and Breitung with CSD), Herwartz and Siedenburg (2008) (HS), and Demetrescu and Hanck (2012) (DH) unit root tests have the below hypotheses:

$$H_0: Panels\ contain\ unit\ roots$$

$$H_1: Panels\ are\ stationary$$

2. *Second group*:

Im-Pesaran-Shin unit-root test (IPS) has:

$$H_0:\ Panels\ contain\ unit\ roots$$

$$H_1: Some\ panels\ are\ stationary$$

3. *Third group*:

Fisher unit root test (Fisher with ADF and Fisher with PP) has:

$$H_0:\ Panels\ contain\ unit\ roots$$

$$H_1: At\ least\ one\ panel\ is\ stationary$$

4. *Fourth group:*

Hadri LM stationarity test follows these hypotheses (Hadri LM test):

$$H_0:\ All\ panels\ are\ stationary$$

$$H_1: Some\ panels\ contain\ unit\ roots$$

Based on the first and last group of tests, differences aren't stationary in the period 1981-2020 at the 1% and 5% (except for the LLC test). Similarly, in the period 1949-2020 the majority of the test show non-stationary differences apart from LLC and Tzavalis. However, in the first sample LLC, Tzavalis, and Breitung show stationarity at the 5% whereas Tzavalis, Breitung, and HS for the second sample. The other two groups, namely IPS and Fisher tests indicate that there is at least one stationary panel (apart from the 1981-2020 period as Fisher ADF show). Thus, we can say that for the majority of tests there is no stochastic convergence. However, the results, as we can observe, are influenced by the method/ unit root test/stationarity test which is used.

__Table A1__: Panel unit root/stationarity tests of household disposable income's differences between provinces (lnhdi)

Tests/ Samples	LLC	Tzavalis	Breitung	Breitung with CSD	IPS	Fisher with ADF	Fisher with PP	Hadri LM test	HS	DH
1926-2020 (No NL)	0.0061	0	0.0006	0.0055	0	0.0001	0	0	0.155	0.189
1926-1980 (No NL)	0.1515	0	0	0.0073	0	0.0082	0	0	0.0258	0.1098
1949-2020	0	0	0.9519	0.1037	0	0.0223	0	0	0.5244	0.7757
1981-2020	0.0243	0.1396	0.7491	-	0.0026	0.9465	0	0	0.3636	0.3181

Notes:
p-values are represented.
$p < 0.05$ statistically significant at the 5%.
Unit root/stationarity tests with the null hypothesis that panels aren't stationary.
Hadri stationarity test with the null hypothesis that panels are stationary.

Appendix B: Real household disposable income per capita divided by provincial CPI (hdip)

We divided our data for household disposable income per capita with the provincial consumer price index (CPI) from CANSIM Table: 18-10-0004-01[28]. The data is available since 1978, so our datasets are the same as the initial variable for conditional convergence but not for stochastic:

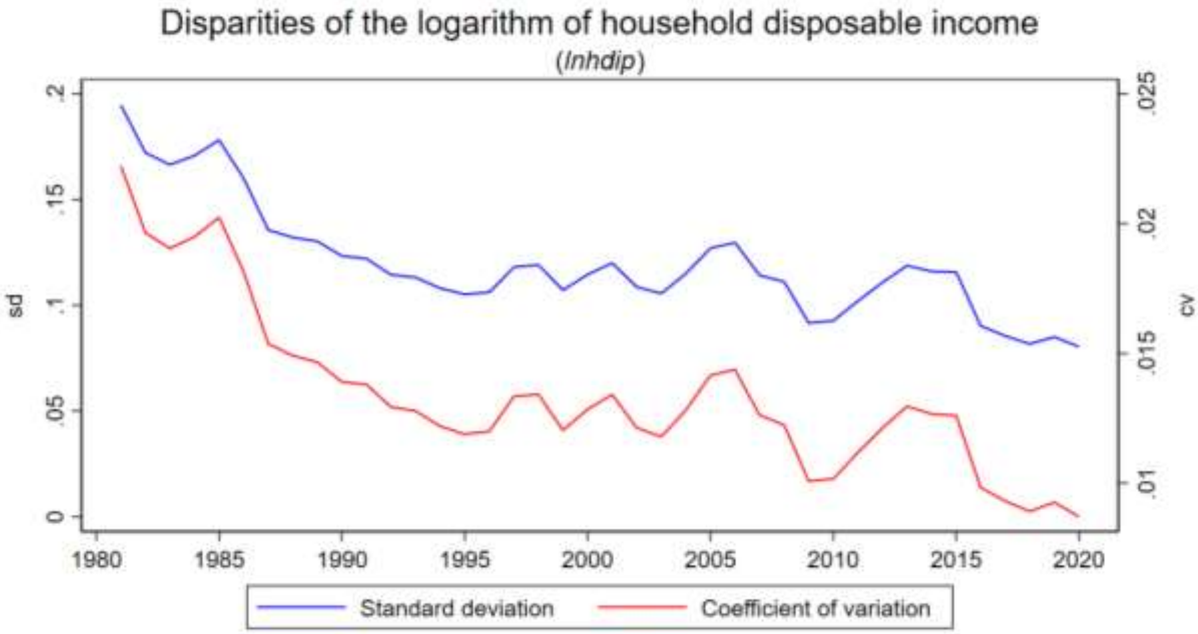
1. 1981-2020

B.1. Sigma convergence

Both the standard deviation and the coefficient of variation show that after 1996 doesn't seem clear to exist convergence since there are fluctuations in disparities which dropped rapidly before 2010, probably because of the financial crisis in 2008.

[28] Consumer Price Index, monthly, not seasonally adjusted
https://www150.statcan.gc.ca/t1/tbl1/en/cv.action?pid=1810000401
The data was monthly and we turn our data in annual frequency taking the average.

***Figure B1**: Standard deviation and coefficient of variation of the logarithm of household disposable income (lnhdip)*



B.2. Absolute convergence

Before analyzing the absolute convergence, graphs with the variable in level are represented in *Fig. B2* for the year 2020. MB, NB, and PE have the lowest values of income while BC and AB have the highest. The second richer provinces are ON, QC, and SK. It is clear that the distribution of income among provinces is similar to those on distribution in the initial variable *lnhdi*.

At the below *Table B1*, it seems that there is no absolute convergence for the periods 1981-2020 and 1996-2020 confirming the initial results.

***Figure B2**: Logarithm of household disposable income in the final year (lnhdip)*

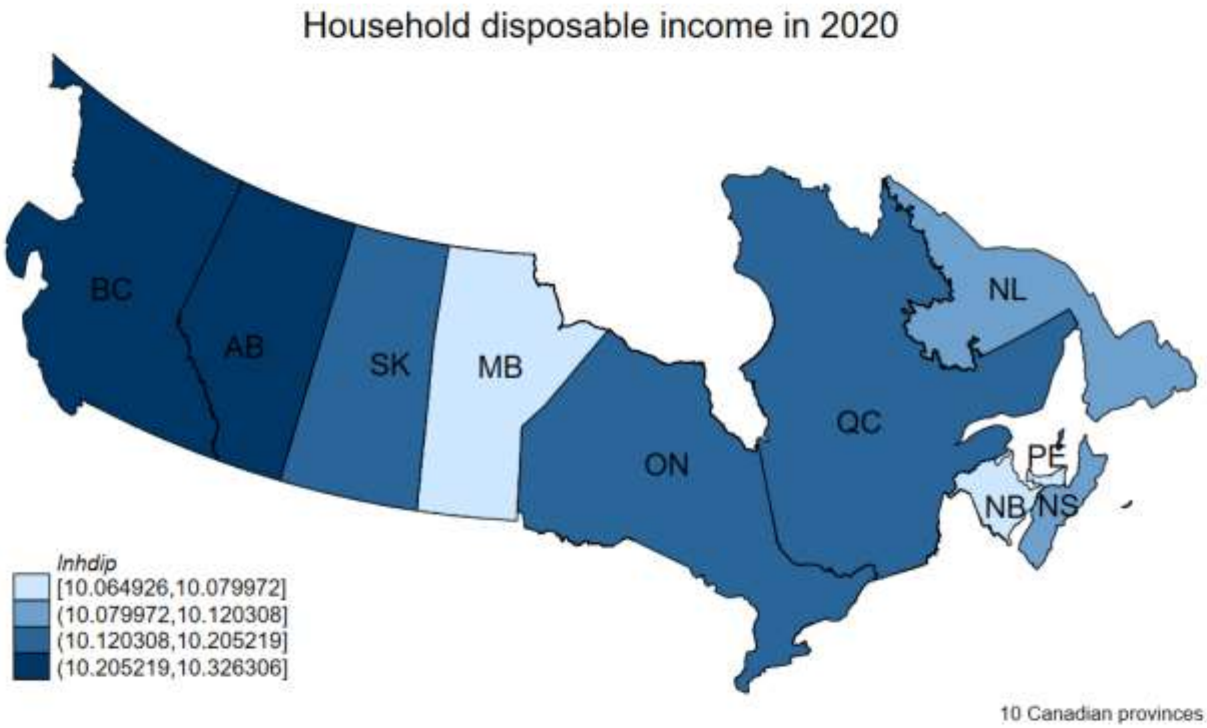


***Table B1**: Absolute convergence for the logarithm of household disposable income (lnhdip)*

Models / Samples	**Pooled OLS**	**FE**	**FE Jackknife**	**RE**	**Hausman test**	**PCSE**
1981-2020 (prov)	-0.0109018	-0.0042214	-0.0042214	-0.0109018		-0.0109018
	(0.0079901)	(0.006885)	(0.0068183)	(0.0058497)*	0.1685	(0.0130029)
1996-2020 (prov)	-0.0126159	-0.0142337	-0.0142337	-0.0126159		-0.0126159
	(0.0114203)	(0.0107617)	(0.0107877)	(0.0090423)	0.8246	(0.0182925)

Notes:
Coefficients of the previous *lnhdip* are represented in the above table. A negative and statistically significant coefficient indicates absolute convergence.
Robust standard errors in parentheses () except for the FE Jackknife (Jackknife standard errors) and PCSE (panel corrected standard errors).
Dependent variable: growth rate of *lnhdip*.
Statistically significant *: at the 10% **: at the 5% ***: at the 1% (two-sided t test).

B.3. Stochastic convergence

It is observed that for the majority of provinces doesn't occur stochastic convergence according to the unit root and stationarity tests (*Table B2*). About the Johansen cointegration test (λ_{trace}) accepts the long-run relationship for 51.1% and 46.67% of the total pairs of provinces at the 5% and 10% level, respectively implying that there is no stochastic convergence at the 10%[29] (*Table B3*). Moreover, the panel unit root tests conclude that for the majority of tests in 1st group there is no stationarity and therefore stochastic convergence at the 5% (*Table B4*). Finally, the OLS regressions, in *Table B5*, show that the distance doesn't affect significantly the possibility of two provinces being cointegrated at all levels 1%, 5%, and 10%[30].

This variable (*lnhdip*) tends to lead to similar rudimentary conclusions to the initial variable (*lnhdi*) indicating that the national and provincial CPI don't change the main results. However, it is possible if there was data about provincial CPI since 1926, they would end up in different results.

[29] Only Ontario is cointegrated with other rich provinces (AB, BC, ON) while only 3 from 6 pairs of poor provinces are cointegrated. However, some rich provinces cointegrated with middle-income ones (6 from 9 possible pairs) and with poor ones (5 from 12 possible pairs) whereas some middle-income provinces with the poorest (4 from 12 possible pairs).

[30] Taking into consideration the Johansen test (λ_{max}) at the 10%, distance won't affect the cointegration possibility at all.

***Table B2**: Unit root tests and stationarity test for the logarithm of household disposable income (lnhdip)*

Tests / Samples	ADF	KPSS	ZA	ERS	KSS	AESTAR	bootstrapped
1981-2020 (prov)	0/45	8/45	6/45	1/45	12/45	2/45	7/45

<u>Notes</u>:
Pairwise methods.
Unit root/stationarity tests for income differences among 2 provinces.
The appropriate lag length is selected based on SBIC in ERS unit root test.
There are 45 pairs for the datasets with all 10 provinces while 36 for the datasets without NL (9 provinces).
The numbers indicate the number of tests that the null hypothesis about non-stationarity (stationarity) has been rejected (hasn't been rejected) at the 5% / possible pairs.
There is stochastic convergence if this rate is higher or equal to 50%.

***Table B3**: Johansen test for the logarithm of household disposable income (lnhdip)*

Tests / Samples	Johansen 5%	Johansen 10%	Johansen max 5%	Johansen max 10%
1981-2020 (prov)	23/45	21/45	22/45	20/45

<u>Notes</u>:
Johansen cointegration test for *lnhdip* between 2 provinces.
The appropriate lag length is selected based on SBIC.
There are 45 pairs for the datasets with all 10 provinces while 36 for the datasets without NL (9 provinces).
The numbers indicate the number of tests that there is cointegration at the 5% and 10% / possible pairs.
There is stochastic convergence if this rate is higher or equal to 50%.
The critical values for (λ_{trace}) are 12.53 for null hypothesis r=0 and 3.84 for r=1 at the 5% while there are 10.47 for null hypothesis r=0 and 2.86 for r=1 at the 10%.
The critical values for (λ_{max}) are 11.44 for null hypothesis r=0 and 3.84 for r=1 at the 5% while there are 9.52 for null hypothesis r=0 and 2.86 for r=1 at the 10%.

Table B4*: Panel unit root/stationarity tests of household disposable income's differences between provinces (lnhdip)*

Tests / Samples	LLC	Tzavalis	Breitung	Breitung with CSD	IPS	Fisher with ADF	Fisher with PP	Hadri LM test	HS	DH
1981-2020 (prov)	0.0091	0.0616	0.9551	0	0.0044	0.9661	0	0	0.6683	0.6057

Notes:
p-values are represented.
$p < 0.05$ statistically significant at the 5%.
Unit root/stationarity tests with the null hypothesis that panels aren't stationary.
Hadri stationarity test with the null hypothesis that panels are stationary.

Table B5*: OLS regression for cointegration determinants (Distance among provinces) (lnhdip)*

Models / Samples	OLS Robust	OLS Jackknife	OLS Bootstrap
1981-2020 (prov)	-0.0455	-0.0454956	-0.0454956
	(0.1084349)	(0.1246464)	(0.119271)

Notes:
Coefficients of *lnD* are represented in the above table.
Relative standard errors in parentheses ().
Dependent variable: Dummy $C_{i,j}$.
Statistically significant *: at the 10% **: at the 5% ***: at the 1%.

Appendix C: Real household disposable income per capita as the given variable (hdir)

The data on real household disposable income per capita (*hdir*) is from CANSIM Table: 36-10-0229-01[31]. This variable wasn't divided by CPI and provincial population since it was already in real and per capita terms. The available period of this variable is 1926-2016.

Therefore, we take the below samples:

For absolute convergence:

1. 1927-2016 (without NL)
2. 1927-1980 (without NL)
3. 1927-1949 (without NL)
4. 1950-2016 (without NL)
5. 1950-2016
6. 1981-2016
7. 1996-2016

For stochastic convergence:

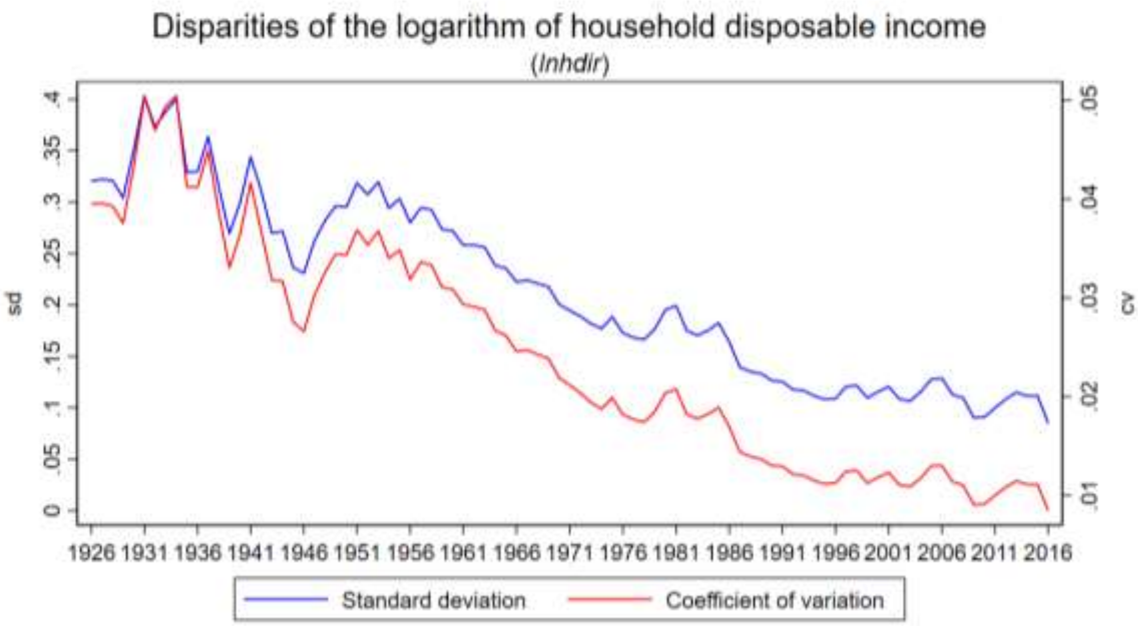
1. 1926-2016 (without NL)
2. 1926-1980 (without NL)
3. 1949-2016
4. 1981-2016

[31] Long-run provincial and territorial data https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3610022901

C.1. Sigma convergence

The measures of disparities follow a similar pattern to relative measures of *lnhdi*. Periods near to World War II, oil shocks, and the recent financial crisis would be potential divergence periods.

***Figure C1**: Standard deviation and coefficient of variation of the logarithm of household disposable income (lnhdir)*



C.2. Absolute convergence

***Figure C2**: Logarithm of household disposable income in the initial year (lnhdir)*

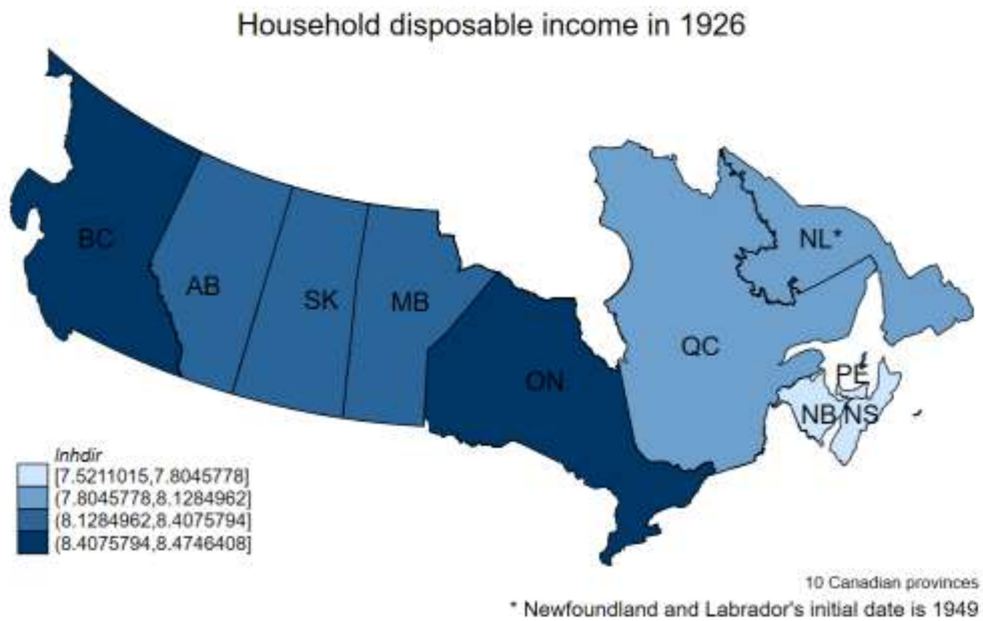
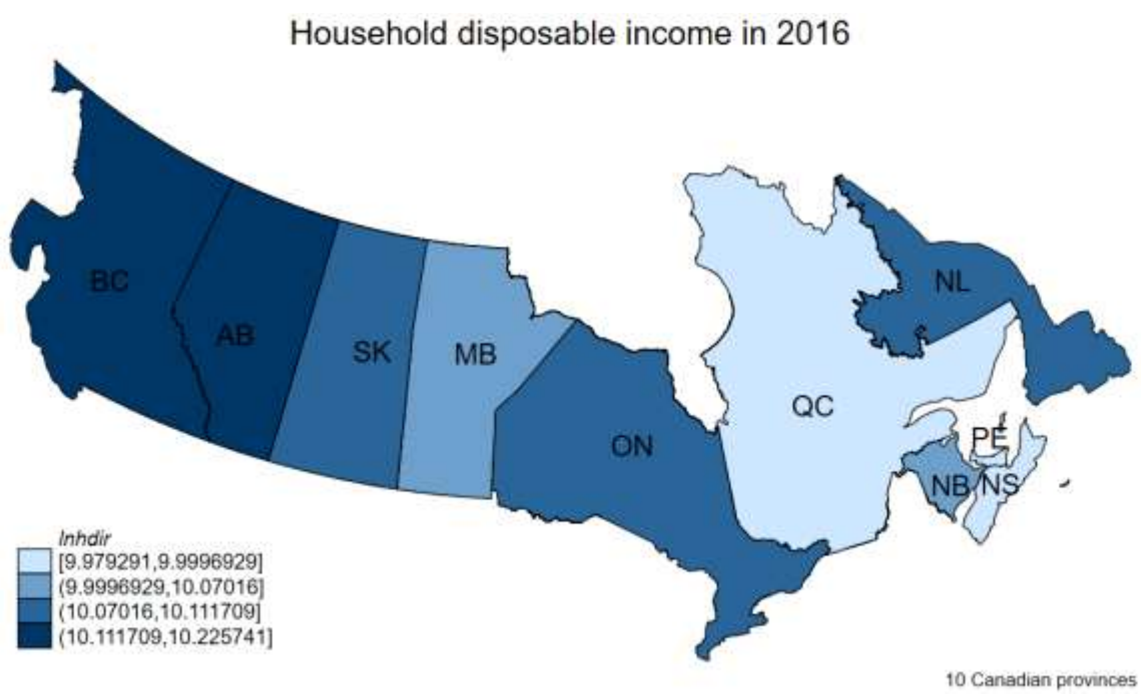


***Figure C3**: Logarithm of household disposable income in the final year (lnhdir)*



The logarithms for *hdir* are distributed differently than the main variable. In *Fig. C2*, BC and ON was the richest provinces in 1926 while AB, MB, and SK were the second ones. NL and QC are the second poorer regions. NB, NS, and PE had the lowest income though, as happens in *lnhdi*. Furthermore, in *Fig. C3*, AB and BC belong to the richest group, and NL, ON, and SK to the second richer group. Moreover, MB and NB are in the third richer group, and NS, PE and QC are in the last one.

Table C1 indicates that there is convergence for the whole period and for the subperiod 1950-2016 with and without NL since the coefficients of convergence are negative and statistically significant at the 5%. Comparing the FE Jackknife's coefficients observe that they are almost identical for cases 1927-2016 and 1950-2016 whereas in the sample 1950-2016 (without NL), this coefficient becomes negative and significant[32].

[32] Comparing the results from *lnhdir* with the ones from *lnhdi* in the same periods (e.i. the final year is 2016) we can say that the coefficients of absolute convergence are significant for the same dataset, namely 1927-2016 and 1950-2016 (with and without NL). The latter coefficients are lower in absolute terms though.

Table C1: Absolute convergence for the logarithm of household disposable income (lnhdir)

Models / Samples	Pooled OLS	FE	FE Jackknife	RE	Hausman test	PCSE
1927-2016 (No NL)	-0.014242	-0.0139563	-0.0139563	-0.014242		-0.014242
	(0.005674)**	(0.0041881)***	(0.0043242)**	(0.0040324)***	0.8024	(0.0068073)**
1927-1980 (No NL)	-0.0089602	-0.0072023	-0.0072023	-0.0089602		-0.0089602
	(0.0095951)	(0.0097095)	(0.0103259)	(0.0082623)	0.663	(0.0132822)
1927-1949 (No NL)	-0.0352631	-0.0546576	-0.0546576	-0.0352631		-0.0352631
	(0.0224612)	(0.0261757)*	(0.0317085)	(0.0191994)*	0.4258	(0.0333104)
1950-2016 (No NL)	-0.0208451	-0.0210193	-0.0210193	-0.0208451		-0.0208451
	(0.0063165)***	(0.0040399)***	(0.0040704)***	(0.0037416)***	0.9103	(0.0071691)***
1950-2016	-0.0194822	-0.0191882	-0.0191882	-0.0194822		-0.0194822
	(0.0051951)***	(0.0037825)***	(0.0038283)***	(0.0032853)***	0.837	(0.0062286)***
1981-2016	-0.0147215	-0.0057046	-0.0057046	-0.0147215		-0.0147215
	(0.0085375)*	(0.0082313)	(0.0086742)	(0.0053326)***	0.1375	(0.0130302)***
1996-2016	-0.0136774	-0.014224	-0.014224	-0.0136774		-0.0136774
	(0.0126088)	(0.0111279)	(0.0112971)	(0.0072836)*	0.9472	(0.0174127)

Notes:
Coefficients of the previous *lnhdir* are represented in the above table. A negative and statistically significant coefficient indicates absolute convergence.
Robust standard errors in parentheses () except for the FE Jackknife (Jackknife standard errors) and PCSE (panel corrected standard errors).
Dependent variable: growth rate of *lnhdir*.
Statistically significant *: at the 10% **: at the 5% ***: at the 1% (two-sided t test).

C.3. Stochastic convergence

Unit root tests show that there is no convergence since the majority of differences is non-stationary. Only the ZA unit root tests indicate that there is stochastic convergence in 1926-1980 for 58.3% of pairs (*Table C2*). Similarly, the Johansen cointegration test (λ_{trace} and

λ_{max}) doesn't find long-run relationships apart from the period 1949-2016 where 62.2% of pairs are cointegrated at the 10% indicating stochastic convergence to some degree, in contrast to the initial variable[33] (*Table C3* vs *Table 3*). However, if we look closely the results (λ_{trace}), we can say that although in the 1926-2016 and the 1926-1980 periods indeed there is no stochastic convergence among provinces, in the period 1949-2016 the majority of the richest provinces (based on *hdir* in 1949), AB, BC and ON are cointegrated with each other. Moreover, half of the middle-income provinces (MB, NB, NS, QC, SK) are cointegrated with each other too. That indicated that there is stochastic convergence inside these two groups. Furthermore, all poor provinces, namely, NL and PE are cointegrated with rich ones and with the majority of middle-income ones (9 cointegrated pairs of 10 possible pairs). However, the two richest clubs are cointegrated only for 6 of 15 possible pairs. On the other hand, in the period 1981-2016, the middle-income provinces (based on *hdir* in 1981), namely MB, QC, and SK are cointegrated with each other. The poor ones (NB, NL, NS, PE) are cointegrated too. The rest cointegrated pairs are among different groups but we can't say that there is stochastic convergence across these groups.

[33] For 1949-2016 (trace): The richest provinces (AB, BC, ON) are cointegrated with all the poorest ones (NL, PE) and with some of the middle-income ones (6 from 15 possible pairs) while only the ON is cointegrated with other rich provinces. Finally, 9 from 10 possible pairs among middle-income with poor provinces are cointegrated.
For 1981-2016 (trace): The middle-income provinces in 1981 (MB, QC, SK) are cointegrated with each other so, there is stochastic convergence for this group while 4 from 6 possible pairs of poor provinces (NB, NL, NS, PE) are cointegrated and 1 from 3 pairs of rich ones (AB, BC, ON). Finally, 5/12, 3/12, and 3/9 pairs are cointegrated among poor with rich provinces, poor with middle-income provinces, and rich with middle-income provinces respectively.

Table C2: Unit root tests and stationarity test for the logarithm of household disposable income (lnhdir)

Tests / Samples	ADF	KPSS	ZA	ERS	KSS	AESTAR	bootstrapped
1926-2016 (No NL)	4/36	3/36	17/36	13/36	11/36	7/36	4/36
1926-1980 (No NL)	1/36	5/36	21/36	2/36	8/36	4/36	4/36
1949-2016	6/45	4/45	10/45	5/45	13/45	16/45	6/45
1981-2016	0/45	9/45	9/45	2/45	13/45	3/45	8/45

Notes:
Pairwise methods.
Unit root/stationarity tests for income differences among 2 provinces.
The appropriate lag length is selected based on SBIC in ERS unit root test.
There are 45 pairs for the datasets with all 10 provinces while 36 for the datasets without NL (9 provinces).
The numbers indicate the number of tests that the null hypothesis about non-stationarity (stationarity) has been rejected (hasn't been rejected) at the 5% / possible pairs.
There is stochastic convergence if this rate is higher or equal to 50%.

In addition, panel unit root tests in *Table C4* end up in mixed results which are similar to that in *Appendix A*. For instance, Hadri stationarity test, HS and DH support the non-stationarity hypothesis while Tzavalis, and LLC are in favor of stationarity for all samples except the last one. Finally, OLS regressions in *Table C5* show that distance affects negatively the possibility of cointegration and therefore the possibility of stochastic convergence among two provinces for the period 1949-2016 at the 5% and at the 10% and for the period 1926-2016 at the 10%. Similar results are given by OLS regressions where Johansen λ_{max} (10%) is used. Comparing the distance's coefficient for the period 1949-2016/20, it reduces from -0.2449221 to -0.15603.

Table C3: Johansen test for the logarithm of household disposable income (lnhdir)

Tests / Samples	Johansen 5%	Johansen 10%	Johansen max 5%	Johansen max 10%
1926-2016 (No NL)	11/36	12/36	11/36	16/36
1926-1980 (No NL)	7/36	5/36	7/36	5/36
1949-2016	26/45	28/45	27/45	27/45
1981-2016	18/45	19/45	18/45	21/45

Notes:
Johansen cointegration test for *lnhdir* between 2 provinces.
The appropriate lag length is selected based on SBIC .
There are 45 pairs for the datasets with all 10 provinces while 36 for the datasets without NL (9 provinces).
The numbers indicate the number of tests that there is cointegration at the 5% and 10% / possible pairs.
There is stochastic convergence if this rate is higher or equal to 50%.
The critical values for (λ_{trace}) are 12.53 for null hypothesis r=0 and 3.84 for r=1 at the 5% while there are 10.47 for null hypothesis r=0 and 2.86 for r=1 at the 10%.
The critical values for (λ_{max}) are 11.44 for null hypothesis r=0 and 3.84 for r=1 at the 5% while there are 9.52 for null hypothesis r=0 and 2.86 for r=1 at the 10%.

Table C4: Panel unit root/stationarity tests of household disposable income's differences between provinces (lnhdir)

Tests / Samples	LLC	Tzavalis	Breitung	Breitung with CSD	IPS	Fisher with ADF	Fisher with PP	Hadri LM test	HS	DH
1926-2016 (No NL)	0.0212	0	0.0327	0.005	0	0	0	0	0.303	0.2655
1926-1980 (No NL)	0.0476	0	0	0.0034	0	0.0012	0	0	0.1513	0.1415
1949-2016	0.0028	0	0.9997	0.1453		0.1456	0	0	0.5535	0.7616
1981-2016	0.1197	0.2718	0.9999	-	0.0437	0.9889	0	0	0.8297	0.7354

Notes:
p-values are represented.
$p < 0.05$ statistically significant at the 5%.
Unit root/stationarity test with the null hypothesis that panels aren't stationary.
Hadri stationarity test with the null hypothesis that panels are stationary.

Table C5: OLS regression for cointegration determinants (Distance among provinces) (lnhdir)

Models / Samples	OLS Robust	OLS Jackknife	OLS Bootstrap
1926-2016 (No NL)	-0.1928574	-0.19286	-0.1928574
	(0.0973381)*	(0.1067753)*	(0.1071984)*
1926-1980 (No NL)	-0.0312359	-0.03124	-0.0312359
	(0.0622193)	(0.0671498)	(0.0740945)
1949-2016	-0.1560256	-0.15603	-0.1560256
	(0.0646157)**	(0.0666903)**	(0.0710318)**
1981-2016	-0.1577971	-0.1578	-0.1577971
	(0.11958)	(0.1432127)	(0.1252485)

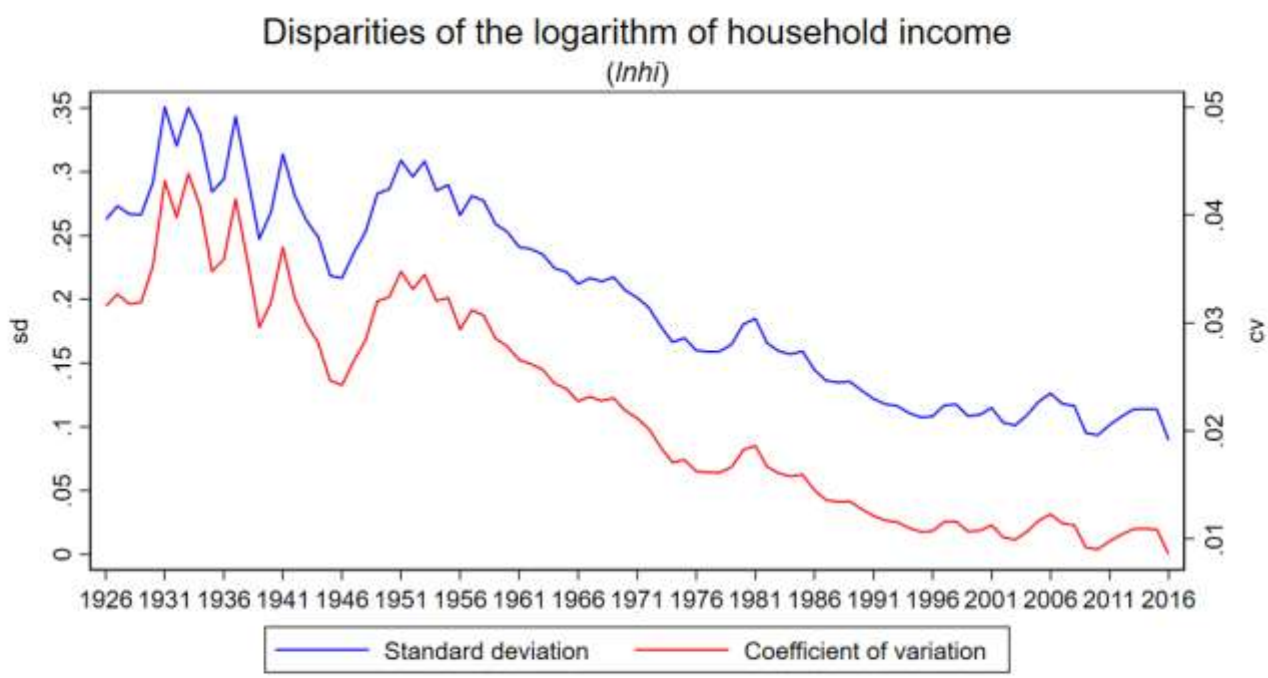
Notes:
Coefficients of *lnD* are represented in the above table.
Relative standard errors in parentheses ().
Dependent variable: Dummy $C_{i,j}$.
Statistically significant *: at the 10% **: at the 5% ***: at the 1%.

Appendix D: Real household income per capita (hi)

The data of household income per capita (*hi*) is from CANSIM Table: 36-10-0229-01[34] too. However, *hi* are divided first with the national CPI. The available period and the subsamples are the same with *hdir* too.

D.1. Sigma convergence

***Figure D1**: Standard deviation and coefficient of variation of the logarithm of household income (lnhi)*



Overall, the pattern of disparities is almost identical to this in *lnhi*.

[34] Long-run provincial and territorial data
https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3610022901

D.2. Absolute convergence

Figure D2: *Logarithm of household income in the initial year (lnhi)*

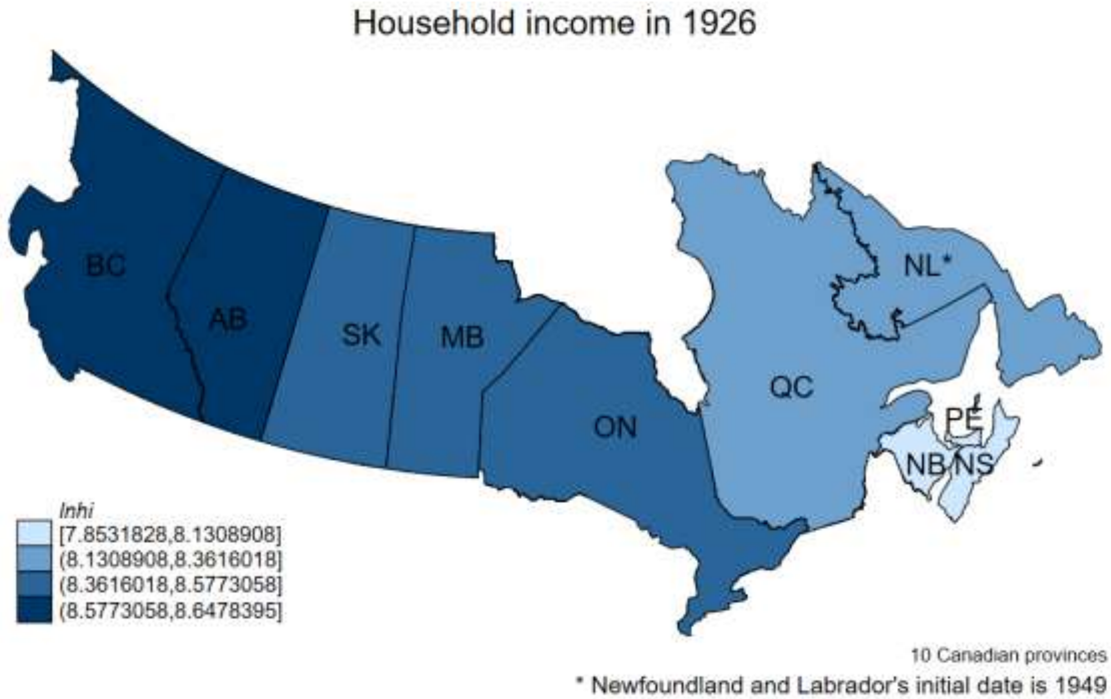
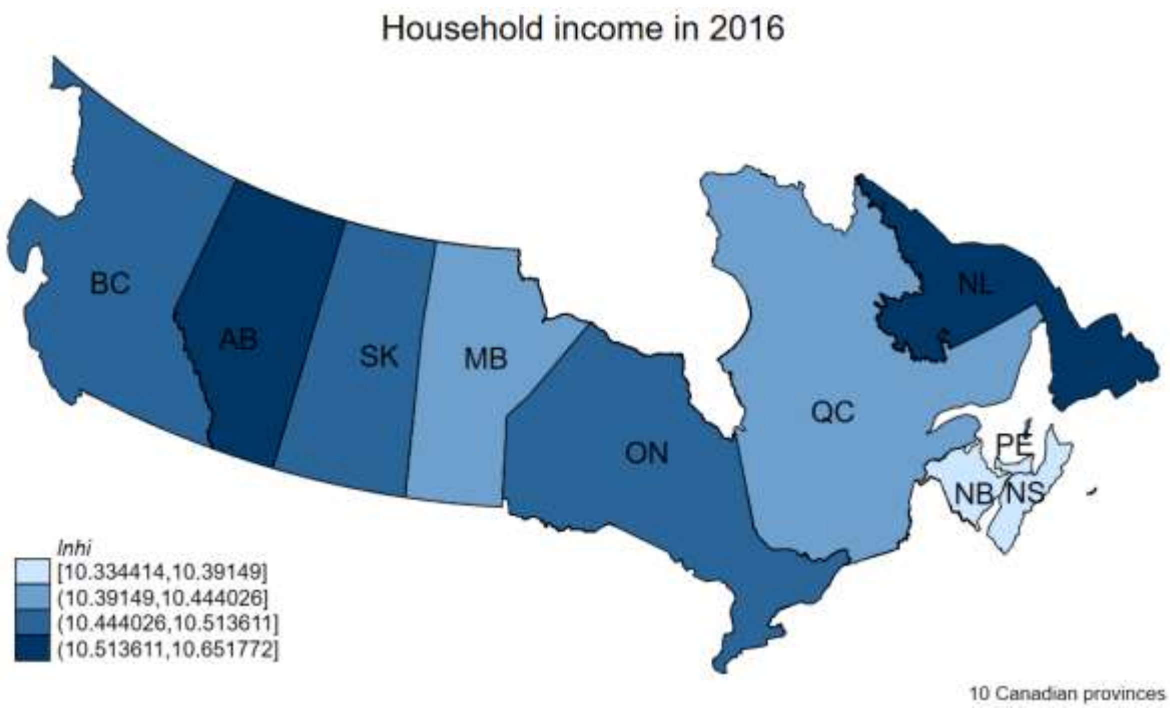


Figure D3: *Logarithm of household income in the final year (lnhi)*



At *Fig. D2* and Fig. D3, it is obvious that there are differences between household disposable income and household income in the final year while the distribution of the logarithm of income is the same for both variables in the year 1926 (as *Fig. 2*). Firstly, in 2016, AB and NL have the highest income while BC, ON, and SK are followed second. Moreover, MB and QC have the second lower income.

At *Table D1*, absolute convergence occurs in the 1927-2016 and 1950-2016 (with and without NL) samples since the coefficients of convergence are negative and statistically significant at the 5%. Although these results are similar to *Appendix C*, comparing the FE Jackknife's coefficients, we observe that the coefficients are reduced in the periods 1927-2016 and 1950-2016, while the coefficient becomes negative and significant in the sample 1950-2016 (without NL).

Comparing these results with those on *lnhdir*, the coefficients of *lnhi* which are statistically significant are common for both variables in the case of unconditional convergence. However, the ones of *lnhi* are lower, in absolute terms[35].

[35] Comparing the results from *lnhi* with the ones from *lnhdi* in the same periods (e.i. the final year is 2016) we can say that the coefficients of absolute convergence are significant for the same dataset, namely 1927-2016 and 1950-2016 (with and without NL). The latter coefficients are higher in absolute terms though.

Table D1: Absolute convergence for the logarithm of the household income (lnhi)

Models / Samples	Pooled OLS	FE	FE Jackknife	RE	Hausman test	PCSE
1927-2016 (No NL)	-0.0119313	-0.0117029	-0.0117029	-0.0119313		-0.0119313
	(0.0050921)**	(0.0032061)***	(0.0032975)***	(0.0031956)***	0.7957	(0.0067549)*
1927-1980 (No NL)	-0.0055671	-0.0041484	-0.0041484	-0.0055671		-0.0055671
	(0.0087927)	(0.008174)	(0.0085973)*	(0.0073968)	0.6544	(0.013654)
1927-1949 (No NL)	-0.0279296	-0.0374163	-0.0374163	-0.0279296		-0.0279296
	(0.021454)	(0.0208987)	(0.0248865)	(0.0179985)	0.6228	(0.0384492)
1950-2016 (No NL)	-0.0185352	-0.0185591	-0.0185591	-0.0185352		-0.0185352
	(0.0053297)***	(0.0025123)***	(0.0025281)***	(0.0025021)***	0.9832	(0.0062884)***
1950-2016	-0.0175479	-0.0170726	-0.0170726	-0.0175479		-0.0175479
	(0.0043929)***	(0.0025189)***	(0.0025659)***	(0.0022354)***	0.6553	(0.0055819)***
1981-2016	-0.0122379	-0.0051565	-0.0051565	-0.0122379		-0.0122379
	(0.0071994)*	(0.0064036)	(0.0070478)	(0.0038059)***	0.0777	(0.0111806)
1996-2016	-0.0135429	-0.0171713	-0.0171713	-0.0146259		-0.0135429
	(0.011861)	(0.0139531)	(0.015261)	(0.0059779)**	0.6627	(0.01643)

Notes:
Coefficients of the previous *lnhi* are represented in the above table. A negative and statistically significant coefficient indicates absolute convergence.
Robust standard errors in parentheses () except for the FE Jackknife (Jackknife standard errors) and PCSE (panel corrected standard errors).
Dependent variable: growth rate of *lnhi*.
Statistically significant *: at the 10% **: at the 5% ***: at the 1% (two-sided t test).

D.3. Stochastic convergence

As happens in previous variables, the unit root and stationarity tests don't support stochastic convergence with an exception for the ZA test in which the number of acceptances of the stationarity is higher than others (*Table D2*). In contrast, with the case of *lnhdi*, cointegration tests (λ_{trace}) show long-run relationships for the periods 1949-2016 and 1981-2016 at the 5% (approximately 64.44% and 57.8% respectively) and 10% (approximately 68.9%[36] and 57.8%[37] respectively) for the majority of pairs (*Table D3*).

***Table D2**: Unit root tests and stationarity test for the logarithm of household income (lnhi)*

Tests / Samples	ADF	KPSS	ZA	ERS	KSS	AESTAR	bootstrapped
1926-2016 (No NL)	5/36	6/36	20/36	9/36	7/36	2/36	3/36
1926-1980 (No NL)	2/36	7/36	16/36	1/36	7/36	2/36	5/36
1949-2016	3/45	5/45	10/45	3/45	9/45	13/45	3/45
1981-2016	3/45	3/45	12/45	2/45	6/45	4/45	7/45

Notes:
Pairwise methods.
Unit root/stationarity tests for income differences among 2 provinces.
The appropriate lag length is selected based on SBIC in ERS unit root test.
There are 45 pairs for the datasets with all 10 provinces while 36 for the datasets without NL (9 provinces).
The numbers indicate the number of tests that the null hypothesis about non-stationarity (stationarity) has been rejected (hasn't been rejected) at the 5% / possible pairs.
There is stochastic convergence if this rate is higher or equal to 50%.

[36] The poorest provinces (NL, PE) are cointegrated with each other and the richest group is cointegrated too. Moreover, the poorest ones are cointegrated with all rich ones in 1949 (AB, BC, MB, ON) and the majority of middle ones, i.e 6/8 (NB, NS, QC, SK) whereas the majority of rich with the middle group are cointegrated too (9/16 pairs).

[37] The poorest provinces (NL, PE), the richest and middle-income groups are cointegrated with each other as separated groups. However, we can't say that there is stochastic convergence among poor provinces with other income groups [Only 2 from 6 pairs for poor-rich (AB, BC, ON) pairs and 4/10 for poor-middle income (MB, NB, NS, QC, SK) pairs]. Nevertheless, it seems that there is convergence among rich provinces with the middle-income group (10/15 pairs).

Table D3: Johansen test for the logarithm of household income (lnhi)

Tests / Samples	Johansen 5%	Johansen 10%	Johansen max 5%	Johansen max 10%
1926-2016 (No NL)	4/36	5/36	2/36	5/36
1926-1980 (No NL)	2/36	1/36	1/36	0/36
1949-2016	29/45	31/45	32/45	31/45
1981-2016	26/45	26/45	27/45	27/45

Notes:
Johansen cointegration test for *lnhi* between 2 provinces.
The appropriate lag length is selected based on SBIC.
There are 45 pairs for the datasets with all 10 provinces while 36 for the datasets without NL (9 provinces).
The numbers indicate the number of tests that there is cointegration at the 5% and 10% / possible pairs.
There is stochastic convergence if this rate is higher or equal to 50%.
The critical values for (λ_{trace}) are 12.53 for null hypothesis r=0 and 3.84 for r=1 at the 5% while there are 10.47 for null hypothesis r=0 and 2.86 for r=1 at the 10%.
The critical values for (λ_{max}) are 11.44 for null hypothesis r=0 and 3.84 for r=1 at the 5% while there are 9.52 for null hypothesis r=0 and 2.86 for r=1 at the 10%.

Furthermore, at *Table D4*, LLC, Breitung, Hadri HS, and DH are against stationarity for the majority of periods. Finally, according to the FE Jackknife model, at *Table D5*, the distance is still a significant determinant for cointegration for the period 1949-2016 which affects negatively and similarly the cointegration's possibility. The results by OLS regressions in the case of Johansen (λ_{max}) at the 10% don't differ. However, in these OLS regressions, although the distance is significant in the period 1926-1980, this correlation is positive. Thus, one increase in distance by 1% will increase the possibility of cointegration by 0.0164013%. It is worth to be mentioned that for the period 1949-2016 there is stochastic convergence among poor provinces NL and PE (based on *hi* in 1949) and among rich ones (AB, BC, MB, ON). Furthermore, all rich provinces are cointegrated with the poor ones and with many middle ones (NB, NS, QC, SK), while it seems that there is convergence among poor with middle-income ones too. On the other hand, in the period 1981-2016 the poorest provinces, NL and PE (based on *hi* in 1981), the richest ones (AL, BC, ON) and middle-income ones (MB, NB, NS, QC, SK) are cointegrated as separated groups but not together, except for the majority of rich-middle income pairs.

***Table D4**: Panel unit root/stationarity tests of household income's differences between provinces (lnhi)*

Tests / Samples	LLC	Tzavalis	Breitung	Breitung with CSD	IPS	Fisher with ADF	Fisher with PP	Hadri LM test	HS	DH
1926-2016 (No NL)	0.182	0	0.1221	0.0068	0	0.0025	0	0	0.2388	0.2574
1926-1980 (No NL)	0.5465	0	0	0.0107	0	0.0558	0	0	0.0328	0.1406
1949-2016	0.0172	0	1	0.3216	0.1363	0.1612	0.0002	0	0.5431	0.8299
1981-2016	0.7773	0.998	1	-	0.9471	0.9752	0.0064	0	0.7461	0.5583

Notes:
p-values are represented.
$p < 0.05$ statistically significant at the 5%.
Unit root/stationarity tests with the null hypothesis that panels aren't stationary.
Hadri stationarity test with the null hypothesis that panels are stationary.

Comparing these results with those on *lnhdir*, stochastic convergence occurs from 1949 to 2016 for both variables, based on Johansen tests (λ_{trace}). In the case of disposable income, the number of pairs which is cointegrated is fewer. However, in non-disposable income, it seems that there is convergence in the period 1981-2016, in contrast to *lnhdir*. About the role of distance, it is negative for the period 1949-2016, where once again this coefficient is higher in the case of non-disposable income. For the same variable, also, in contrast to *lnhdir*, the distance affects positively the possibility of long-run relationships in the period 1926-1980.

__Table D5__: OLS regression for cointegration determinants (Distance among provinces) (lnhi)

Models / Samples	OLS Robust	OLS Jackknife	OLS Bootstrap
1926-2016 (No NL)	0.0485922	0.0485922	0.0485922
	(0.0533262)	(0.0549608)	(0.0619064)
1926-1980 (No NL)	0.0164013	0.0164013	0.0164013
	(0.0177922)	(0.0066948)**	(0.0218218)
1949-2016	-0.2217053	-0.2217053	-0.2217053
	(0.061429)***	(0.0682601)***	(0.0686105)***
1981-2016	-0.0992208	-0.0992208	-0.0992208
	(0.1217635)	(0.1462854)	(0.1299488)

Notes:
Coefficients of *lnD* are represented in the above table.
Relative standard errors in parentheses ().
Dependent variable: Dummy $C_{i,j}$.
Statistically significant *: at the 10% **: at the 5% ***: at the 1%.

Appendix E: Real personal disposable income per capita (pdi)

Analytically, we use personal disposable income per capita from CANSIM Table 36-10-0345[38] for the period 1926-1980 and personal disposable income from CANSIM Table 36-10-0322[39] for the period 1981-2010. After that, we divide the last dataset of personal income by provincial population (CANSIM Table 17-10-0005-01[40]) and we create the personal income per capita (pc). Finally, we divide personal income pc by national CPI.

Moreover, we estimate absolute convergence for the below periods:

1. 1927-2010 (without NL)
2. 1927-1980 (without NL)
3. 1927-1949 (without NL)
4. 1950-2010 (without NL)
5. 1950-2010
6. 1981-2010
7. 1996-2010

And for stochastic convergence:

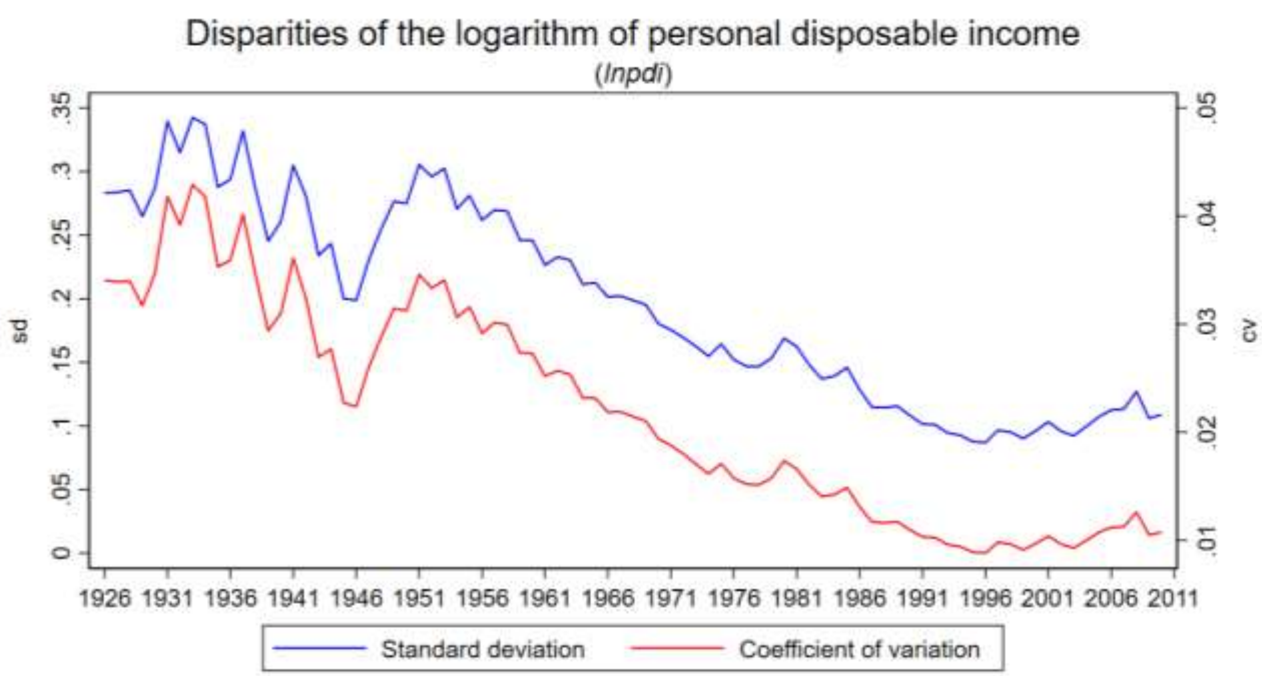
1. 1926-2010
2. 1926-1980
3. 1949-2010

[38] Selected economic indicators, provincial economic accounts, annual, 1926 – 1980
https://open.canada.ca/data/en/dataset/0fcd2d06-d8d8-4623-bcf8-3a574a917796
[39] Sources and disposition of personal income, provincial economic accounts, annual, 1981 – 2010
https://open.canada.ca/data/en/dataset/13906294-b550-4d0a-a58f-ccfa2f4475b8
[40] Population estimates on July 1st, by age and sex
https://www150.statcan.gc.ca/t1/tbl1/en/cv.action?pid=1710000501

E.1. Sigma convergence

Sigma convergence follows similar path to previous variables.

Figure E1: Standard deviation and coefficient of variation of the logarithm of personal disposable income (lnpdi)



E.2. Absolute convergence

At *Fig. E2*, *lnpdi* is represented for the initial year 1926, except for the case of NL whose initial year is 1949. The difference with *lnhdi* is that ON and AB change group each other. However, the distribution of income is the same as this for *lnhdir* in the initial year. At *Fig. E3* are represented the incomes values for the final year of data, namely 2010. AB and ON have the highest income whereas BC, MB, and SK are followed. Finally, the poorest regions are NB, NL, and PE.

Figure E2: Logarithm of personal disposable income in the initial year (lnpdi)

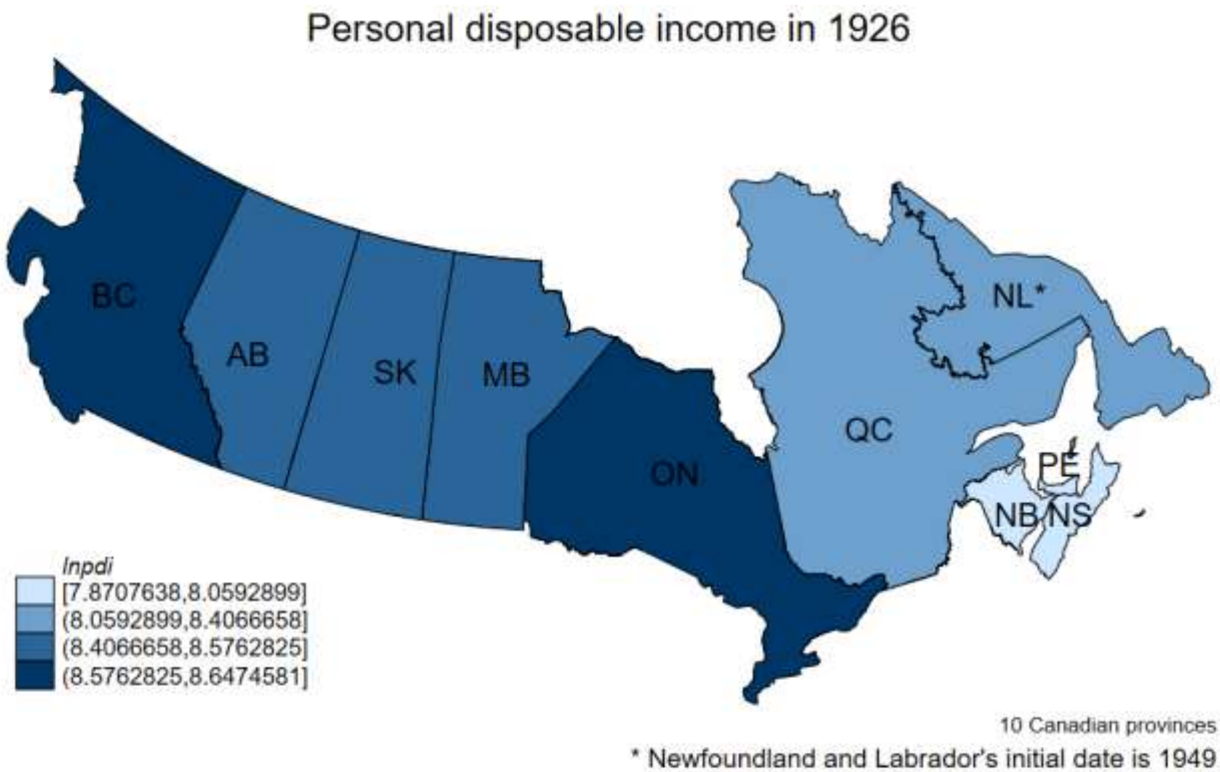


Figure E3: Logarithm of personal disposable income in the final year (lnpdi)

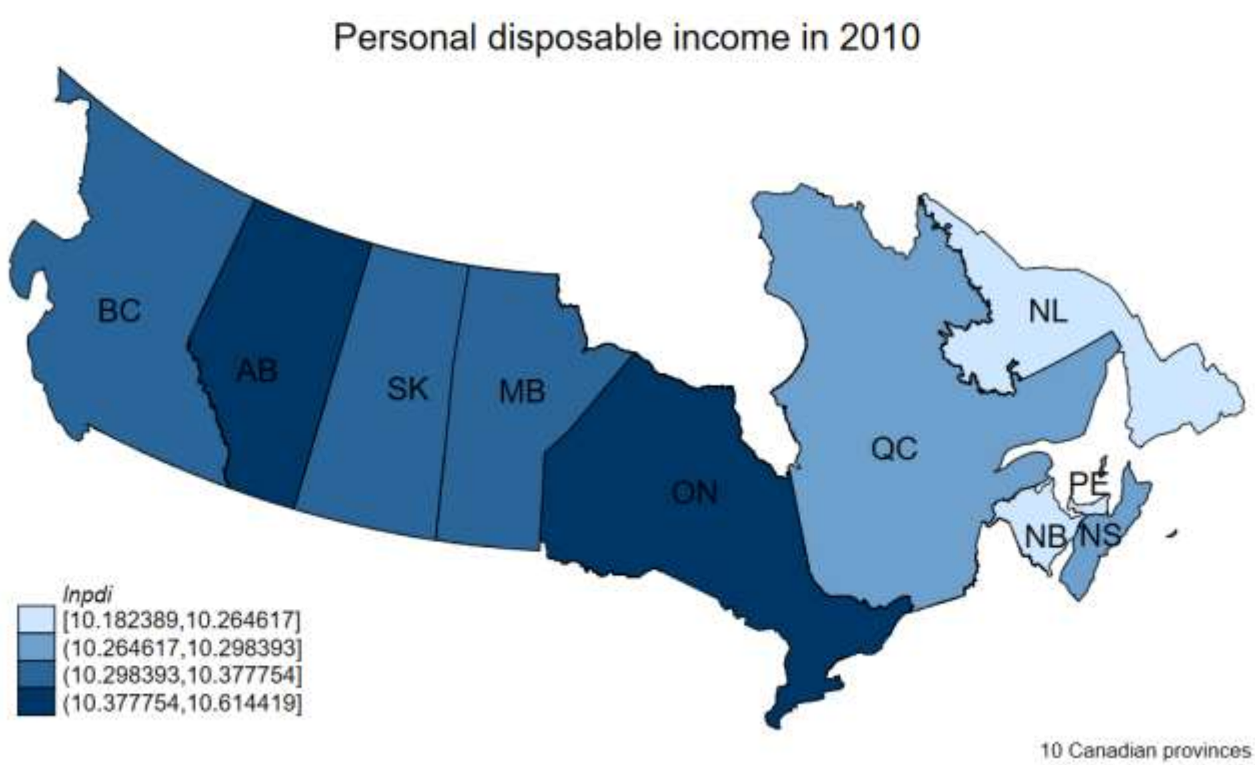


***Table E1**: Absolute convergence for the logarithm of personal disposable income (lnpdi)*

Models / Samples	Pooled OLS	FE	FE Jackknife	RE	Hausman test	PCSE
1927-2010 (No NL)	-0.014532	-0.014301	-0.014301	-0.014532		-0.014532
	(0.0063227)**	(0.0047903)**	(0.0049092)**	(0.0046231)***	0.8578	(0.008272)*
1927-1980 (No NL)	-0.01003	-0.009098	-0.009098	-0.01003		-0.01003
	(0.0098229)	(0.0101793)	(0.0108023)	(0.0087889)	0.8065	(0.0148042)
1927-1949 (No NL)	-0.035816	-0.050057	-0.050057	-0.035816		-0.035816
	(0.0224062)	(0.0232566)*	(0.0283705)	(0.0193602)*	0.5003	(0.0397423)
1950-2010 (No NL)	-0.021314	-0.021553	-0.021553	-0.021314		-0.021314
	(0.0068714)***	(0.0051675)***	(0.0051536)***	(0.0048693)***	0.8975	(0.0082646)***
1950-2010	-0.02047	-0.020346	-0.020346	-0.02047		-0.02047
	(0.0056427)***	(0.0044445)***	(0.0044196)***	(0.0040102)***	0.9444	(0.0072654)***
1981-2010	-0.013707	-0.002884	-0.002884	-0.013707		-0.013707
	(0.0127814)	(0.0135698)	(0.0140285)	(0.0108328)	0.3846	(0.0185074)
1996-2010	0.0102103	0.0104312	0.0104312	0.0102103		0.0102103
	(0.0195651)	(0.0167433)	(0.0182907)	(0.0166313)	0.9909	(0.0253476)

Notes:
Coefficients of the previous *lnpdi* are represented in the above table. A negative and statistically significant coefficient indicates absolute convergence.
Robust standard errors in parentheses () except for the FE Jackknife (Jackknife standard errors) and PCSE (panel corrected standard errors).
Dependent variable: growth rate of *lnpdi*.
Statistically significant *: at the 10% **: at the 5% ***: at the 1% (two-sided t-test).

The results about absolute convergence are similar to previous variables *lnhdir* and *lnhdi* where absolute convergence is supported for periods: 1927-2010 and 1950-2010 (with and without NL) (*Table E1*).

E.3. Stochastic convergence

***Table E2**: Unit root tests and stationarity test for the logarithm of personal disposable income (lnpdi)*

Tests / Samples	ADF	KPSS	ZA	ERS	KSS	AESTAR	bootstrapped
1926-2010 (No NL)	3/36	3/36	23/36	0/36	9/36	7/36	3/36
1926-1980 (No NL)	3/36	7/36	19/36	0/36	9/36	2/36	4/36
1949-2010	3/45	3/45	14/45	3/45	9/45	9/45	4/45

Notes:
Pairwise methods.
Unit root/stationarity tests for income differences among 2 provinces.
The appropriate lag length is selected based on SBIC in ERS unit root test.
There are 45 pairs for the datasets with all 10 provinces while 36 for the datasets without NL (9 provinces).
The numbers indicate the number of tests that the null hypothesis about non-stationarity (stationarity) has been rejected (hasn't been rejected) at the 5% / possible pairs.
There is stochastic convergence if this rate is higher or equal to 50%.

***Table E3**: Johansen test for the logarithm of personal disposable income (lnpdi)*

Tests / Samples	Johansen 5%	Johansen 10%	Johansen max 5%	Johansen max 10%
1926-2010 (No NL)	2/36	6/36	2/36	3/36
1926-1980 (No NL)	8/36	5/36	7/36	5/36
1949-2010	29/45	27/45	28/45	26/45

Notes:
Johansen cointegration test for *lnpdi* between 2 provinces.
The appropriate lag length is selected based on SBIC .
There are 45 pairs for the datasets with all 10 provinces while 36 for the datasets without NL (9 provinces).
The numbers indicate the number of tests that there is cointegration at the 5% and 10% / possible pairs.
There is stochastic convergence if this rate is higher or equal to 50%.
The critical values for (λ_{trace}) are 12.53 for null hypothesis r=0 and 3.84 for r=1 at the 5% while there are 10.47 for null hypothesis r=0 and 2.86 for r=1 at the 10%.
The critical values for (λ_{max}) are 11.44 for null hypothesis r=0 and 3.84 for r=1 at the 5% while there are 9.52 for null hypothesis r=0 and 2.86 for r=1 at the 10%.

Table E4: Panel unit root/stationarity tests of personal disposable income's differences between provinces (lnpdi)

Tests / Samples	LLC	Tzavalis	Breitung	Breitung with CSD	IPS	Fisher with ADF	Fisher with PP	Hadri LM test	HS	DH
1926-2010 (No NL)	0.1604	0	0.1118	0.0099	0	0.0089	0	0	0.1837	0.2105
1926-1980 (No NL)	0.1334	0	0	0.0081	0	0.0113	0	0	0.0266	0.1167
1949-2010	0.0034	0	0.9869	0.1267	0.0003	0.1268	0	0	0.7719	0.7491

Notes:
p-values are represented.
$p < 0.05$ statistically significant at the 5%.
Unit root/stationarity test with the null hypothesis that panels aren't stationary.
Hadri stationarity test with the null hypothesis that panels are stationary.

As happens in the previous variables, the unit root and stationarity tests aren't in favor of stationarity apart from the ZA tests which reject the null hypothesis for 31.1% - 65.7% of the pairs (*Table E2*). Moreover, the Johansen test (λ_{trace}) follows the same direction as previous similar tests in other variables implying that there is stochastic convergence in the period 1949-2010 for 64.44% of pairs at the 5% and 60%[41] at the 10% (*Table E3*). According to panel unit root tests at *Table E4*, we can say that all panels aren't stationary for the majority of tests while some of them are. However, we don't know how many. Finally, at *Table E5*, someone can notice that distance doesn't impact the cointegration's possibility either for the Johansen test (λ_{trace}) or for the Johansen test (λ_{max}).

[41] The middle-income provinces (NB, NS, QC, SK) in 1949 are cointegrated with each other. Similarly, the richest ones (AB, BC, MB, ON) are cointegrated with each other too. The majority of poor provinces (NL, PE) are cointegrated with middle-income ones (4/8 pairs) and with rich ones (7/8 pairs). The rich ones, also, are cointegrated with the middle ones (9/16 pairs).

Table E5: OLS regression for cointegration determinants (Distance among provinces) (lnpdi)

Models / Samples	OLS Robust	OLS Jackknife	OLS Bootstrap
1926-2010 (No NL)	-0.06009	-0.06009	-0.06009
	(0.1069921)	(0.1459972)	(0.1036444)
1926-1980 (No NL)	-0.06537	-0.06537	-0.06537
	(0.0864016)	(0.0997278)	(0.0965571)
1949-2010	0.001594	0.001594	0.001594
	(0.0970592)	(0.1112557)	(0.1022245)

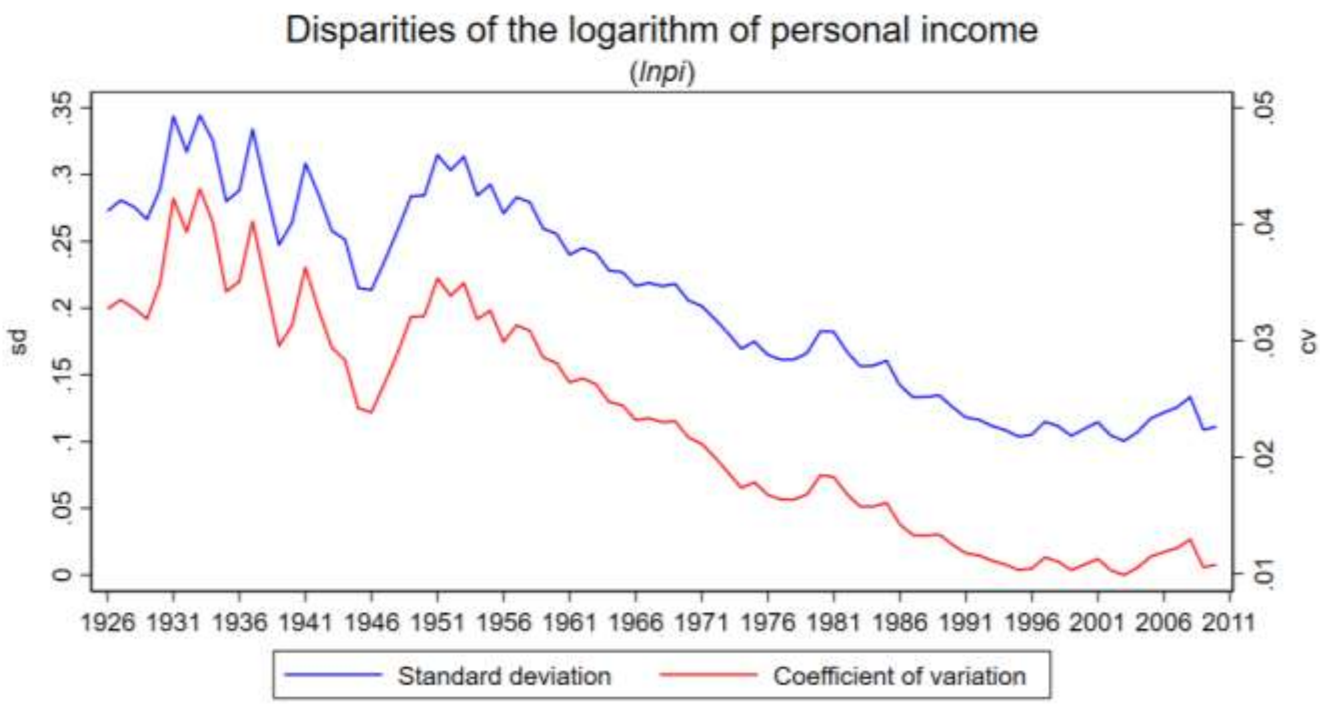
Notes:
Coefficients of *lnD* are represented in the above table.
Relative standard errors in parentheses ().
Dependent variable: Dummy $C_{i,j}$.
Statistically significant *: at the 10% **: at the 5% ***: at the 1%.

Appendix F: Real personal income per capita (pi)

The data sources and subsamples for *pi* are the same as *pdi*.

F.1. Sigma convergence

***Figure F1**: Standard deviation and coefficient of variation of the logarithm of personal income (lnpi)*



F.2. Absolute convergence

The logarithm of personal income in the initial year at *Fig. F2* is distributed similar to *lnhdi*. Regarding incomes values in the final year of 2010 (*Fig. F3*), a comparison with *lnhdi* is better to be avoided because of the significant difference in years. However, these values can be compared with those on *pdi* in the year 2010 (*Fig. E3*). The only changes are that QC takes the place of NB and vice versa and SK takes the place of ON and vice versa.

Figure F2: Logarithm of personal income in the initial year (lnpi)

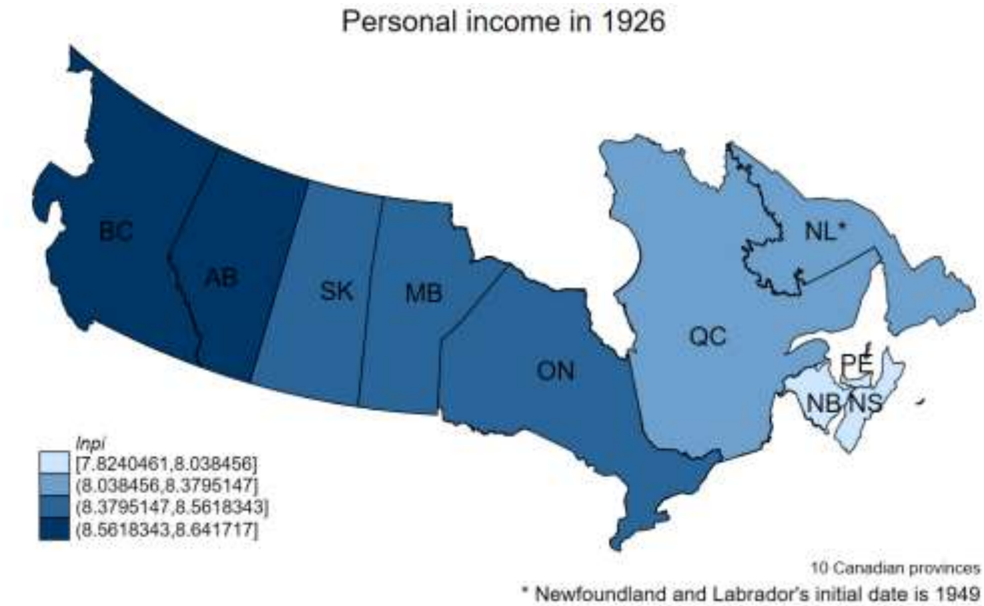
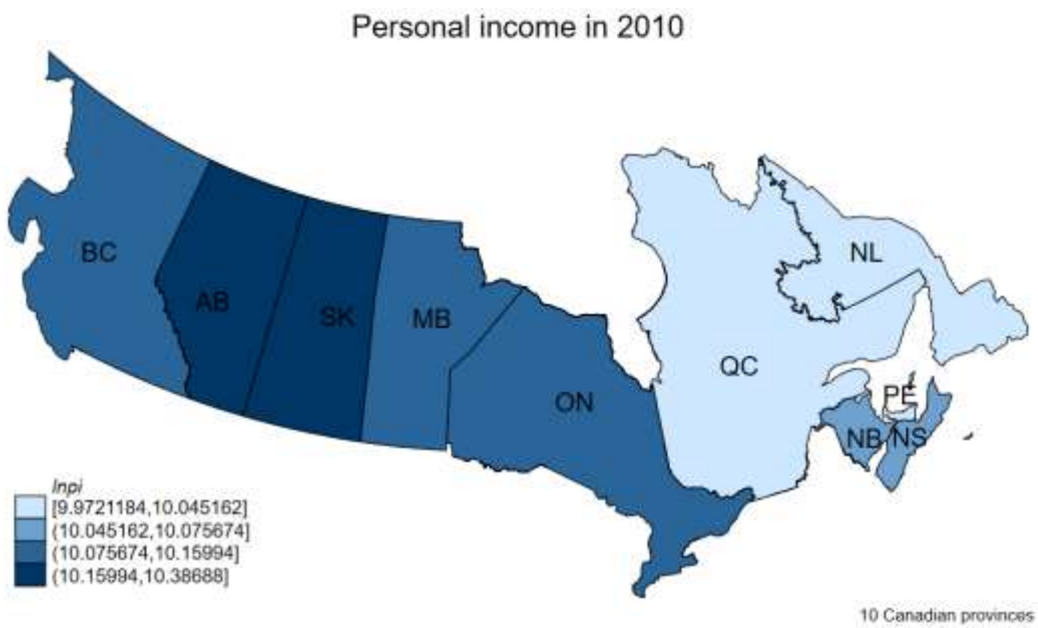


Figure F3: Logarithm of personal income in the final year (lnpi)



It is clear that *lnpi* follows the same pattern as *lnpdi* and therefore it follows a similar path to *lnhdi* in the case of absolute convergence which occurred in 1927-2010, 1950-2010 (without NL) and 1950-2010. The FE Jackknife coefficients, in this case, are lower, in absolute terms, than *lnpdi* and *lnhdi* (only for the case 1950-2020 with NL) but higher, in absolute terms, than the coefficient of *lnhdi* in 1927-2020 (*Table F1*).

Comparing these results with *lnpdi*'s results which end up in the same conclusion, it seems that the coefficients, in this case, are greater indicating a higher speed of convergence.

***Table F1**: Absolute convergence for the logarithm of personal income (lnpi)*

Models / Samples	Pooled OLS	FE	FE Jackknife	RE	Hausman test	PCSE
1927-2010 (No NL)	-0.012582	-0.012398	-0.012398	-0.012582		-0.012582
	(0.005408)**	(0.0036771)***	(0.0037575)**	(0.0036028)***	0.8648	(0.0074556)*
1927-1980 (No NL)	-0.005684	-0.004543	-0.004543	-0.005684		-0.005684
	(0 .0084935)	(0.0081005)	(0.0085177)	(0.0071336)	0.7213	(0.0135979)
1927-1949 (No NL)	-0.027786	-0.037843	-0.037843	-0.027786		-0.027786
	(0.0203862)	(0.0202506)*	(0.0240622)	(0.0173257)	0.6355	(0.0383358)
1950-2010 (No NL)	-0.020317	-0.020589	-0.020589	-0.020317		-0.020207
	(0.0058124)***	(0.0035032)***	(0.003491)***	(0.0033892)***	0.855	(0.0088634)
1950-2010	-0.019687	-0.019665	-0.019665	-0.019687		-0.019687
	(0.0048272)***	(0.0030635)***	(0.0024067)***	(0.0028446)***	0.9878	(0.0063529)***
1981-2010	-0.019726	-0.015634	-0.015634	-0.019726		-0.019726
	(0.0102386)*	(0.0111404)	(0.0114945)	(0.0088192)**	0.6624	(0.0144946)
1996-2010	-0.005157	-0.015004	-0.015004	-0.005319		-0.005157
	(0.0189923)	(0.0143899)	(0.0160996)	(0.0141839)	0.0937	(0.022187)

Notes:
Coefficients of the previous *lnpi* are represented in the above table. A negative and statistically significant coefficient indicates absolute convergence.
Robust standard errors in parentheses () except for the FE Jackknife (Jackknife standard errors) and PCSE (panel corrected standard errors).
Dependent variable: growth rate of *lnpi*.
Statistically significant *: at the 10% **: at the 5% ***: at the 1% (two-sided t test).

F.3. Stochastic convergence

Both *Table F2*, *Table F3*, and *Table F4* show similar results to *lnpdi* about stochastic convergence. According to the majority of (panel) unit root tests and (panel) stationarity test, there is no stochastic convergence. Johansen test (λ_{trace}) agrees with the previous stationarity's methods for the first two samples. It disagrees with *lnhdi* though for the period 1949-2010 since indicates, as do in the case of *lnpdi* too, that there is stochastic convergence for the majority of pairs (approximately 88.89% and 80%[42] respectively) at the 5% and 10%, percentages which is higher than *lnpdi*'s case. Furthermore, in the 1949-2010 period the 3 income groups are cointegrated as a group and among them too. Finally, about the role of distance in cointegration, it seems that the distance has a significant role only for the sample 1927-2010 where the corresponding coefficient is statistically significant at the 5% and positive (FE Jackknife), which is different from the estimations of *lnpdi*, which support that the distance doesn't affect the possibility of cointegration (*Table F5*). If we take into consideration Johansen (λ_{max}) at the 10% then the distance doesn't affect at all the cointegration's possibilities.

[42] The poorest provinces (NL, PE) in 1949 are cointegrated. Similarly, the richest ones (AB, BC, MB, ON, SK) and middle-income ones (NB, NS, QC). The rich ones are cointegrated with the poor ones (7/10 pairs) and with middle-income ones (11/15 pairs) and the middle-income provinces with poor ones (5/6 pairs).

***Table F2**: Unit root tests and stationarity test for the logarithm of personal income (lnpi)*

Tests / Samples	ADF	KPSS	ZA	ERS	KSS	AESTAR	bootstrapped
1926-2010 (No NL)	3/36	3/36	26/36	10/36	9/36	5/36	3/36
1926-1980 (No NL)	2/36	6/36	15/36	1/36	8/36	2/36	4/36
1949-2010	3/45	4//45	19/45	4/45	11/45	13/45	7/45

Notes:
Pairwise methods.
Unit root/stationarity tests for income differences among 2 provinces.
The appropriate lag length is selected based on SBIC in ERS unit root test.
There are 45 pairs for the datasets with all 10 provinces while 36 for the datasets without NL (9 provinces).
The numbers indicate the number of tests that the null hypothesis about non-stationarity (stationarity) has been rejected (hasn't been rejected) at the 5% / possible pairs.
There is stochastic convergence if this rate is higher or equal to 50%.

***Table F3**: Johansen test for the logarithm of personal income (lnpi)*

Tests / Samples	Johansen 5%	Johansen 10%	Johansen max 5%	Johansen max 10%
1926-2010 (No NL)	1/36	4/36	0/36	3/36
1926-1980 (No NL)	3/36	1/36	2/36	0/36
1949-2010	40/45	36/45	31/45	27/45

Notes:
Johansen cointegration test for *lnpi* between 2 provinces.
The appropriate lag length is selected based on SBIC.
There are 45 pairs for the datasets with all 10 provinces while 36 for the datasets without NL (9 provinces).
The numbers indicate the number of tests that there is cointegration at the 5% and 10% / possible pairs.
There is stochastic convergence if this rate is higher or equal to 50%.
The critical values for (λ_{trace}) are 12.53 for null hypothesis r=0 and 3.84 for r=1 at the 5% while there are 10.47 for null hypothesis r=0 and 2.86 for r=1 at the 10%.
The critical values for (λ_{max}) are 11.44 for null hypothesis r=0 and 3.84 for r=1 at the 5% while there are 9.52 for null hypothesis r=0 and 2.86 for r=1 at the 10%.

***Table F4**: Panel unit root/stationarity tests of personal income's differences between provinces (lnpi)*

Tests / Samples	LLC	Tzavalis	Breitung	Breitung with CSD	IPS	Fisher with ADF	Fisher with PP	Hadri LM test	HS	DH
1926-2010 (No NL)	0.3944	0	0.1423	0.0108	0	0.0092	0	0	0.1837	0.1764
1926-1980 (No NL)	0.5532	0	0	0.0106	0	0.0457	0	0	0.0314	0.1247
1949-2010	0.015	0	0.9997	0.187	0.0354	0.1287	0	0	0.5745	0.862

Notes:
p-values are represented.
$p < 0.05$ statistically significant at the 5%.
Unit root/stationarity tests with the null hypothesis that panels aren't stationary.
Hadri stationarity test with the null hypothesis that panels are stationary.

***Table F5**: OLS regression for cointegration determinants (Distance among provinces) (lnpi)*

Models / Samples	OLS Robust	OLS Jackknife	OLS Bootstrap
1926-2010 (No NL)	-0.0455605	-0.0455605	-0.0455605
	(0.0690502)	(0.0832702)	(0.0804484)
1926-1980 (No NL)	0.0198071	0.0198071	0.0198071
	(0.0213372)	(0.0077134)**	(0.0259865)
1949-2010	-0.0056422	-0.0056422	-0.0056422
	(0.1127631)	(0.1368188)	(0.1164876)

Notes:
Coefficients of *lnD* are represented in the above table.
Relative standard errors in parentheses ().
Dependent variable: Dummy $C_{i,j}$.
Statistically significant *: at the 10% **: at the 5% ***: at the 1%.

Appendix G: House price measures

According to Holmes et al. (2011), fluctuations in regional house prices can affect relative regional economic activity while Meen (1999) claims that there is a ripple effect between regional house prices and the economy. Thus, we use the house price index (*i*), the seasonally adjusted house price index (*sai*) and the sales pair count (*sp*) from Teranet–National Bank House Price Index[43] for 11 metropolitan areas, namely, Calgary (CL), Edmonton (ED), Halifax (HL), Hamilton (HM), Montreal (MR), Ottawa (OT), Quebec (QCc), Toronto (TR), Vancouver (VN), Victoria (VC) and Winnipeg (WN).

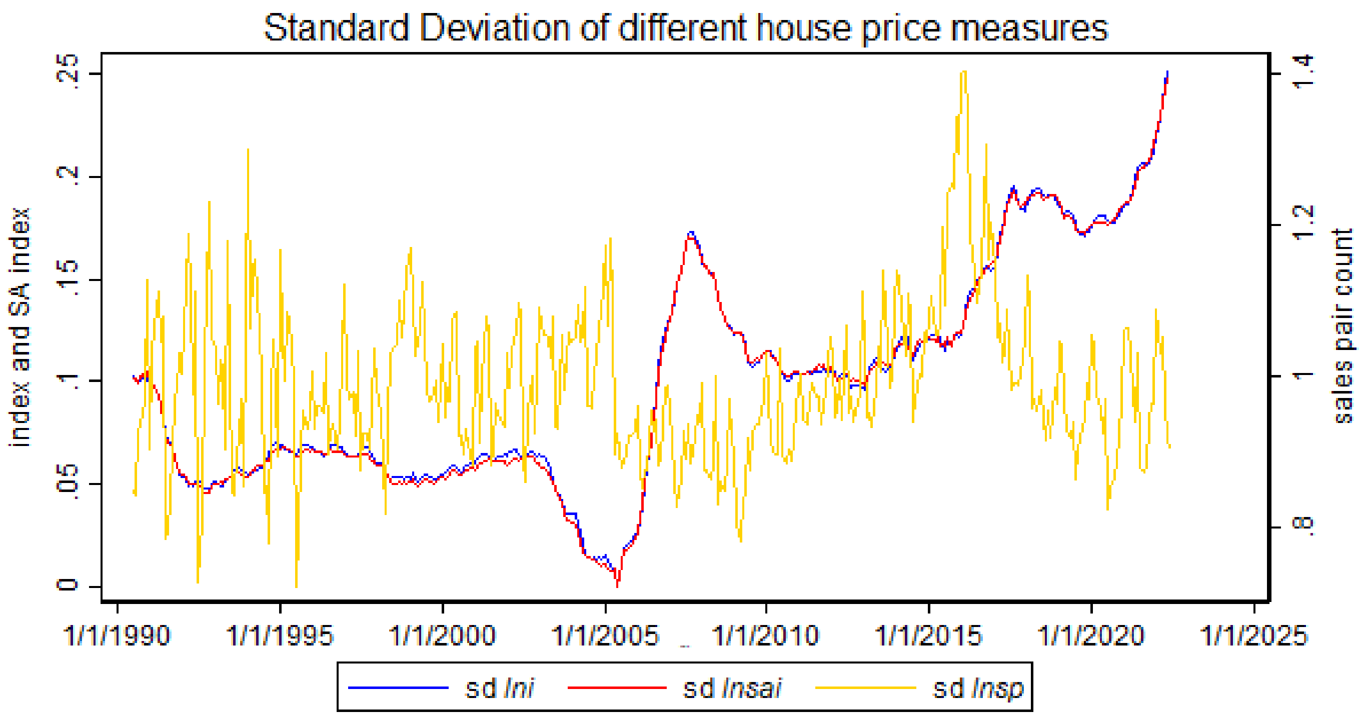
We separate the sample into subperiods: 1990M7-2022M6 and 1990M7-2005M5 with 6 cities (HL, MR, QCc, VN, VC, WN), 1998M7-2005M5 with 9 cities (HL, HM, MR, OT, QCc, TR, VN, VC, WN) and 1999M3-2005M5, 2005M6-2022M6, 2005M6-2007M8 (only for absolute convergence) and 2007M9-2022M6 with all 11 cities.

G.1. Sigma convergence

In *Fig. G1*, the standard deviation is represented for all house price measures. It is clear that not only there isn't convergence for indices but in the cases of *lni* and *lnsai* there is divergence since the disparities of these measures have increased. We follow the same approach with incomes, namely the standard deviation is represented for 6 cities until 1998M6 and after that for 9 cities until 1999M5. Finally, standard deviation is represented for all 11 cities since 1999M6.

43 https://housepriceindex.ca/#maps=c11

Figure G1: Standard deviation of the logarithm of different house price measures



G.2. Absolute convergence

Regarding the house price index and the seasonally adjusted house price index, there is a divergence for the majority of subperiods, especially before 2005 and after 2007 (*Tables G1* and *G2*). However, in the case of sales pair counts, the results are different since they indicate that there is convergence, which is stronger than the previous divergence (more higher coefficients in absolute terms) in all samples (*Table G3*).

Table G1: Absolute convergence for the logarithm of the house price index (lni)

Models/ Samples	Pooled OLS	FE	FE Jackknife	RE	PCSE
8/90-6/22+	0.0029	0.002926	0.002926	0.002914	0.0029
	(0.0003871)***	(0.0006202)***	(0.0005998)***	(0.0006147)***	(0.0006097)***
8/90-5/05+	0.015336	0.017266	0.017266	0.016255	0.015336
	(0.0015849)***	(0.0019987)***	(0.0020003)***	(0.0020668)***	(0.0018023)***
8/98-5/05++	0.012372	0.015216	0.015216	0.012372	0.012372
	(0.0015156)***	(0.0037214)***	(0.00379)***	(0.0031026)***	(0.0024829)***
4/99-5/05	0.008592	0.011383	0.011383	0.008592	0.008592
	(0.0012812)***	(0.0033569)***	(0.0034278)***	(0.0026302)***	(0.002332)***
6/05-6/22	0.003507	0.003657	0.003657	0.003601	0.003507
	(0.0009637)***	(0.0029742)	(0.0030057)	(0.0028624)	(0.0016623)**
6/05-8/07	0.041799	0.018023	0.018023	0.041799	0.041799
	(0.0065566)***	(0.011995)	(0.0163603)	(0.0095319)***	(0.0101773)***
9/07-6/22	0.008887	0.01062	0.01062	0.010406	0.008887
	(0.0011373)***	(0.0023647)***	(0.0023937)***	(0.0022634)***	(0.0018678)***

Notes:
Coefficients of the previous *lni* are represented in the above table. A negative and statistically significant coefficient indicates absolute convergence.
Robust standard errors in parentheses () except for the FE Jackknife (Jackknife standard errors) and PCSE (panel corrected standard errors).
+: Dataset with 6 cities.
++: Dataset with 9 cities.
Dependent variable: growth rate of *lni*.
Statistically significant *: at the 10% **: at the 5% ***: at the 1% (two-sided t test).

Table G2: Absolute convergence for the logarithm of the seasonally adjusted house price index (lnsai)

Models/ Samples	Pooled OLS	FE	FE Jackknife	RE	PCSE
8/90-6/22+	0.002829	0.002854	0.002854	0.002845	0.002829
	(0.000334)***	(0.0005975)	(0.0005784)***	(0.0005936)	(0.0004854)***
8/90-5/05+	0.015109	0.016948	0.016948	0.016242	0.015109
	(0.001327)***	(0.0020393)***	(0.0020369)***	(0.002069)***	(0.0013253)***
8/98-5/05++	0.012122	0.014619	0.014619	0.012122	0.012122
	(0.0013102)***	(0.0037193)***	(0.0037867)***	(0.003134)***	(0.0017082)***
4/99-5/05	0.009142	0.011718	0.011718	0.009142	0.009142
	(0.0010707)***	(0.0033003)***	(0.0033688)***	(0.0026219)***	(0.0015211)***
6/05-6/22	0.003504	0.003648	0.003648	0.003609	0.003504
	(0.0008058)***	(0.0029103)	(0.0029474)	(0.00283)	(0.0011743)***
6/05-8/07	0.037525	0.012628	0.012628	0.034262	0.037525
	(0.0056737)***	(0.0119543)	(0.01634)	(0.0095816)***	(0.0083277)***
9/07-6/22	0.008557	0.010163	0.010163	0.010032	0.008557
	(0.0009215)***	(0.0023466)***	(0.0023815)***	(0.0022829)***	(0.0013022)***

Notes:
Coefficients of the previous *lnsai* are represented in the above table. A negative and statistically significant coefficient indicates absolute convergence.
Robust standard errors in parentheses () except for the FE Jackknife (Jackknife standard errors) and PCSE (panel corrected standard errors).
+: Dataset with 6 cities.
++: Dataset with 9 cities.
Dependent variable: growth rate of *lnsai*.
Statistically significant *: at the 10% **: at the 5% ***: at the 1% (two-sided t test).

***Table G3**: Absolute convergence for the logarithm of the sales pair count (lnsp)*

Models/ Samples	Pooled OLS	FE	FE Jackknife	RE	PCSE
8/90-6/22+	-0.05265	-0.23493	-0.23493	-0.13862	-0.05265
	(0.0071215)***	(0.0141912)***	(0.0146442)***	(0.0246148)***	(0.0063212)***
8/90-5/05+	-0.05971	-0.24779	-0.24779	-0.12931	-0.05971
	(0.0112977)***	(0.028762)***	(0.0298561)***	(0.0234949)***	(0.0107551)***
8/98-5/05++	-0.04548	-0.27515	-0.27515	-0.04548	-0.04548
	(0.0134545)***	(0.0339111)***	(0.0346146)***	(0.0155893)***	(0.0128816)***
4/99-5/05	-0.05664	-0.32184	-0.32184	-0.05804	-0.05664
	(0.0147985)***	(0.0463067)***	(0.0480675)***	(0.0194108)***	(0.0144426)***
6/05-6/22	-0.04999	-0.20935	-0.20935	-0.06586	-0.04999
	0.006971	(0.0188171)***	(0.0190089)***	(0.0186588)***	(0.0069355)***
6/05-8/07	-0.04735	-0.27318	-0.27318	-0.04735	-0.04735
	(0.0200005)**	(0.021941)***	(0.0229064)***	(0.0208652)**	(0.0210244)***
9/07-6/22	-0.0503	-0.20472	-0.20472	-0.05868	-0.0503
	(0.0074367)***	(0.021907)***	(0.0221902)***	(0.0168946)***	(0.0073395)***

Notes:
Coefficients of the previous *lnsp* are represented in the above table. A negative and statistically significant coefficient indicates absolute convergence.
Robust standard errors in parentheses () except for the FE Jackknife (Jackknife standard errors) and PCSE (panel corrected standard errors).
+: Dataset with 6 cities.
++: Dataset with 9 cities.
Dependent variable: growth rate of *lnsp*.
Statistically significant *: at the 10% **: at the 5% ***: at the 1% (two-sided t test).

It is important to be mentioned that according to Andre et al. (2022) house price indices can show divergence if the first observation is taken as the base year while they can show convergence if the last observation is taken as the base year. Thus, they solve this problem by taking house prices in level. However, the index by Teranet–National Bank is constructed based on "repeat sales methodology"[44] using pre-base indices and post-base indices. The post-base indices are dependent upon previous indices but not on all future ones. For this reason, these indices can possibly show divergence while actually there isn't. So, we use the seasonally adjusted composite benchmark price (*cbp*) from Canadian Real Estate Association's Multiple Listing Service dataset (CREA MLS[45]) for the same 11 cities for the monthly period 2005M1-2022M9.

The results confirm that there is, indeed, divergence after 2007 (*Table G4*).

Table G4*: Absolute convergence for the logarithm of the composite benchmark price (lncbp)*

Models/ Samples	**11 cities**
2/2005-9/2022	0.002024
	(0.0020358)
1/2007-9/2022	0.00632
	(0.0017258)***

Notes:
Coefficients of the previous *lncbp* are represented in the above table. A negative and statistically significant coefficient indicates absolute convergence.
Jackknife standard errors in parentheses ().
Dependent variable: growth rate of *lncbp*.
Statistically significant *: at the 10% **: at the 5% ***: at the 1% (two-sided t test).

[44] https://housepriceindex.ca/wp-content/uploads/2017/08/Teranet-National-Bank-House-Price-Index-Methodology-Overview.pdf
[45] https://www.crea.ca/housing-market-stats/mls-home-price-index/hpi-tool/

Moreover, using the average rent prices from CANSIM Table: 34-10-0133-01[46] for the annual period 1993-2021 for the same 11 cities, we find that there isn't convergence (FE Jackknife). However, taking into consideration the residential property value for the annual period 2006-2015 from CANSIM Table: 34-10-0013-01[47], we conclude that there is convergence among provinces, among the 11 same cities and among the 33 cities[48] (FE Jackknife).

G.3. Stochastic convergence

It is clear that there isn't stochastic convergence for the house price index and seasonally adjusted house price index according to the unit root tests and stationarity test. However, there is stochastic convergence for the sales pair count (*Tables G5*, *G6* and *G7*).

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[46] Canada Mortgage and Housing Corporation, average rents for areas with a population of 10,000 and over https://www150.statcan.gc.ca/t1/tbl1/en/cv.action?pid=3410013301&fbclid=IwAR3Y7zWz5wosn20diLNYgeP2aLRKJObrA56ckmJM81qqkJw_Q5njuY8y1zs

[47] Residential property values (x 1,000,000) https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3410001301

[48] City (Province): Abbotsford-Mission (BC), Barrie (ON), Brantford (ON), Calgary (AB), Edmonton (AB), Greater Sudbury (ON), Guelph (ON), Halifax (NS), Hamilton (ON), Kelowna (BC), Kingston (ON), Kitchener-Cambridge-Waterloo (ON), London (ON), Moncton (NB), Montréal (QC), Oshawa (ON), Ottawa-Gatineau (ON/QC), Peterborough (ON), Québec city (QC), Regina (SK), Saguenay (QC), Saint John (NB), Saskatoon (SK), Sherbrooke (QC), St. Catharines-Niagara (ON), St. John's (NL), Thunder Bay (ON), Toronto (ON), Trois-Rivières (QC), Vancouver (BC), Victoria (BC), Windsor (ON), Winnipeg (MB).

Table G5: Unit root tests and stationarity test for the logarithm of the house price index (lni)

Tests / Samples	ADF	KPSS	ZA	ERS	KSS	AESTAR	bootstrapped
7/90-6/22+	1/15	0/15	0/15	0/15	1/15	5/15	0/15
7/90-5/05+	3/15	0/15	0/15	0/15	6/15	8/15	3/15
7/98-5/05++	0/36	3/36	4/36	0/36	1/36	3/36	0/36
3/99-5/05	0/55	12/55	16/55	0/55	2/55	6/55	2/55
6/05-6/22	0/55	0/55	1/55	0/55	5/55	14/55	1/55
9/07-6/22	1/55	0/55	1/55	0/55	3/55	13/55	3/55

Notes:
Pairwise methods.
Unit root/stationarity tests for income differences among 2 cities.
The appropriate lag length is selected based on SBIC in ERS unit root test.
There are 55 pairs for the datasets with all 11 cities.
+: There are 15 pairs for the datasets with all 6 cities.
++: There are 36 pairs for the dataset with 9 cities.
The numbers indicate the number of tests that the null hypothesis about non-stationarity (stationarity) has been rejected (hasn't been rejected) at the 5% / possible pairs.
There is stochastic convergence if this rate is higher or equal to 50%.

Table G6: Unit root tests and stationarity test for the logarithm of the seasonally adjusted house price index (lnsai)

Tests / Samples	ADF	KPSS	ZA	ERS	KSS	AESTAR	bootstrapped
7/90-6/22+	0/15	0/15	0/15	0/15	1/15	3/14	1/15
7/90-5/05+	4/15	0/15	0/15	0/15	5/15	7/15	4/15
7/98-5/05++	0/36	4/36	1/36	0/36	0/36	6/36	1/36
3/99-5/05	0/55	5/55	4/55	0/55	3/55	9/55	0/55
6/05-6/22	1/55	0/55	0/55	1/55	4/55	10/55	1/55
9/07-6/22	2/55	0/55	0/55	0/55	1/55	11/55	2/55

Notes:
Pairwise methods.
Unit root/stationarity tests for income differences among 2 cities.
The appropriate lag length is selected based on SBIC in ERS unit root test.
There are 55 pairs for the datasets with all 11 cities.
+: There are 15 pairs for the datasets with all 6 cities.
++: There are 36 pairs for the dataset with 9 cities.
The numbers indicate the number of tests that the null hypothesis about non-stationarity (stationarity) has been rejected (hasn't been rejected) at the 5% / possible pairs.
There is stochastic convergence if this rate is higher or equal to 50%.

Table G7: Unit root tests and stationarity test for the logarithm of the sales pair count (lnsp)

Tests / Samples	ADF	KPSS	ZA	ERS	KSS	AESTAR	bootstrapped
7/90-6/22+	15/15	1/15	15/15	15/15	15/15	15/15	15/15
7/90-5/05+	15/15	7/15	15/15	13/15	15/15	14/15	15/15
7/98-5/05++	35/36	19/36	31/36	31/36	33/36	33/36	35/36
3/99-5/05	51/55	32/55	44/55	47/55	51/55	47/55	53/55
6/05-6/22	48/55	6/55	51/55	50/55	49/55	48/55	48/55
9/07-6/22	47/55	7/55	49	48/55	49/55	49/55	47/55

Notes:
Pairwise methods.
Unit root/stationarity tests for income differences among 2 cities.
The appropriate lag length is selected based on SBIC in ERS unit root test.
There are 55 pairs for the datasets with all 11 cities.
+: There are 15 pairs for the datasets with all 6 cities.
++: There are 36 pairs for the dataset with 9 cities.
The numbers indicate the number of tests that the null hypothesis about non-stationarity (stationarity) has been rejected (hasn't been rejected) at the 5% / possible pairs.
There is stochastic convergence if this rate is higher or equal to 50%.

Nevertheless, the results of the index change when we run the Johansen cointegration tests. Now, in these cases, there is stochastic convergence for all subperiods and for all house prices measures with the lowest percentages of the cointegrated cities to be around 73%, 67% and 81% of pairs for *lni*, *lnsai* and *lnsp* respectively.

Table G8: Johansen test for the logarithm of the house price index (lni)

Tests / Samples	Johansen 5%	Johansen 10%	Johansen max 5%	Johansen max 10%
7/90-6/22^{+}	13/15	12/15	13/15	12/15
7/90-5/05^{+}	12/15	11/15	12/15	11/15
7/98-5/05^{++}	28/36	27/36	28/36	27/36
3/99-5/05	42/55	40/55	42/55	40/55
6/05-6/22	51/55	49/55	51/55	50/55
9/07-6/22	43/55	43/55	43/55	43/55

Notes:
Johansen cointegration test for *lni* between 2 cities.
The appropriate lag length is selected based on SBIC.
There are 55 pairs for the datasets with all 11 cities.
$^{+}$: There are 15 pairs for the datasets with all 6 cities.
$^{++}$: There are 36 pairs for the dataset with 9 cities.
The numbers indicate the number of tests that there is cointegration at the 5% and 10% / possible pairs.
There is stochastic convergence if this rate is higher or equal to 50%.
The critical values for (λ_{trace}) are 12.53 for null hypothesis r=0 and 3.84 for r=1 at the 5% while there are 10.47 for null hypothesis r=0 and 2.86 for r=1 at the 10%.
The critical values for (λ_{max}) are 11.44 for null hypothesis r=0 and 3.84 for r=1 at the 5% while there are 9.52 for null hypothesis r=0 and 2.86 for r=1 at the 10%.

Table G9: Johansen test for the logarithm of the seasonally adjusted house price index (lni)

Tests / Samples	Johansen 5%	Johansen 10%	Johansen max 5%	Johansen max 10%
7/90-6/22+	13/15	12/15	13/15	12/15
7/90-5/05+	10/15	10/15	10/15	10/15
7/98-5/05++	29/36	26/36	29/36	26/36
3/99-5/05	41/55	34/55	41/55	35/55
6/05-6/22	50/55	51/55	52/55	50/55
9/07-6/22	40/55	45/55	42/55	44/55

Notes:
Johansen cointegration test for *lnsai* between 2 cities.
The appropriate lag length is selected based on SBIC.
There are 55 pairs for the datasets with all 11 cities.
+: There are 15 pairs for the datasets with all 6 cities.
++: There are 36 pairs for the dataset with 9 cities.
The numbers indicate the number of tests that there is cointegration at the 5% and 10% / possible pairs.
There is stochastic convergence if this rate is higher or equal to 50%.
The critical values for (λ_{trace}) are 12.53 for null hypothesis r=0 and 3.84 for r=1 at the 5% while there are 10.47 for null hypothesis r=0 and 2.86 for r=1 at the 10%.
The critical values for (λ_{max}) are 11.44 for null hypothesis r=0 and 3.84 for r=1 at the 5% while there are 9.52 for null hypothesis r=0 and 2.86 for r=1 at the 10%.

Table G10: Johansen test for the logarithm of the sales pair count (lnsp)

Tests / Samples	Johansen 5%	Johansen 10%	Johansen max 5%	Johansen max 10%
7/90-6/22+	15/15	15/15	15/15	15/15
7/90-5/05+	15/15	15/15	15/15	15/15
7/98-5/05++	32/36	32/36	32/36	32/36
3/99-5/05	47/55	50/55	48/55	51/55
6/05-6/22	45/55	48/55	46/55	51/55
9/07-6/22	45/55	50/55	49/55	51/55

Notes:
Johansen cointegration test for *lnsp* between 2 cities.
The appropriate lag length is selected based on SBIC.
There are 55 pairs for the datasets with all 11 cities.
+: There are 15 pairs for the datasets with all 6 cities.
++: There are 36 pairs for the dataset with 9 cities.
The numbers indicate the number of tests that there is cointegration at the 5% and 10% / possible pairs.
There is stochastic convergence if this rate is higher or equal to 50%.
The critical values for (λ_{trace}) are 12.53 for null hypothesis r=0 and 3.84 for r=1 at the 5% while there are 10.47 for null hypothesis r=0 and 2.86 for r=1 at the 10%.
The critical values for (λ_{max}) are 11.44 for null hypothesis r=0 and 3.84 for r=1 at the 5% while there are 9.52 for null hypothesis r=0 and 2.86 for r=1 at the 10%.

We, also, refer to results of composite benchmark price which agree with house price index results. In the case of the Johansen tests, the lowest rate of cointegrated cities reaches at 60% of pairs.

***Table G11**: Unit root tests and stationarity test for the logarithm of the composite benchmark price (lncbp)*

Tests/ Samples	ADF	KPSS	ZA	ERS	KSS	AESTAR	bootstrapped
1/2005-9/2022	0/55	0/55	2/55	1/55	10/55	17/55	0/55
1/2007-9/2022	1/55	1/55	2/55	0/55	8/55	25/55	2/55

<u>*Notes*</u>:
Pairwise methods.
Unit root/stationarity tests for income differences among 2 cities.
The appropriate lag length is selected based on SBIC in ERS unit root test.
There are 55 pairs for the datasets with all 11 cities.
The numbers indicate the number of tests that the null hypothesis about non-stationarity (stationarity) has been rejected (hasn't been rejected) at the 5% / possible pairs.
There is stochastic convergence if this rate is higher or equal to 50%.

***Table G12**: Johansen test for the logarithm of the composite benchmark price (lncbp)*

Tests/ Samples	Johansen 5%	Johansen 10%	Johansen max 5%	Johansen max 10%
1/2005-9/2022	38/55	39/55	38/55	39/55
1/2007-9/2022	33/55	37/55	35/55	36/55

<u>*Notes*</u>:
Johansen cointegration test for *lncbp* between 2 cities.
The appropriate lag length is selected based on SBIC.
There are 55 pairs for the datasets with all 11 cities.
The numbers indicate the number of tests that there is cointegration at the 5% and 10% / possible pairs
There is stochastic convergence if this rate is higher or equal to 50%.
The critical values for (λ_{trace}) are 12.53 for null hypothesis r=0 and 3.84 for r=1 at the 5% while there are 10.47 for null hypothesis r=0 and 2.86 for r=1 at the 10%.
The critical values for (λ_{max}) are 11.44 for null hypothesis r=0 and 3.84 for r=1 at the 5% while there are 9.52 for null hypothesis r=0 and 2.86 for r=1 at the 10%.

In regards to the importance of distance in cointegration, it is obvious that in the majority of cases the distance doesn't affect significantly the possibility of cointegration. The only case that the distance has a statistically significant impact in this possibility is the period 1999M3-2005M5 for seasonally adjusted house price index (*Tables G13* and *G14*).

Table G13*: OLS regression for cointegration determinants (Distance among cities)*

Variables/ Samples	***lni***	***lnsai***	***Lnsp***
7/98-5/05	-0.0580715	-0.0400897	0.0235668
	(0.0512758)	(0.0515166)	(0.0369961)
3/99-5/05	-0.0654646	-0.0953248	-0.0133183
	(0.0453012)	(0.0468572)**	(0.0226483)
6/05-6/22	0.0463671	0.004823	-0.0072357
	(0.0395614)	(0.0168458)	(0.0502099)
9/07-6/22	0.0493694	-0.000246	-0.0257456
	(0.0506836)	(0.0398295)	(0.0418253)

Notes:
Coefficients of *lnD* are represented in the above table.
Jackknife standard errors in parentheses ().
Dependent variable: Dummy $C_{i,j}$.
Statistically significant *: at the 10% **: at the 5% ***: at the 1%.

Table G14*: OLS regression for cointegration determinants (Distance among cities) (lncbp)*

Tests / Samples	**OLS Robust**	**OLS Jackknife**	**OLS Bootstrap**
1/2005-9/2022	-0.0612753	-0.0612753	-0.0612753
	(0.0563209)	(0.0608732)	(0.0589925)
1/2007-9/2022	-0.0047341	-0.0047341	-0.0047341
	(0.0559277)	(0.0597618)	(0.0564674)

Notes:
Coefficients of *lnD* are represented in the above table.
Relative standard errors in parentheses ().
Dependent variable: Dummy $C_{i,j}$.
Statistically significant *: at the 10% **: at the 5% ***: at the 1%.

Briefly, the only case that the house price data we use supports convergence is when the sales pair count measure is used.

Appendix H: Club convergence in Canadian provinces (Phillips and Sul, 2007)

A model with a time varying factor representation is

$$lnhdi_{i,t} = \delta_{i,t}\mu_t \qquad \text{(H.1)}$$

where,

$$\delta_{i,t} = \delta_i + \sigma_i \xi_{i,t} L(t)^{-1} t^{-a} \qquad \text{(H.2)}$$

where,

$\delta_{i,t}$= a *transition parameter* since describes the transition path of economy i to the steady state growth path

μ_t = a *common growth component*, the hypothesized steady state growth path common to all i

δ_i = is fixed

$\xi_{i,t}$ ~ iid (0,1)

$L(t)$ = a slowly varying function (like log t) for which $L(t) \rightarrow \infty$ as $t \rightarrow \infty$

The Phillips and Sul (2007) procedure is, basically, a regression t test of the null hypothesis of convergence:

$$H_0 : \delta_i = \delta \text{ and } \alpha \geq 0 , \quad \text{overall convergence}$$
$$H_1 : \delta_i \neq \delta \text{ for all } i \text{ and/or } \alpha < 0 , \quad \text{non} - \text{convergence or club convergence}$$

We can, also, represent our panel data using the *eq. (H.3)*.

$$lnhdi_{i,t} = p_{i,t} + a_{i,t} \tag{H.3}$$

where,

$p_{i,t}$ = systematic components

$a_{i,t}$ = represents transitory components

To separate common from idiosyncratic components, Phillips and Sul (2007) turn the *eq. (H.3)* into *eq. (H.4)*.

$$lnhdi_{i,t} = \left(\frac{p_{i,t}+a_{i,t}}{\mu_t}\right)\mu_t = \delta_{i,t}\mu_t \quad \text{for all } i \text{ and } t \tag{H.4}$$

One method for extraction of the long-run component $\delta_{i,t}\mu_t$ and separate out the cycle effect ($lnhdi_{i,t} = \delta_{i,t}\mu_t + cycleeffect_{it}$) is the Whittaker–Hodrick–Prescott (WHP) smoothing filter (Phillips and Sul, 2009).

Following the idea of stochastic convergence, the incomes of two provinces ι, j can have stochastic trends and a common steady state. However, sometimes, $lnhdi_{i,t}$ and $lnhdi_{j,t}$ can be cointegrated asymptotically because $\delta_{i,t}$ and $\delta_{j,t}$ converge to some common δ as $t \rightarrow \infty$. However, when the speed of divergence of μ_t is faster than the speed of convergence of $\delta_{i,t}$ the cointegration tests would have low power to detect the asymptotic cointegration.

Thus, Phillips and Sul (2007) try to solve this problem, separating the group into smaller groups so that there is convergence in each group. For example, one region could cointegrated with other regions in the same group (i.e. *Group α*) with cointegrating vector [1,-1]′ and with regions from other group (i.e. *Group β*) with cointegrating vector [1, -$\delta_{\alpha}/\delta_{\beta}$) or two regions could be not cointegrated even though there is convergence in subgroups. Regarding to this process, club convergence seems to be closer to the definition of the stochastic convergence.

The *eq. (H.5)*, which is called log t regressions, is really important to this approach.

$$log\frac{H_1}{H_t} - 2logL(t) = \hat{a} + \hat{b}logt + \widehat{u_t} \qquad \text{(H.5)}$$

where

$\frac{H_1}{H_t}$ = the cross-sectional variance ratio

$L(t)$= can be $log(t)$, $log^2(t)$, or $log\{log(t)\}$ with the first option ($log(t)$) to produce the least size distortion and the best test power.

They run an autocorrelation and heteroskedasticity robust one-sided t-test on b coefficient with HAC standard errors. The null hypothesis of convergence is rejected if

$$t_{stat} < -1.65$$

Johnson and Papageorgiou (2020) mention that b is twice the speed of convergence when μ_t is a random walk. They, also, support that $0 < b < 2$ implies conditional convergence while $2 \leq b$ implies absolute convergence.

Risking simplicity and wrong interpretation, we mention briefly that Phillips and Sul (2007) first examine if there is overall convergence. If null hypothesis is rejected then they propose a clustering and merging algorithm to check for club convergence using the following steps:

Step 1: **Last observation ordering**. Order individuals in the panel decreasingly according to the last observation in the panel.

Step 2: **Core group formation**. They select the first θ regions, $2 \leq \theta < N$, with higher income (highest individuals) to create a group, i.e. core group. Next, they run the log t regression and calculate the $t_{\theta stat}$. They choose the core group size θ^* by maximizing over θ, adding one by one the other regions (by specific order as *Step 1*), according to the criterion:

$$\left.\begin{aligned} &\theta^* = \underset{\theta}{\operatorname{argmax}}(t_{\theta stat}) \\ \text{in subject to} \quad & \\ &\min\,(t_{\theta stat}) > -1.65 \end{aligned}\right\} \tag{H.6}$$

If the restriction doesn't hold for then the highest individual in the group is dropped and the test is repeated. If the condition doesn't hold again, the highest individual in the new group is dropped and the procedure is repeated again etc.

Step 3: **Sieve individuals for club membership**. In addition, we run log t regressions using the same approach as Step 1 for the subgroups with the rest individuals not included in the core group. One individual from the group of remaining individuals is added at each time to the core group and we run the log t test. If the condition is hold, we include the individual in the core group and the process has to be repeated until $t_{\theta stat} < -1.65$.

Step 4: **Stopping rule**. Finally, for the remaining individuals that are not include in previous group, a log t test is performed. If $t_{stat} > -1.65$, the subgroup forms another convergence club and there are 2 convergence clubs. Otherwise, *steps 1-3* are used to determine whether there are smaller subgroups inside the group. If there is no θ in which $t_{\theta stat} > -1.65$, the remaining individuals diverge.

Step 4: **Club merging**. They perform the log t test for all pairs of the subsequent initial clubs as Schnurbus, Haupt, and Meier (2017) did. Merge those clubs fulfilling the convergence hypothesis jointly. The new club classifications would be obtained by the above procedure. After that, one can repeat this procedure on the new club until no clubs can be merged.

It is important to mention here that the hypotheses turn into:

$$H_0 : \text{club convergence}$$
$$H_1 : \text{non} - \text{club convergence}$$

As Johnson and Papageorgiou (2020) mentioned, the Phillips and Sul's (2007) method is a clustering approach that divide the economies into less heterogeneous groups. For further details see Phillips and Sul (2007) and Du (2017).

H.1. Club convergence

Following Du (2017), the t_{stat} and the clubs are represented in *Tables H1* and *H2* respectively. We conclude that with Phillips and Sul's (2007) method there is no convergence club for the whole period and for the majority of subperiods since the null hypothesis of overall convergence cannot be rejected. Only after the 1980 period, there are convergent groups. Thus, the clubs depend on the variable and the period. However, it is important to mention here that, using this procedure, *lnhdi* and *lnhdip* don't lead to the same clubs.

***Table H1**: Phillips and Sul's (2007) process using the cluster algorithm (t_{stat})*

Variables/ Clubs	***lnhdi***	***lnhdir***	***lnhi***	***lnpdi***	***lnpi***	***lnhdip***
1981-Final year						
club1	4.823	3.193	-0.916	8.687	8.865	3.99
club2		-49.022	7.964	-	-	-
1996-Final year						
club1	0.098	2.977	2.685	4.777	4.863	0.579
club2	8.454	3.212	6.699	-771.258	-2494.73	1.021
club3	-	-142.857	-	-	-	-

Notes:
Phillips and Sul's (2007) method.
t_{stat} are represented in cells.
$H_o: There\ is\ a\ convergent\ group\ \div H_1: There\ is\ not\ a\ convergent\ group.$
The null hypothesis isn't rejected if $t_{stat} > -1.65$ at the 5%.
Final year is 2020 for *lnhdi*, *lnhdip*, 2016 for *lnhdir*, *lnhi* and 2010 for *lnpdi*, *lnpi*.

Table H2: Phillips and Sul's (2007) method (club identification)

Variables/ Clubs	*lnhdi*	*lnhdir*	*lnhi*	*lnpdi*	*lnpi*	*lnhdip*
			1981-Final year			
club1	BC, MB, NB, NL, NS, ON, PE, QC, SK	BC, MB, NB, NL, NS, ON, QC, SK	AB, BC, MB, NB, NL, ON, SK	BC, MB, NB, NL, NS, ON, PE, QC, SK	BC, MB, NB, NL, NS, ON, PE, QC, SK	AB, BC, MB, NB, NL, NS, ON, QC, SK
club2	Not convergent group: AB	Not convergent group: AB, PE	NS, PE, QC	Not convergent group: AB	Not convergent group: AB	Not convergent group: PE
			1996-Final year			
club1	AB, BC, NB, NL, NS, ON, SK	AB, BC, NB, NL, ON, SK	AB, NL, ON, SK	BC, MB, NB, NL, NS, ON, SK	BC, MB, NB, NL, NS, ON, QC, SK	AB, BC, MB, NB, NL, ON, SK
club2	MB, PE, QC	NS, QC	MB, NB, NS, PE, QC	Not convergent group: AB, PE, QC	Not convergent group: AB, PE	NS, PE, QC
club3	-	Not convergent group: MB, PE	Not convergent group: BC	-	-	-

<u>Notes</u>:
The clubs as Phillips and Sul's (2007) method define them.

H.2. Stochastic convergence based on categorization of Philips and Sul's (2007)

Finally, the results of stochastic convergence in clubs are reported in *Table H3*. We conclude that there isn't stochastic convergence too for all cases except for *lnhdip*. We mention only these results since we don't examine the stochastic convergence for datasets with a range of years less than 30.

Table H3: Stochastic convergence for clubs

Variables/ Clubs	*lnhdi*	*lnhdir*	*lnhi*	*lnhdip*
1981-Final year				
club1	12/36	14/28	13/21	35/36
club2	-	-	0/3	-
	-	-		-

<u>Notes</u>:
Pairwise methods.
Johansen cointegration test for income among 2 provinces.
The appropriate lag length is selected based on SBIC.
The numbers indicate the number of tests that there is cointegration at the 5% and 10% / possible pairs.
There is stochastic convergence if this rate is higher or equal to 50%.
The critical values for (λ_{trace}) are 12.53 for null hypothesis r=0 and 3.84 for r=1 at the 5% while there are 10.47 for null hypothesis r=0 and 2.86 for r=1 at the 10%.
The critical values for (λ_{max}) are 11.44 for null hypothesis r=0 and 3.84 for r=1 at the 5% while there are 9.52 for null hypothesis r=0 and 2.86 for r=1 at the 10%.
Final year is 2020 for *lnhdi*, *lnhdip* and 2016 for *lnhdir*, *lnhi*.

H.3. Alternative method for club convergence (Maximal clique algorithm)

In literature there are papers which use clustering approaches to identify club convergence. There are, also, papers such as Beylunioğlu et al. 's (2020) paper that uses maximum and maximal clique algorithms to detect club convergence. Similarly, we try to use a maximal clique approach based partially on previous authors.

Briefly,

i. We use the relative results to stochastic convergence, i.e the results of ADF unit root test, ERS unit root test and KPSS stationarity tests.
ii. Next, we create an adjacency matrix which takes the value 1 if the income gap among provinces is stationary and the value 0 otherwise.
iii. Finally, we use *nwplot* command in STATA to create network analysis graphs.

Similarly, to Beylunioğlu et al. (2020) we define a group with max ε, (ε>1) provinces only if all the possible pairs of income gaps among these same ε provinces in this group satisfy the stationarity hypothesis. Beylunioğlu et al. (2020) mention that maximum clique algorithm detects the largest clique disregarding the smaller ones which may be meaningful from an economic point of view. For this reason, they use the maximal clique algorithm that finds potential convergence clubs. In this case, economies can be detected in more than one group and they are members of all these clubs since they may share essential common economical characteristics.

The results depend, once again, on the variable of income and the tests. Here, we represent, only the case of main variable, *lnhdi* (*Table H4*). In the majority of cases, there are one only possible club or many small potential clubs and some provinces belong to more than one or two indicating that these provinces may be share different common economic factors with the other provinces into these different groups. In *Fig. H1* and *Fig. H2* are represented a network analysis from which the potential clubs can be identified in the case of ERS unit root test in the period 1926-2020 and in the case of KPSS stationarity test in the period 1926-1980, respectively. Johnson and Papageorgiou (2020) mention, referring to Beylunioğlu et al. (2020), that the existence of a large number of very small clusters makes the hypothesis of club convergence difficult to sustain.

Finally, we use the same method with Johansen λ_{trace} at 10%. Analytically, we create the adjacency matrix which takes the value 1 if the income among provinces is cointegrated and the value 0 otherwise and after that we run the network analysis. The results for the main variable are represented in *Table H5*. Beylunioğlu et al. (2020) support that pairwise approaches and maximal clique algorithm can used to detect club convergence. However, they use unit root tests in their analysis and not cointegration tests. So, these results should be taken into consideration although Beylunioğlu et al. (2020) refer that the accuracy of club formation using these tests depends on the power properties of the statistics tests that are used[49]. Nonetheless, the potential clubs are many and, in some cases, small too.

Table H4: Potential clubs based on pairwise approaches and maximal clique algorithm

Periods/ Potential clubs	1926-2020	1926-1980	1949-2020	1981-2020
ADF				
P. Club1	AB, NB	AB, NB	AB, SK	BC, NB
P. Club2	MB, NS	AB, NS	MB, QC	BC, NS
P. Club3	NB, SK	MB, NS	NB, SK	
P. Club4	NS, SK	NB, SK	NS, SK	
P. Club5	QC, SK	NS, SK		
ERS				
P. Club1	AB, SK	MB, NS	MB, NS	-
P. Club2	BC, SK	PE, QC		
P. Club3	MB, NB, SK	AB, MB, SK		
P. Club4	MB, PE, SK	MB, NB, PE		
P. Club5	MB, QC, SK	MB, NB, SK		
P. Club6	NS, ON, SK			
KPSS				
P. Club1	NB, SK	AB, NB	AB, BC	AB, PE
P. Club2	QC, SK	MB, NS	AB, SK	BC, NS
P. Club3		NB, SK	NS, SK	AB, NB, SK
P. Club4		PE, SK	QC, SK	
P. Club5		AB, NS, QC		

Notes:
Potential clubs based on pairwise approaches and maximal clique analysis[50].

[49] However, in their analysis, in contrast to ours, they have a type Error II equal to zero (See Beylunioğlu et al., 2020).

[50] We also, run the command "max_cliques" in the "igraph" package in R studio for confirmation in same datasets of main variable since there isn't, as far as we know any similar command in STATA.

***Figure H1**: Maximal clique algorithm for ERS unit root test in the 1926-2020 period*

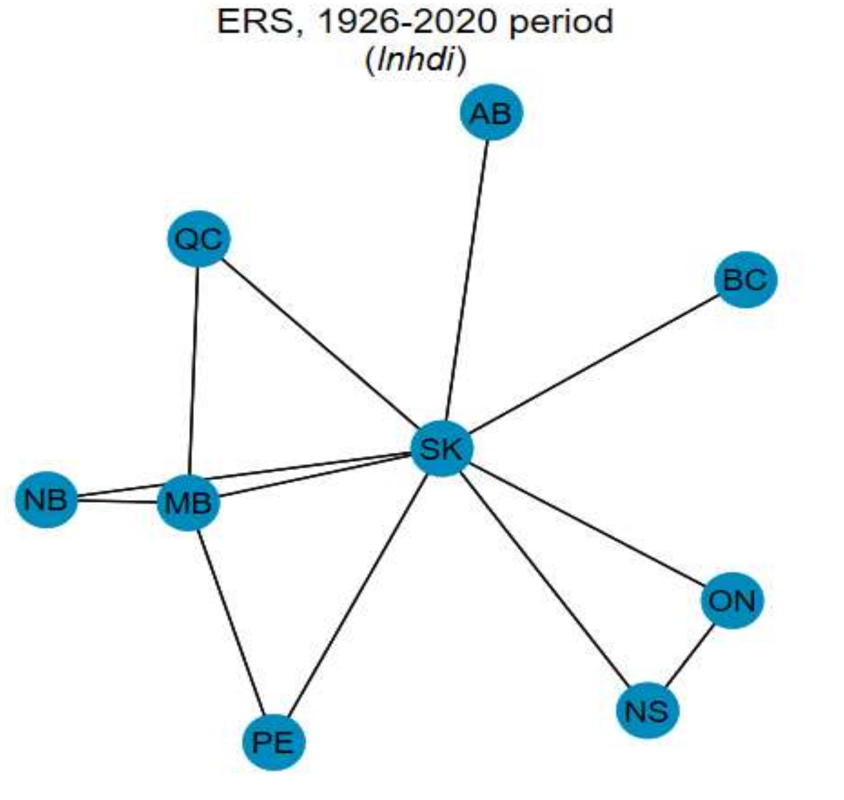

***Figure H2**: Maximal clique algorithm for KPSS stationarity test in the 1926-1980 period*

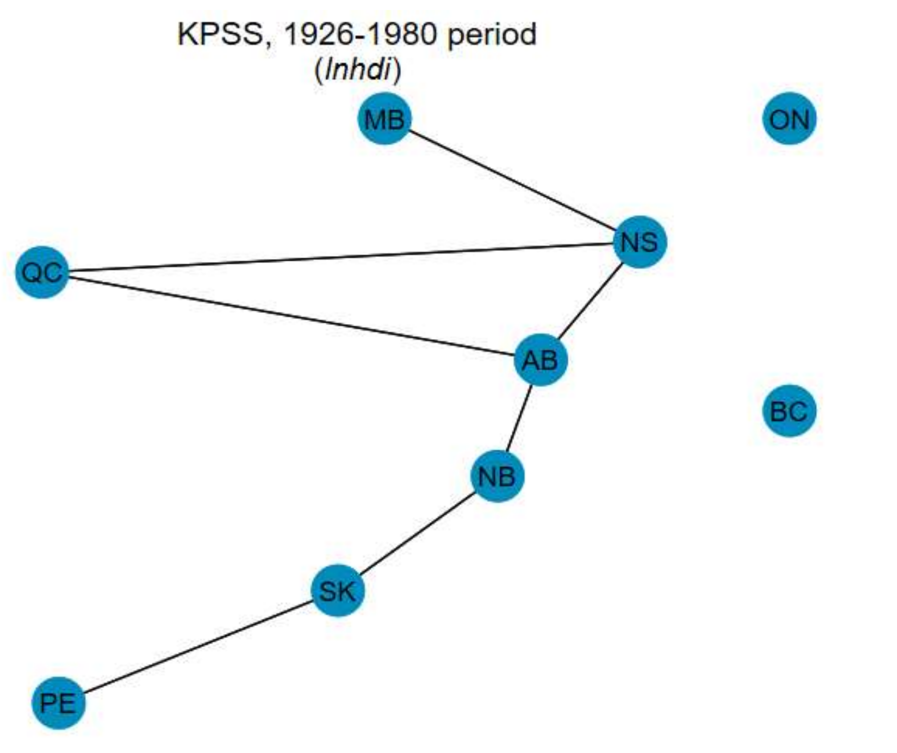

Table H5: Potential clubs based on Johansen λ_{trace} at 10% and maximal clique algorithm

Periods/ Potential clubs	1926-2020	1926-1980	1949-2020	1981-2020
Johansen λ_{trace}				
P. Club1	AB, BC	BC, QC	PE, SK	MB, NL
P. Club2	AB, ON	MB, QC	AB, NL, ON	NB, NL
P. Club3	AB, PE	ON, QC	AB, PE, ON	NB, ON
P. Club4	BC, MB	ON, PE	BC, NB, NL	NL, PE
P. Club5	BC, QC		BC, NB, PE	ON, PE
P. Club6	MB, PE		MB, NB, NL, NS	AB, BC, ON
P. Club7	NB, NS		MB, NB, NS, PE	AB, NL, NS
P. Club8	NB, QC		NB, NL, NS, ON	AB, NL, QC
P. Club9	NS, PE		NB, NL, ON, QC	AB, NS, ON
P. Club10	ON, MB		NB, NS, ON, PE	AB, ON, QC, SK
P. Club11	ON, QC		NB, ON, PE, QC	

Notes:
Potential clubs based on Johansen λ_{trace} and maximal clique analysis.

To sum up, in this case, the maximal clique approach leads to a lot of small clusters which possible, following previous comment by Johnson and Papageorgiou (2020), is evidence in favor of non-club-convergence.

Appendix I: Cointegration test with known cointegrating vector [1,-1]′ for lnhdi

So far, we examine the weak hypothesis of stochastic convergence where the long-run homogeneity is relaxed, using the Johansen test with unknown cointegrating vector. Thus, we analyze the case of strong cointegration and therefore convergence using a VEC model. We assume that there is cointegration in real household disposable income per capita among two provinces. Using again the proper number of lacks according to SBIC. After that we use the restriction in cointegrating vector and we see in which cases there is indeed long-run relationship and simultaneously this restriction holds.

***Table I1**: Cointegration tests with known cointegrating vector [1,-1]′ (lnhdi)*

Samples\Tests	**Cointegration with known vector [1,-1]′**	
	$\boldsymbol{a = 5\%}$	$\boldsymbol{a = 10\%}$
1926-2020 (No NL)	4/36	4/36
1926-1980 (No NL)	10/36	12/36
1949-2020	14/45	12/45
1981-2020	13/45	12/45

Notes:
Pairwise methods.
Restricted VECM for income among 2 provinces.
The numbers indicate the number of tests that there is cointegration and the restriction of known cointegrating vector [1,-1]′ holds at the 5% and 10% / possible pairs.
There is stochastic convergence if this rate is higher or equal to 50%.

It is clear, that there isn't strong cointegration and therefore there isn't strong convergence for any period. We can say that in case of the strong definition of stochastic convergence, i.e. the cointegrating vector is [1,-1]′, the convergence is more unlikely to happen. For this reason, a lot of researchers examine, also, weak cointegration and weak stochastic convergence.

Appendix J: One-sided t-test for beta convergence (FE Jackknife)

In this Appendix we represent the absolute convergence with hypotheses:

$$Ho: statistically\ unsignificant\ \beta\ coefficient\ (\beta = 0)$$
$$H_1: statistically\ significant\ and\ negative\ \beta\ coefficient\ (\beta < 0)$$

***Table J1**: Absolute convergence one-sided t test (FE Jackknife)*

Variables/ Samples	***Lnhdi***	***Lnhdip***	***lnhdir***	***lnhi***	***lnpdi***	***lnpi***
1927-Final year (No NL)	-0.0134983		-0.0139563	-0.0117029	-0.0143011	-0.0123981
	(0.0042714)***		(0.0043242)***	(0.0032975)***	(0.0049092)***	(0.0037575)***
1927-1980 (No NL)	-0.0089425		-0.0072023	-0.0041484	-0.0090977	-0.004543
	(0.0107818)		(0.0103259)	(0.0085973)*	(0.0108023)	(0.0085177)
1927-1949	-0.0500618		-0.0546576	-0.0374163	-0.0500567	-0.0378431
	(0.0294068)*		(0.0317085)*	(0.0248865)*	(0.0283705)*	(0.0240622)*
1950-Final year (No NL)	0.0013649		-0.0210193	-0.0185591	-0.0215531	-0.0205891
	(0.0067981)		(0.0040704)***	(0.0025281)***	(0.0051536)***	(0.003491)***
1950-Final year	-0.0181742		-0.0191882	-0.0170726	-0.0203455	-0.0196649
	(0.0032648)***		(0.0038283)***	(0.0025659)***	(0.0044196)***	(0.0024067)***
1981-Final year	0.0010327	-0.0042214	-0.0057046	-0.0170726	-0.0028843	-0.0156335
	(0.0050533)	(0.0068183)	(0.0086742)	(0.0070478)	(0.0140285)	(0.0114945)
1996-Final year	-0.0160471	-0.0142337	-0.014224	-0.0171713	0.0104312	-0.0150036
	(0.011739)	(0.0107877)	(0.0112971)	(0.015261)	(0.0182907)	(0.0160996)

<u>*Notes*</u>:
Coefficients of the previous *variable* are represented in the above table. A negative and statistically significant coefficient indicates absolute convergence.
Jackknife standard errors in parentheses ().
Final year is 2020 for *lnhdi* and *lnhdip*, 2016 for *lnhdir* and *lnhi* and 2010 for *lnpdi* and *lnpi*.
<u>Dependent variable</u>: growth rate of *variable*.
Statistically significant *: at the 10% **: at the 5% ***: at the 1% (one-sided t test).

Our results don't change at the significance level 5% in one-sided t tests. However, there is absolute convergence in the period 1927-1980 at the 10%. Finally, the choice of two-sided or one-sided t-test can slightly change the results.